E-FLOWS FOR THE LIMPOPO RIVER BASIN:

BASIN REPORT

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(Submitted in fulfilment of Milestone 2: Report on basin ecosystems, biophysical characteristics and risk regions mapping)

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About IWMI

The International Water Management Institute (IWMI) is an international, research-for-development organization that works with governments, civil society and the private sector to solve water problems in developing countries and scale up solutions. Through partnership, IWMI combines research on the sustainable use of water and land resources, knowledge services and products with capacity strengthening, dialogue and policy analysis to support implementation of water management solutions for agriculture, ecosystems, climate change and inclusive economic growth. Headquartered in Colombo, Sri Lanka, IWMI is a CGIAR Research Center with offices in 13 countries and a global network of scientists operating in more than 30 countries.

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This specific project undertaken by IWMI was titled *Environmental flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources*

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Below is the list of Project Reports. This report is highlighted

Report number	Report title E-FLOWS FOR THE LIMPOPO RIVER BASIN:
1	Inception Report
2	Basin Report
3	From Vision to Management
4	Specialist Literature and Data Review
5	Present Ecological State - Drivers of Ecosystem Change
6	Present Ecological State - Ecological Response to Change
7	Environmental Flow Determination
8	Risk of Altered Flows to the Ecosystem Services

Cover photo: Limpopo River at Spanwerk. Picture G. O'Brien .

PROJECT TITLE:

Environmental flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources

REPORT TITLE:

E-Flows for the Limpopo River Basin: Basin Report.

PROJECT OBJECTIVES:

This project will provide the necessary evidence to secure environmental flows (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.

TERMS OF REFERENCE:

USAID has funded Chemonics to implement the Resilient Waters Program. In turn this project was a response to a Grant call that had as its overall goal "*to build more resilient communities and ecosystems through improved management of transboundary natural resources*……".

The International Water Management Institute (IWMI) was commissioned by Resilient Waters to undertake a project titled: *Environmental flows (e-flows) for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources*. The study incorporated the PROBFLO method to determine e-flows and eveluate the risk of altered flows and non-flow variables to the ecosystems services in the Limpopo Basin. The project has resulted in two final reports including:

- Environmental flow determination in the Limpopo Basin.
- Risk of altered flows to the ecosystems services of the Limpopo Basin.

This report presents a description of the basin providing the context in which e-flows can be set.

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LIST OF ABBREVIATIONS

ADB	African Development Bank
ARA	*Administração Regional de Águas*
AWARD	Association for Water and Rural Development
CMAs	Catchment Management Agencies
CMIP5	Coupled Model Intercomparison Project Phase 5
DNA	National Directorate of Water - *Direcção Nacional de Águas*
DTI	Department of Trade and Industry
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
DWS	Department of Water and Sanitation
EC	Electrical conductivity
EIS	Ecological Importance and Sensitivity
EMA	Environmental Management Act
EMSEZ	Electro Metallurgical Special Economic Zone
GCMs	General Circulation Models
GDP	Gross Domestic Product
GLeWAP	Groot Letaba Water Development Project
GMTCA	Greater Mapungubwe Transfrontier Conservation Area
GoB	Government of Botswana
GOM-DNA	Government of Mozambique - National Water Directorate
GoZ	Government of Zimbabwe
IMPACT	Int. Model for Policy Analysis of Agric. Commodities and Trade
IPCC	Inter-governmental Panel on Climate Change
IUA	Integrated Units of Analysis
IWRM	Integrated Water Resources Management
KNP	Kruger National Park
LBPTC	Limpopo Basin Permanent Technical Commission
LGC	Limpopo Groundwater Committee

LIMCOM	Limpopo Watercourse Commission
LIMCOM	Limpopo Watercourse Commission
Limpopo RAK	Limpopo River Awareness Kit
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MCC	Mzingwane Catchment Council
MCWAP	Mokolo Crocodile West Augmentation Project
NFEPA	National Freshwater Ecosystem Priority Areas
NMAR	Natural Mean Annual Runoff
ORWRDP	Olifants River Water Resources Development Project
PCRGLOBWB	PCRaster Global Water Balance
PES	Present Ecological State
PRR	Preliminary Risk Regions
RCMs	Regional Climate Models
RdM	República de Moçambique
REC	Recommended Ecological Category
Resilim O	Resilience in the Limpopo – Olifants
Resilim	Resilience in the Limpopo
RQOs	Resource Quality Objectives
RSA	Republic of South Africa
RSAP	Regional Strategic Action Plans
SADC	Southern African Development Community
SARDC	Southern African Research and Documentation Centre
SASS5	South African Scoring System version 5
SWAT	Soil and Water Assessment Tool
UNFCCC	United Nations Framework Convention on Climate Change
WRC	Water Resource Class
WSM	Water Simulation Module
WWTWs	Wastewater Treatment Works
ZINWA	Zimbabwe National Water Authority

SUMMARY

This report contributes to the study of E-flows for the Limpopo River project supported by USAID, with the overall aim of building more resilient communities and ecosystems across four countries, Botswana, Mozambique, South Africa and Zimbabwe through improved management of transboundary natural resources, especially those related to environmental water requirements. Environmental water requirements (also known as E-flows) relate to the quantity, quality and timing of water required for the environmental protection and the sustainable use of water resources.

E-flows are provided for in detail in the South African Water Act of 1998 where they are called the 'Ecological Reserve', but receive variable focus in the legal frameworks of the other three basin countries. The objective of this report is to provide a baseline or description of what we know about the basin, in preparation for subsequent work in determining the E-flows, and also to provide guidance on their operationalization.

This report describes the Limpopo Basin and its people by providing a baseline description of the basin from a river flow perspective. This study moves away from reporting data at a basin scale but focuses on areas called ***risk regions*** to report the different aspects of the basin. Risk regions are major sub-basin regions as determined by a combination of socio-economic and biophysical characters including transboundary issues. Where information available did not allow for disaggregation of the data, the basin scale was used as the unit of reporting. Level one ecoregions were also developed for the basin as yet another division of the land and waterscape, and assist with interpretation of ecological data in the basin context, and will feed into the next project activities.

This report illustrates that the range of developmental initiatives as planned, together with population increases in the basin, will likely have an impact on water availability and allocation, and associated ecosystem services. Most of the risk regions have large rural populations directly dependent on the river flows. Land use activities (mining, wastewater, agriculture) and land use changes in both rural and urban areas continue to affect water resource quantity and quality (i.e., groundwater recharge, groundwater and surface water quality). The basin contains sensitive ecosystems (e.g., conservation areas forming the Greater Limpopo Trans-frontier Conservation Area) and a high socio-economic dependence by riparian citizens on these ecosystems. With the need for equitable water access that leaves no one behind, and balancing urban and rural needs with ecosystem requirements under a changing climate, opportunities in conjunctive surface water - groundwater use and managed aquifer recharge will increasingly contribute to communities' resilience and adaptation to climate change. The study also brings into focus groundwater and surface water interactions in the basin, and the contribution of groundwater to E-flows.

1. INTRODUCTION

The Limpopo River Basin is one of southern Africa's most studied transboundary basins, including its tributaries and sub-basins. The richness in culture, biodiversity and natural resources contribute towards this attention. The basin is however plagued by droughts, floods and water and food insecurity (Petri et. al. 2015). Climate variability has resulted in the unpredictability of the hydrological regime leaving the river in parts without flows for nearly 70% of the year (ADB, 2014). Notable studies that have been carried out include the 2012-2017 Resilience in the Limpopo Basin study (RESILIM, 2017), the 2013 Monograph reports on the Limpopo (Aurecon, 2013a) and the Joint Limpopo Scoping Study of 2010 (LBPTC, 2010). These reports form a foundation for in-depth analysis of the basin on which this study builds.

1.1 PROJECT OBJECTIVES

This report contributes to the project *E-flows for the Limpopo River - building more resilient communities and ecosystems through improved management of transboundary natural resources*. Overall, the project will provide the necessary evidence to secure environmental flows (E-flows) for increasing the resilience of communities and ecosystems in the Limpopo Basin to changes in stream-flow resulting from basin activities and climate change. This report will therefore provide a baseline description of the basin from a river flow perspective. Building on past studies, the study narrows its focus within the basin by describing as much information as possible according to the risk regions. The study also brings into focus groundwater and surface water interactions in the basin, and the contribution of groundwater to E-flows.

1.2 STRUCTURE OF THE REPORT

This report documents the baseline information describing the basin, in particular its flow-related characteristics.

The report has been structured to include the following:

1. Socio-economic conditions and livelihoods
2. Basin vision and management objectives
3. Physical characteristics
4. Water Resources
5. Water resources availability (for each Risk region)
6. Water quality
7. River ecosystems

1.3 PRELIMINARY RISK REGIONS

Risk regions are major sub-basin regions as determined by a combination of socio-economic and biophysical characters including transboundary issues (see Figure 1.1). For the selection of risk regions in this study a combination of the management objectives, source information, and available habitat data was used to establish geographical risk regions for the relative risk assessment (Landis 2004; O'Brien and Wepener, 2012). This allows the outputs of the assessment to be presented at a spatial scale with multiple regions compared in a relative manner. Through this approach, the dynamism of different regions can be incorporated into the study and allow for a holistic assessment of flow and non-flow variables. The approach can address spatial and temporal relationships of variables between risk regions, such as the downstream effect of a source of stress on multiple risk regions, in the context of the assimilative capacity of the ecosystem or the requirements of ecosystem response components e.g. fish.

The risk regions remain preliminary in this report as they will be subject to updating following the field surveys where some verification of boundaries may take place.

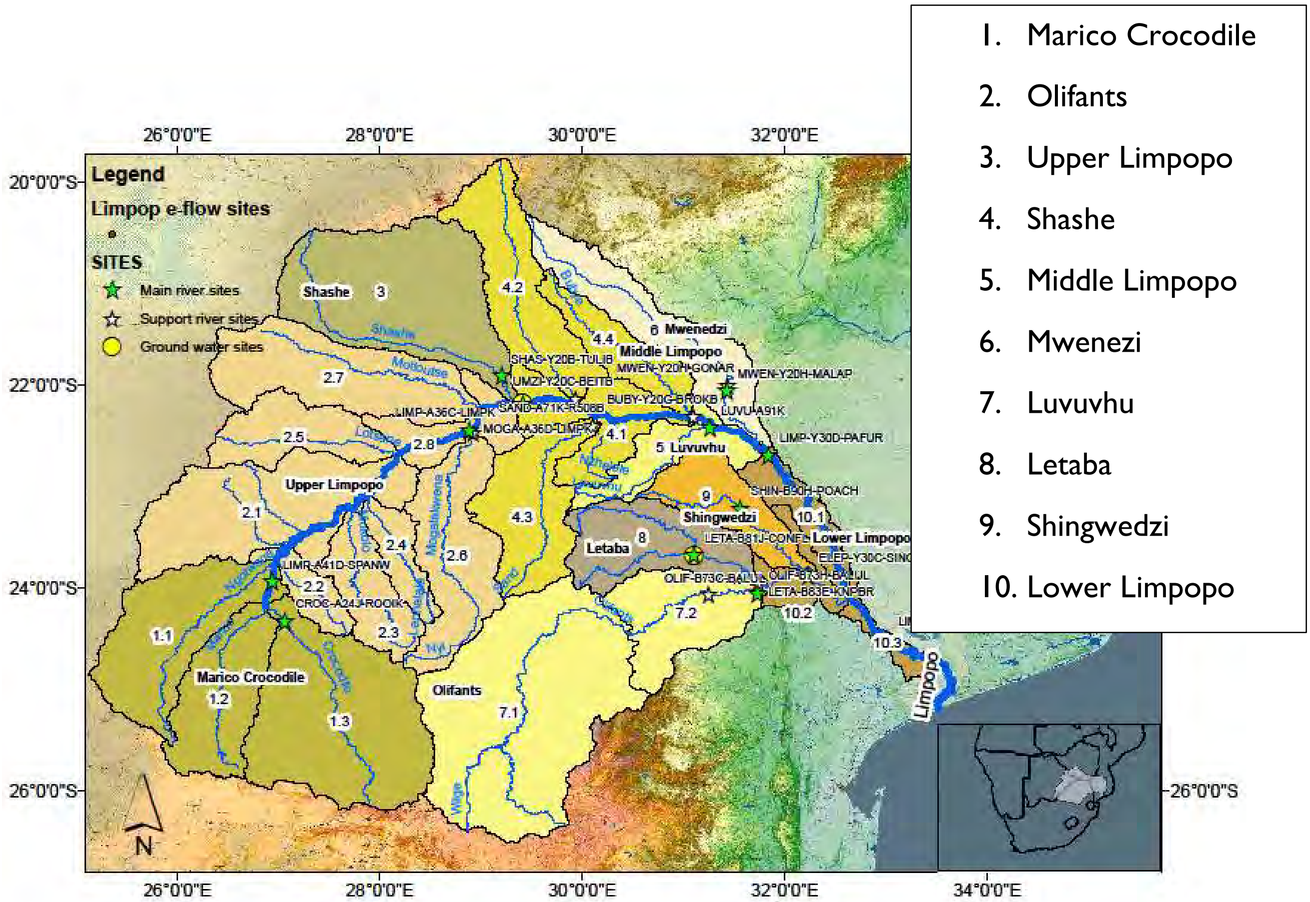

FIGURE 1.1: MAP OF THE LIMPOPO BASIN INDICATING PRELIMINARY RISK REGIONS AND SUB-BASINS

Basin information is reported under the ten preliminary risk regions identified in the Limpopo basin (Figure 1.1). Detail of the risk regions is provided later in the report. The Changane area in Mozambique has not been included in the project and is thus not considered as a risk region. The reason for this exclusion is based on the experience gathered while collecting data for the Monography e-flow study, where although the basin is large with many inhabitants, the area is largely wetland with little flowing river channel. The water was also highly saline resulting from groundwater intrusion. The Changane catchment is also relatively independent of the rest of the river, entering near to the estuary, and thus does not contribute to the overall Limpopo main-stem hydrology.

2. SOCIO-ECONOMIC CONDITIONS

2.1 BY COUNTRY

POPULATION

Shared among the four countries of Botswana, Mozambique, South Africa and Zimbabwe, the Limpopo River Basin, brings together a diversity of cultures. Many of the people in the basin are linked to the flows of the Limpopo, its associated groundwater system and the ecosystem services they provide. However, a growing population, among other factors, exerts increasing pressure and demand on the already stressed river system, and poses a serious threat to the sustainability of river flows (Petri et al. 2015). A large proportion of the population lies within South Africa and the least in Botswana. Mozambique and Zimbabwe have the largest rural populations (Aurecon, 2013a). A considerable proportion (80%) of the population is less than 25 years of age (Resilim O, 2013). Nearly three quarters of the total Botswana population lives in Gaborone which is in the Limpopo Basin (Aurecon, 2013a; Table 1). Altogether, the approximate population in the Limpopo Basin is close to 20 million and is expected to grow by just over 10% by 2040 (Resilim O, 2013).

ECONOMIC DEVELOPMENT

Economic development in the four countries is disproportionate. World Bank estimates of Gross Domestic Product (GDP) per capita (Gross Domestic Product divided by total population) indicate that the people of Botswana and South Africa, who are incidentally also in the upstream countries - have the highest GDP per capita (Figure 2.1). This metric measure allows for a general overview and comparison of living standards across different countries. Mozambique and Zimbabwe have the lowest GDP per capita implying lower living standards. Over the period 2010 – 2018 fluctuations in the GDP of the riparian countries have been particularly evident for South Africa, whose GDP went on a downward trend from 2011-2016. Botswana has also experienced the same variations but has experienced growth over the period 2015-2018 (Figure 2.1).

TABLE 2.1: POPULATION DISTRIBUTION AND SIGNIFICANCE OF THE LIMPOPO BASIN

RIPARIAN COUNTRY	ESTIMATED COUNTRY POPULATION LIVING IN THE LIMPOPO BASIN[1]	ESTIMATED PERCENTAGE OF TOTAL COUNTRY POPULATION[2]	PROPORTION OF BASIN OCCUPIED BY EACH COUNTRY[3]	SIGNIFICANCE OF THE LIMPOPO BASIN TO RIPARIANS
Botswana	1.5 million	70%	20%	Water supply
Mozambique	1.1 million	8%	20%	Flooding, water for agriculture
South Africa	15 million	29%	45%	Upliftment of the lives of previously disadvantaged people for South Africa; irrigation and agricultural development, industry, mining
Zimbabwe	0.95 million	7%	15%	Irrigation and agricultural development

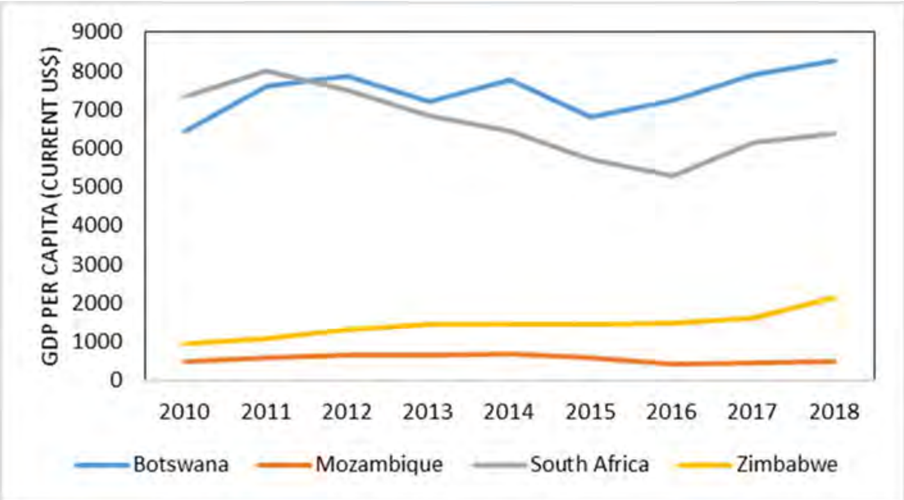

FIGURE 2.1: COUNTRIES OF THE LIMPOPO RIVER BASIN – GDP PER CAPITA (SOURCE: WORLD BANK DATA, 2020)

Economic activities linked to water availability in the basin include (i) irrigation agriculture (ii) commercial forestry (iii) mining (iv) power generation (v) industry and (iv) eco-tourism. Data from 2013 shows that almost 1.5 million people in the basin are directly and indirectly dependent on these activities for employment (Aurecon, 2013a). Sectoral contribution to GDP indicates that mining is the biggest contributor to GDP in the basin and also contributes

[1] Aurecon, 2013a

[2] Aurecon, 2013b

[3] Based on the Transboundary Freshwater Dispute Database

to 55% of direct employment. Irrigation contributes 5% to GDP yet is responsible for 38% of direct job opportunities (Aurecon, 2013a: Table 2.2)

TABLE 2.2: SECTORAL CONTRIBUTION TO GDP AND EMPLOYMENT IN THE LIMPOPO BASIN (ADAPTED FROM AURECON, 2013A)

SECTOR	% CONTRIBUTION TO GDP	% CONTRIBUTION TO DIRECT JOB OPPORTUNITIES
Mining	69	55
Irrigation	5	38
Industry	14	4
Power Generation	11	1
Commercial Forestry	1	1
Eco Tourism	1	1

Demands placed on water resources and associated ecosystem services will depend on the socio-economic standards in the basin. The uneven development in the basin translates into uneven water use. Notably, South Africa is responsible for nearly 60% of the basin total water use (RESILIM, 2013) yet occupies only 45% of the basin (Table 1). Inter-basin and intra-basin transfers are common in the basin with the Olifants being the recipient of large volumes of water from the Vaal River and other smaller systems (Aurecon, 2013a).

TABLE 2.3: IRRIGATION WATER DEMAND IN THE FOUR COUNTRIES RIPARIAN TO THE LIMPOPO RIVER (*SOURCE*, AURECON, 2013A)

RIPARIAN COUNTRY	IRRIGATION WATER DEMAND[4] (MILLION M^3/YEAR
Botswana	26
Mozambique	129
South Africa	2 353
Zimbabwe	339

Irrigated agriculture forms an important economic activity in the four basin countries and is also a large water user. The 2013 estimates indicate that South Africa uses over 2 000 million cubic meters of water per year for irrigation compared to 26 million cubic meters in Botswana (Table 2.3).

[4] Aurecon, 2013a

Poverty incidences are high in the basin across all four countries. Rural populations in particular are vulnerable, most of whom survive by practicing rain fed subsistence agriculture and rely on ecosystem services such as freshwater, forests and fish. While empirical studies continue to determine the exact contribution of ecosystem services in reducing poverty, the dependence of rural communities on flow related ecosystems is nonetheless significant (Suich et al. 2015).

2.2 RISK REGIONS AND SOCIO-ECONOMIC DEVELOPMENT

POPULATION

According to 2013 data, the highest population is in the Marico Crocodile region, home to about 8 million people (Aurecon, 2013a; Table 2.4 and Figure 2.2). This region lies mostly in South Africa and includes major urban centers such as Johannesburg and Pretoria. The Upper Limpopo risk region contains the second largest population of close to 2 million people and lies primarily within Botswana and South Africa. In Zimbabwe, and to a less extent Mozambique, the Mwenezi risk region has a population of about 250 000 people and is the least populated risk region.

TABLE 2.4: SUMMARY OF KEY POPULATION AND WATER CHARACTERISTICS IN THE LIMPOPO BASIN RISK REGIONS

RISK REGION	AREA OF RISK REGION	POPULATION[5]	KEY CHARACTERISTICS
Marico Crocodile	61 070	7 478 894	Irrigation agriculture
Olifants	54 317	4 518 151	Mining, large scale agriculture
Upper Limpopo	93 667	1 757 529	Irrigation and small scale irrigation
Shashe	28 978	431 622	Conservation activities, irrigation, game farming, small scale agriculture, tourism, gold panning
Middle Limpopo	48 658	1 940 334	Irrigation, mining, cattle ranching, wildlife ranching, gold panning, tourism
Mwenezi	14 985	245 901	Irrigation- sugar cane plantations, small scale agriculture
Luvuvhu	7 795	300 113	Tourism, irrigated agriculture, rain fed agriculture
Letaba	13 769	898 195	Large water infrastructure (dams), irrigated agriculture, domestic water supply, sand mining
Shingwedzi	9 194	481 404	Conservation
Lower Limpopo	9 876	465 022	Irrigated agriculture - rice, flood plain agriculture
Total		**17 768 578**[6]	

[5] Data obtained from Aurecon, 2013a

[6] This figure excludes the population in Changane not considered as part of the preliminary risk regions

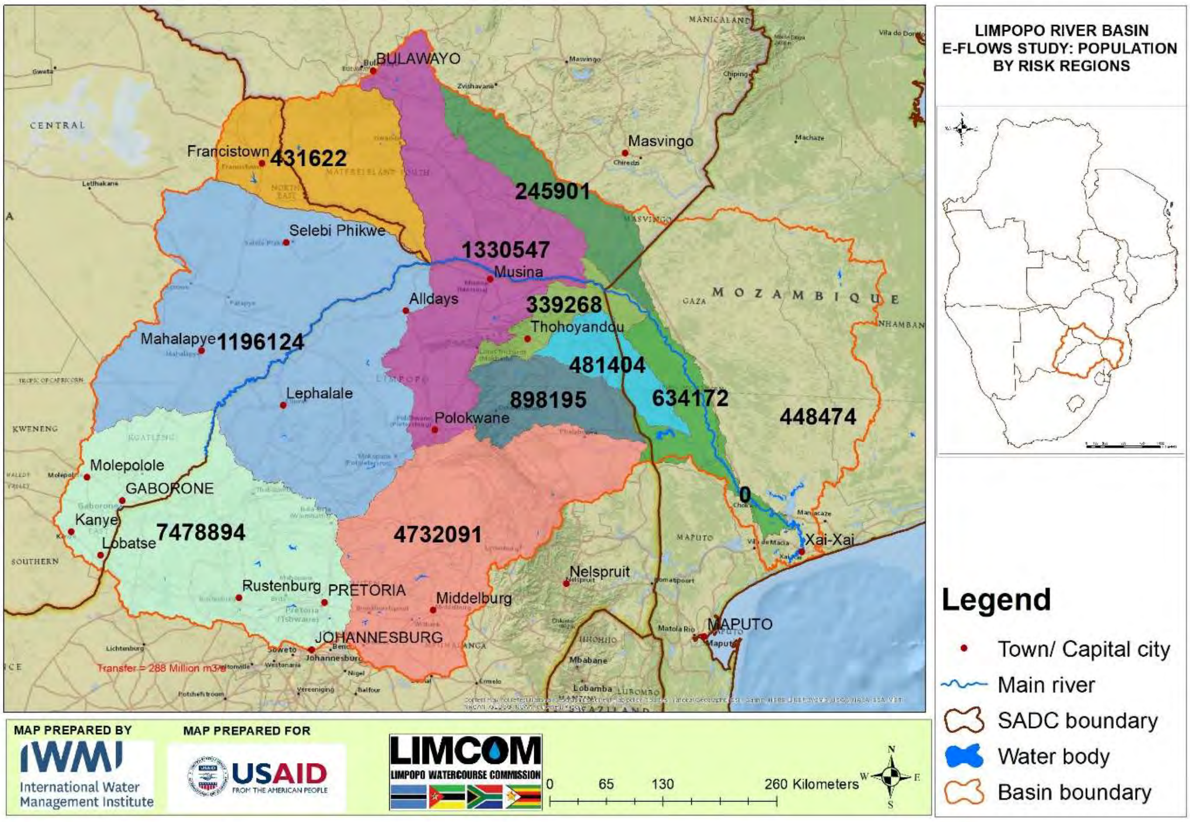

FIGURE 2.2: POPULATION BASED ON RISK REGIONS IN THE LIMPOPO RIVER BASIN.

SOCIO-ECONOMIC CONDITIONS[7]

Marico-Crocodile

The Notwane, Marico and Crocodile catchments comprise the main sub –basins in this region. Together the sub-basins represent considerable development and intensive water use both urban, industrial and agricultural. About 90% of the semi-arid Notwane catchment lies within Botswana where the capital city, Gaborone is also located. Over 30% of the population in Botswana is in the Notwane sub-basin where there is growing demand for domestic water supply (Resilim, 2013). Dams in this region include the Gaborone and Mogobane dams used for domestic and industrial water supply. The Mogobane dam is used mainly for irrigation (IWMI, 2016). Flows in the Notwane on which the Gaborone Dam is built, are sporadic prompting transfers from the Molatedi Dam in the Marico sub-basin of South Africa (Resilim, 2013; Aurecon, 2013a). The Marico sub-basin falls largely within the South African boarders. The Upper Groot Marico River has been flagged as a National Freshwater Ecosystem Priority Area (NFEPA) and is the last free flowing river in the northwest areas of South Africa (Nel et al. 2011; Resilim, 2013). Communities depend on this river for game reserves, ecotourism and livestock farming. The Crocodile sub-basin portion that flows toward the Limpopo, consists of tributaries such as the Moretele whose flood plains support wetland and aquatic

[7] Water resources and water uses are described in greater detail in other sections of this report

ecosystems. In the 2013 *Resilience in the Limpopo* study, the Moretele basin was identified as a hotspot due to the high levels of land degradation, polluted industrial waste from large urban centers like Tshwane, high unemployment, frequent fires and poor spatial planning which aggravate flooding risks (Resilim, 2013).

Olifants

The Olifants risk region falls into Mozambique and South Africa encompassing the catchments of the Olifants River in South Africa and the Elefantes River in Mozambique. Studies have shown that the Olifants River is critical to flows in the Limpopo to Mozambique, particularly in the dry season (Resilim O, 2014). For downstream Mozambique, these flows are central to support the livelihoods of nearly 10 000 small scale farmers and to sustain important ecosystem services (RESILIM O, 2014). Farming on the river's flood plains in Mozambique, where 80% of the population is rural, is an important economic activity for local farmers. Ensuring river flows in South Africa is a balancing act due to the numerous competing demands on the resources. Irrigated commercial farming and subsistence agriculture form an important part of the livelihoods in this risk region. Rural communities have to directly fetch water from the river for domestic use in the Lower and Middle Olifants areas (RESILIM O, 2014). Nearly 70% of the population in the South Africa portion of the Olifants risk region is rural and occupies the former homelands, relying on the natural environment and ecosystem services that the river system provides- their livelihoods inextricably linked to the flows of the river system. Close to 25% of the population relies on wood as a source of energy for cooking (Resilim O, 2014). Wildlife sustained by the flows in this risk region support informal leather goods crafters. The rich plant and wildlife biodiversity supports a thriving tourism industry. The river flows through the Kruger National Park where environmental flow levels have to be maintained. Due to worsening pressures on the water resources in this risk region including over allocation and climate change, compliance with environmental flows has been a challenge compromising even the international flow obligations to Mozambique (AWARD, 2019).

Upper Limpopo

In the South African portion, the Upper Limpopo Basin consists of several sub basins: Mokolo, Mogalakwena, Lephalale, Matlabas. These catchments are mostly developed and heavily utilized for activities such as mining, irrigation and supply to power stations such as the Matimba Power Station supplied by water from the Mokolo Dam. The Mogalakwena catchment has approximately 700 farm dams in addition to three large dams providing water for irrigation. There is also extensive groundwater exploitation within this catchment (DWS, 2016). The Botswana portion comprises the Bonwapitse, Mahalapswe, Lotsane and Motloutse sub basins. Data on the socio economic activities on the Botswana sub-basins is scarce, however the main economic activities in Botswana are associated with cattle and game farming (Aurecon, 2013a).

Shashe

The rich cultural and ecological heritage in this risk region is encapsulated in the Greater Mapungubwe Transfrontier Conservation Area (GMTFA), shared among Botswana, South Africa and Zimbabwe. The GMTFA is located on the confluence of the Shashe and Limpopo River. Local communities around this region are largely dependent on ecological provisions such as firewood and pastures for livestock and domestic water. In the past decade, degradation of ecosystems in the Botswana portion of the risk region have meant residents have had to travel further to fetch firewood and graze their livestock (Mugari et al. 2018). Droughts frequently ravage the region leading to reduction in agricultural production and loss of species diversity in wildlife and aquatic ecosystems (Molefe and Masundire, 2016). Small scale irrigated agriculture and livestock production support the livelihoods of many of the households in the risk region. There are 9 dams in the sub-basin and 30[8] mines (LBPTC, 2010).

Middle Limpopo

Major sub-basins in the Middle Limpopo risk region include the Mzingwane, Bubi, Sand and Nzhelele, and spans across South Africa and Zimbabwe. On the Zimbabwe portion of the basin, livelihood activities are characterized by smallholder irrigation schemes dotted around the catchment as well as gold panning along river beds (ZINWA, 2009). Close to 60% of the domestic water in Bulawayo is supplied from the Mzingwane Catchment although the city lies within the Zambezi catchment (Aurecon, 2013a). Zhovhe Dam supplies water for domestic and irrigation use. Sand dams are a common feature in the Upper Mzingwane Catchment providing irrigation and domestic water to local rural households. On the South African side of the Limpopo, the Sand river sub catchment is considered dry and dependent on groundwater (DWS, 2016). There are significant mining and irrigation activities in this catchment as the main water users. Many rural communities in the Sand catchment rely on groundwater resources for domestic and other uses. The water demand introduced by the controversial proposed Musina Special Economic Zone and Limpopo Eco-Industrial Park planned for Musina may have to be met by water transfers from Zimbabwe by 2028 (DWS, 2016). A growing population in the rural communities of the Nzhelele sub-basin increases demand for grazing land and wood for fuel (Resilim, 2013). Close to half of the population here is unemployed and are mostly women. Access to basic services like water and electricity is severely limited (Resilim, 2013).

Mwenezi

The Mwenezi sub-basin and risk region falls largely within the borders of Zimbabwe and a smaller portion in Mozambique. The Mwenezi is a seasonal river with sandy alluvial soils that can store large volumes of water. The Manyuchi Dam is the largest dam in the sub-basin with three quarters of its water allocated to irrigated sugar cane plantations in the region (Love, 2006). The lower reaches of the river are critical for wildlife in the Great Limpopo

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[8] Some of these mines may not currently be operational. Mine closures have been reported particularly in the Botswana portion.

Transfrontier Park (Love, 2006). Local communities are mostly rural and depend on livestock farming and to a less extent crop agriculture, as most households tend to purchase their food (Ncube et al. 2010).

Luvuvhu

The Luvuvhu sub-basin falls within the Limpopo Province of South Africa. economic activities include large scale agriculture of citrus, fruit and grains, afforestation and ecotourism. Local communities are rural, the majority of them poor and dependent on social grants (Resilim, 2013). Over 20 000 hectares of land are under irrigation representing close to 3% of the total land area (Aurecon, 2013a). In the valleys of the Soutpansberg mountains are fertile lands for agriculture, however rural communities contend with poverty and poor infrastructure for basic services. Proliferation of alien vegetation and increasing population demands compromise the river's ability to provide ecological services (Resilim, 2013).

Letaba

A greater part of the Letaba risk region falls within the borders of South Africa, while a small portion extends into Mozambique. Large dam developments characterize this region, with over 20 dams constructed on the Groot Letaba in South Africa (Table 4). Tzaneen and Giyani are some of the larger town centers. The water constrained Letaba risk region supplies water for domestic, industrial and agricultural needs (Kanjere et al. 2014). The largely rural local communities engage in widespread smallholder agriculture dependent on surface water. Similarly, large scale commercial farms also rely on surface water for irrigation. Livestock grazing and clearing of vegetation by local communities contributes to siltation and impacts on available river flows (DEA, 2001). Sand mining for building and construction is also an important livelihood activity in the risk region. A number of negative impacts on habitats and ecosystems such as loss of habitat and hydraulic changes in the river channels have been associated with sand mining (Lai et al. 2014; Koehnken et al. 2020).

Shingwedzi

Large portions of this region falls within the Kruger National Park (KNP), a wildlife conservation area of close to 2 million ha. Communities outside the national park practice subsistence agriculture. Informal urban settlements and poor land use practices on the flood plains of the Shingwedzi river are an area of concern in the region (Aurecon, 2013a). Small dams are dotted within the region including the Kanniedood and Sirheni dams within the KNP. While small volumes of water are extracted from these dams, they may still have an impact on the flow of the river (Fouché, and Vlok, 2012).

Lower Limpopo

The Lower Limpopo risk region falls mostly within Mozambique and falls within the proposed Great Limpopo Transfrontier Park. Low lying and flood prone, this risk region has been investigated both from a hydrological and socio economic point of view. The region experiences significant water quality and flow regime changes due to upstream development activities (ADB, 2014; Aurecon, 2013a) The proposed Mapai dam would serve to mitigate some of the flooding associated with this region as well as deliver on hydropower (ADB, 2014). Flood plain agriculture forms one of the key economic activities for the local communities. Mineral sand mining activities occur at the edge of the risk region. The irrigation schemes at Chokwe, termed the 'granary of the nation' have potential for further growth when utilized to their full potential (Mondlane, 2017). The government of Mozambique continues to support the development of large irrigation schemes such as Chokwe and other small scale agriculture, raising concerns around the availability of water to support these expansions and demands for primary users (van de Zaag et al. 2010). Climate variation and increased incidence of flooding coupled with upstream development adds to the uncertainties that surround water availability in the Lower Limpopo.

2.3 KEY MESSAGES

- A growing population will impose greater demands on available freshwater and associated ecosystem services. Most of the sub-basins have large rural populations directly dependent on the river flows.
- Economic expansion places a greater risk on sustaining the environmental flows of the Limpopo evidenced by economic expansion plans. Planned future activities in the South African sub-basins may require water transfers from Zimbabwe.
- Uneven economic growth in the basin means water use volumes will vary widely causing inequities and stress in particular regions of the basin. Currently South Africa is the biggest water user in the basin.

3. DESCRIPTION OF EXISTING VISION AND MANAGEMENT OBJECTIVES:

3.1 INTRODUCTION

This chapter will present the basin vision and management objectives as articulated by regional and national policies and legislation. This exercise filters basin management objectives as related to flows in the Limpopo from the four governments' perspective and reconciles these to the Limpopo Watercourse Commission (LIMCOM) basin vision. Note that a comprehensive vision setting exercise was not in the mandate of this project.

This section presents regional and basin level visions and management objectives, as presented through national and regional policies for the sustainable use of water resources and the protection of environmental flows (E-flows) and the benefits directly related to river flow in the Limpopo basin.

Institutions in each country serve to support and implement the basin vision, and as such institutional arrangements in the basin will be briefly discussed.

3.2 INSTITUTIONAL ARRANGEMENTS IN THE LIMPOPO

REGIONAL LEVEL

The Southern African Development Community (SADC) is the regional body that builds on the connectedness of the region both in culture and natural resources, to bring about socio-economic integration and co-operation. All four countries in the Limpopo River Basin are members of the SADC and subscribe to its mandates. Through its policies and strategies SADC, seeks to harmonize regional policies. The SADC Revised Protocol on Shared Watercourses (2000) is a regional treaty aimed at a coordinated management of shared watercourses in the region to promote sustainable development. The Protocol upholds the principles of reasonable and equitable utilization as well as not causing significant harm. Specific provisions are made for the protection and preservation of the aquatic environment. (SADC, 2015).

TRANSBOUNDARY LEVEL

LIMCOM is an international basin organization overseeing the Limpopo Basin. Instituted in 2011 through the 2003 *Agreement on the establishment of the Limpopo Watercourse Commission* its capacity has been limited in recent years with the first permanent Executive Secretary appointed in 2017 (Resilim, 2017). This has hampered meaningful oversight and implementation of basin wide plans developed under previous studies such as the Limpopo River Basin Integrated Water Resources Management Plan 2016-2020. Staff appointments have since taken off in the past year (2019), a move that may have a positive impact on overall progress towards attaining basin management objectives. LIMCOM serves only as an advisor to member states with limited powers to hold individual governments accountable. The riparian national governments therefore tend to protect their own national interests, a limitation that could hinder progress toward building climate resilience in the basin (Resilim, 2017). Three task teams form part of LIMCOM related to legislation, floods and droughts (Figure 3.1).

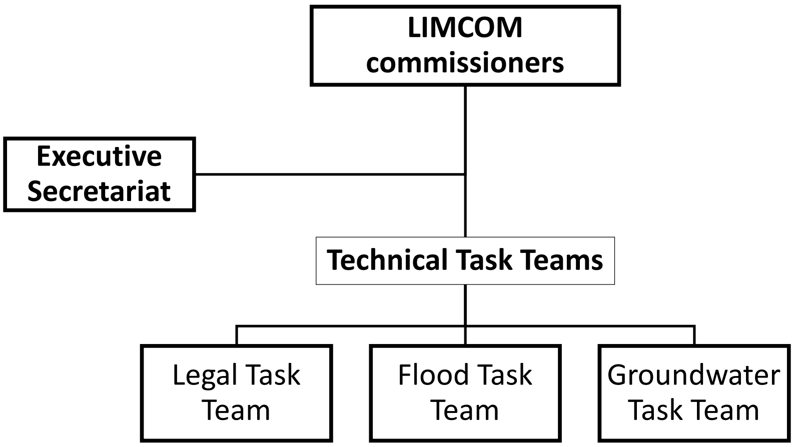

FIGURE 3.1: LIMCOM ORGANOGRAM

Limpopo Groundwater Committee

In 2019, the Limpopo Groundwater Committee (LGC) was established to play a role in coordinating the development of groundwater resources across the basin. The LGC's main activities are centered on joint planning activities to promote better coordination and harmonization and include (i) research on groundwater challenges through studies/pilots, information exchange on findings, training and implementation of solutions to emergent and priority groundwater management challenges and (ii) support the need to update Protocols/Agreements with reference to solutions that address shared groundwater challenges, sharing of data and benefits from the cooperation.

BOTSWANA

Water legislation and policies in Botswana (i.e., Water Act of 1968, National Water Policy, 2012) are implemented through the Department of Water and Sanitation (DWS) which falls under the Ministry of Land Management, Water and Sanitation Services (MoLMWSS). Institutional arrangements related to water resources are under a state of transition and realignment as part of the water policy reform measures. Currently, the DWS is responsible for water resource management, planning, protection and monitoring. Ongoing policy reforms are modeled after the integrated water resources management principles similar to Mozambique, South Africa and Zimbabwe (Resilim, 2013). Unlike Mozambique, South Africa and Zimbabwe, water resources management in Botswana is largely centralized with no catchment level institutions (Resilim, 2013).

MOZAMBIQUE

The 1991 Water Law 16/91 is the main legal provision for water resources management in Mozambique. Supported by the 1995 Water Policy and the National Water Resources Management Strategy of 2006. The National Directorate of Water - *Direcção Nacional de Águas* (DNA)- functions under the Ministry of Public Works and Housing. The DNA is responsible for the development of water related policies and their implementation (Resilim, 2013). Day-to-day management of water resources is decentralized to *Administração Regional de Águas (ARA)* - Regional Water Authorities established through Article 18 of the Water Law. Regional Water Authorities operate according to hydrological demarcations. The Limpopo Basin falls under the administration of ARA Sul (LBTC, 2010).

SOUTH AFRICA

In 2019 realignment of government departments led to the establishment of the Ministry of Human Settlement Water and Sanitation under which the Department of Water and Sanitation (DWS) falls. The DWS is responsible for water resource management and implementation of the National Water Act of 1998 together with supporting policies such as the 2013 National Water Resources Strategy II. While the National Water Act of 1998 institutes Catchment Management Agencies (CMAs) for local level water resources management, their establishment has been protracted with only 2 out of the 9 envisaged CMAs currently operational (DWS, 2018).

ZIMBABWE

Through the Zimbabwe National Water Act of 1998, there are provisions for development and utilization of water resources, decentralization of water management to catchment councils and sub catchment councils to oversee resource allocation and catchment protection (Chitakira, M. and Nyikadzino, B., 2020). Catchment councils and sub-catchment councils are also responsible for local level participatory management of water resources (MCC, 2019).

The enactment of the Environmental Management Act (EMA Act) Chapter 20:27 transferred pollution control and ecological protection functions to the Environmental Management Agency from the Zimbabwe National Water Authority (ZINWA). ZINWA would then be responsible for water resources planning and supply functions. However, a lack of coordinated efforts between the two institutions has resulted in water resources management challenges related to stream bank cultivation among others (Chitakira and Nyikadzino, 2020).

3.3 BASIN VISION AND MANAGEMENT OBJECTIVES

Shared basin visions allow countries in transboundary settings to work toward common goals in the utilization of shared resources while at the same time taking into account the many competing demands. Among the four countries sharing the Limpopo, the need to improve the socio-economic standards of their communities is prominent among national development strategies. Poverty reduction as well as the need to sustainably utilize water resources present management challenges to the governments particularly in view of other compounding factors such as climate change and increasing water demands.

METHODOLOGY

Flow related basin visions and management objectives were collected in legal and policy documentation at regional and national levels. These included regional policies from SADC, LIMCOM legal and policy framework and the national legal and policy frameworks as follows: -

1. SADC protocols and regional strategic plans
2. National policy documents and related documents.
    a. National departments for water policies related to environmental flows
    b. Similarly, other local level policies were considered
3. Contact government department officials for the provision of relevant policy documents

Flow related basin management objectives were identified under the following categories.

1. Socio-economic e.g., domestic water supply, sand abstraction, flood plain agriculture
2. Aquatic ecosystems e.g., wetlands, freshwater ecosystems and ecological water requirements, biodiversity and ecosystem protection e.g., fish
3. Agriculture production e.g., irrigation expansion

3.4 REGIONAL VISION, MANAGEMENT PLANS AND PRIORITY ACTIONS

Management of transboundary resources in the SADC – under which the Limpopo basin falls - is guided by the 2000 SADC Revised Protocol on Shared Watercourses. The spirit of this protocol calls for harmonized and sustainable utilization of the region's shared water resources. Through the Water Division of the SADC, Regional Strategic Action Plans (RSAP) have been developed to guide water development in the region across the thirteen shared basins (SADC, 2016). The current plan runs from 2016-2020. Regional guiding principles and visions are provided in strategic documents and shown in Table 3.1.

TABLE 3.1: SADC ENVIRONMENTAL FLOW RELATED REGIONAL VISIONS, OBJECTIVES AND PRIORITY INTERVENTIONS (SOURCE: SADC, 2016)

SADC REGIONAL AGREEMENT	Provisions in the SADC revised Protocol on Shared Watercourses	(2) (a) Protection and preservation of ecosystems. State Parties shall, individually and where appropriate, jointly protect and preserve the ecosystems of a shared water course. (2) (d) Protection and preservation of the aquatic environment State Parties shall individually, and where appropriate in cooperation with other States, take all measures with respect to a shared water course that are necessary to protect and preserve the aquatic environment, including estuaries, taking into account generally accepted international rules and standards.
VISIONS	SADC Vision	A common future, within a regional community that will ensure economic well- being, improvement of the standards of living and quality of life, freedom and social justice, peace and security of the people of Southern Africa.
	SADC Water vision	An equitable and sustainable utilization of water for social and environmental justice, regional integration and economic benefit for present and future generations
OBJECTIVES IN STRATEGIC PLANS	SADC RSAP IV	To unlock the potential for water (and related resources) to play its role as an engine and catalyst for socio-economic development through water infrastructure development and management to support water supply and sanitation, energy, food security, and security from water related disasters with the ultimate goal of contributing towards peace and stability, industrialization, regional integration and poverty eradication
	Regional Infrastructure Development Master Plan (RIDMP)	To increase access levels to at least 75% by 2027 for both safe drinking water and sanitation and to increase land under irrigation from the current 7% of irrigable land to 20%.
PRIORITY INTERVENTIONS	Ecological Water Requirement	Capacity building programme for methodologies for determining EWR developed.
		The key activity entails developing a capacity building programme for Member States on the methodologies for determination of environmental flows /ecological water requirements and river health classification.
	Industrialization and Nexus Approaches	Building capacity of national irrigation structures to promote large scale commercialized agriculture

3.5 BASIN LEVEL VISION AND MANAGEMENT PLANS

At the basin level, the LIMCOM has oversight over the management of the basin. The LIMCOM agreement which came into effect in 2003 was modeled according to SADC Revised Protocol on Shared Watercourses as well as the 1997 Convention on the Law of the Non-Navigational Uses of International Watercourses (LIMCOM, 2003).

The basin vision as well as the key principles that support the vision from the 2003 LIMCOM agreement as well the vision and goal of the Integrated Water Resources Plan all espouse sustainable use and development of the shared resource and are presented in Table 3.2.

TABLE 3.2: LIMCOM RIVER FLOW RELATED BASIN VISION STATEMENTS ARTICULATED IN THE BASIN AGREEMENT AND VISION DOCUMENTS (LIMCOM, 2003; LIMCOM, 2019)

LIMCOM BASIN VISION	A DYNAMIC, PROSPEROUS AND SUSTAINABLE RIVER BASIN FOR ALL
LIMCOM 2003 AGREEMENT	Preamble COMMITTED towards the realization of the principle of equitable and reasonable utilization as well as of the principle of sustainable development, with regard to the Limpopo; Article 3 3.1 The objectives of the Commission shall be to advise the Contracting Parties and provide recommendations on the uses of the Limpopo, its tributaries and its waters for purposes and measures of protection, preservation and management of the Limpopo. 3.2 For the purposes of this Agreement the general principles of the Protocol shall apply, in particular (2) Sustainable development Article 7 7.1 The Council shall serve as technical advisor to the Contracting Parties on matters relating to the development, utilization and conservation of the water resources of the Limpopo. The Council shall perform such other functions pertaining to the development and utilization of water resources as the Contracting Parties may agree to assign to the Council. 7.2 The Council shall advise the Contracting Parties on the following matters: a) measures and arrangements to determine the long term safe yield of the water available from the Limpopo; b) the equitable and reasonable utilization of the Limpopo to support sustainable development in the territory of each Contracting Party and the harmonization of their policies related thereto; c) the extent to which the inhabitants in the territory of each of the Contracting Parties concerned shall participate in the planning, utilization, sustainable development, protection and conservation of the Limpopo and the possible impact on social and cultural heritage matters. (LIMCOM, 2003)
KEY PRINCIPLES SUPPORTING THE VISION	The principle of sustainable development shall apply to ensure fairness between different uses for the benefit of the environment and the longevity of the natural resource base for future generations. (LIMCOM, 2019)
IMMEDIATE ACTIONS	Identify strategic water infrastructure for disaster management in the Basin Environmental water requirements Protect fragile ecosystems (aquatic and terrestrial) Improve groundwater resources management in the Limpopo River Basin Watershed Conservation (Catchment protection) (LIMCOM, 2019)
IWRM PLAN	*Vision*: Sustainable water security for improved livelihoods in the Limpopo River Basin. *IWRM Programme Goal*: Develop the capacities (individual, organizational and institutional) in the riparian states for the sustainable management and development of the Limpopo River Basin. (Aurecon, 2013a).

Activities for specific immediate actions outlined in Table 3.2, such as environmental water requirements and protection of fragile ecosystems (aquatic and terrestrial) are indicated as follows:

1. Environmental water requirements
    a. Develop initiatives that will update and strengthen assessment of environmental water requirements in the basin
    b. EWR basin assessment
2. Protect fragile ecosystems (aquatic and terrestrial)
    a. Develop basin wide programmes to demonstrate the value of ecosystems and protection for identified priority fragile ecosystems (LIMCOM, 2018)

Strategic objectives in the Integrated Water Resources Plan are formulated around three specific areas (i) disaster management (ii) water quality (iii) water allocation

Flow related objectives include:

1. LIMCOM promotes the equitable and reasonable utilization of water resources in the Limpopo River Basin
2. LIMCOM promotes methods to increase water availability and the efficient use of water resources in the Limpopo River Basin
3. LIMCOM coordinates the management and development of water infrastructure in the Limpopo River Basin to reduce the impacts of floods and droughts

3.6 NATIONAL DEVELOPMENT VISIONS AND WATER POLICY OBJECTIVES

TABLE 3.3: NATIONAL VISIONS AND WATER MANAGEMENT OBJECTIVES FOR WATER RESOURCES IN THE LIMPOPO BASIN RIPARIAN COUNTRIES

BOTSWANA				
We will pursue and promote integrated water resources management strategies, including policy instruments and public education that encourage water efficiency and conservation efforts, conjunctive use of surface and groundwater and promotion of artificial recharge for groundwater (GoB, 2016)	To pursue and promote integrated water resource management strategies, including policy instruments and public education that encourage water efficiency and conservation efforts; conjunctive use of surface and groundwater and promotion of artificial recharge for groundwater (GoB, 2016).	Cognizance shall be taken for the environment and ecosystem requirements to receive priority when planning and allocating water among competing uses and users (GoB, 2012)	The protection of water resources must be promoted and the conservation and sustainability of ecosystems and the goods and services they provide must be ensured (GoB, 2012)	Assess and operationalize an ecological reserve and requirements for all catchments and water resources infrastructure (GoB, 2012)
MOZAMBIQUE				
ARTICLE 13 of the Water Act of 1991 Provides for the protection of the environment, ensuring that uses and use of water take place without damage to the minimum flow and the ecological flow (RdM, 1991)	Common uses are made according to the regime traditional use and without significantly changing the quality of water and its flow (RdM, 1991). Ensure ecological flows according to water needs downstream (RdM, 2006).	The conservation of the free flow of waters includes, in particular, the duty to: a) not change the watercourse without prior authorization and once obtained, ensure that the new bed have adequate dimensions, do not degrade the watercourses or breach third party rights (RdM, 1991)	Develop capacity to deal with water quality issues, ecological flows, infestations of aquatic plants, monitoring of pollution (RdM, 2006). Water resources must be managed in a sustainable manner to ensure the development of fisheries. (RDM, 2006)	Ensure ecological flows according to water needs Downstream ensure ecological flows according to water needs downstream, and avoid the total elimination of low flows or compensate with flow releases regularly reviewing the rules of dam operation (RDM, 2006)
SOUTH AFRICA				
The purpose of the National Water Act is to ensure that …. water resources are protected, used, developed, conserved, managed and controlled in ways that take into	The need for the determination and preservation of the ecological Reserve and the classification of our river fresh water systems will be a priority (DWA, 2013)	Approximately 25% of the MAR of 49 000 million m³/a needs to remain in the rivers and estuaries to support ecological functioning of the catchments, depending on the	By 2030, water in, or from water resources shall be fit for use Fitness-for-use may relate to the water quality requirements of the aquatic ecosystem (DWS, 2018)	The PES and/or REC for all river Freshwater Ecosystem Priority Areas (FEPAs) needs to be maintained or improved. (DWS, 2018)

account amongst other factors—…(g) protecting aquatic and associated ecosystems and their biological diversity (RSA, 1998)	The objective of managing the quantity, quality and reliability of the nation's water resources is to achieve optimum, long-term, environmentally sustainable social and economic benefit for society from their use. (DWS, 2013)	specific river systems. (DWA, 2013)	Review and promulgate aggressive restrictions within the legislation to restore and protect ecological infrastructure (DWS, 2018)	Declare strategic water source areas and critical groundwater recharge areas and aquatic ecosystems recognized as threatened or sensitive as protected areas (DWS, 2018)
ZIMBABWE				
Section 4 of the EMA Act. Before issuance of a license (effluent discharge) …(d) take into consideration the water requirements of riparian residents ecosystems, human settlements, and agricultural schemes which depend on the affected water course (GoZ, 2002)	To ensure the availability of water to all citizens for primary purposes and to meet the needs of aquatic and associated ecosystems particularly when there are competing demands for water. (GoZ, 2012)	Promoting climate resilient water management systems, focusing on both crop and livestock production. (GoZ, 2012)	All ongoing dam projects will be completed and measures put in place to ensure all water bodies are fully utilized (GoZ, 2018) Reclamation of small-scale miners' degradation, including de-siltation of waterways and scooping of dams.	The Environment is a legitimate and important user of water. Therefore, sufficient quantity of water of adequate quality will be allocated to meet the requirements riverine and aquatic eco systems, wildlife, wetlands, bird life etc., based on sound professional assessment. These allocations will be specifically accommodated in Catchment Outline Plans when allocations for other purposes are made (GoZ, 2012)

NATIONAL BASIN MANAGEMENT OBJECTIVES

The following sections describe key documents in the riparian countries where basin objectives are presented and how they will be presented according to Preliminary Risk Regions.

Botswana. Botswana's Water Act 1968 focuses mainly on water allocation and has not been revised. A draft Water Bill is yet to be adopted; however, a water reform process has seen the development of policies that provide guidance on areas such as environmental water requirements. Water management objectives in Botswana are stated in the National Water Policy (2012), the 2036 Vision document (GoB, 2016) and the National Development Plan 2017-2023 (GoB, 2017). These policies, however, provide little basin specific objectives. Water security for domestic and industrial supply remains a top priority and its articulation filters through the policies. In this section, where no specific basin management objectives are given in the policy documents, the national water resources management objectives in Table 3.3 apply.

South Africa. Key legal and policy guidance on basin management objectives was found in;

1. The National Water Act (Act 36 of 1998) (RSA, 1998)
    a. This legal instrument contains directives on the setting of the Reserve, determination of RQO and classification
        i. Section 13(1) provides for the Determination of Water Resource Classes
        ii. Section 13(1)(b) Determination of Resource Quality Objectives
        iii. Part 3 – The Reserve
2. The National Water Resources Strategy II (DWA, 2013)
    a. This policy documents provides guidance and what the strategy for managing the water resources and is valid until
3. The National Water and Sanitation Master Plan (DWS, 2019)
    a. This is an integrated plan that includes sanitation after the institutional reform that saw the transition from Department of Water Affairs to Department Water and Sanitation
4. National Freshwater Ecosystem Priority Areas (NFEPA)
    a. The NFEPA were developed by a consolidated group of government departments and water institutions toward harmonizing management and protection of environmental, ecological and water resources

A description of terms used in the classification and setting of RQOs (Resource Quality Objectives) is provided in Table 3.4. RQOs are determined per Integrated Unit of Analysis (IUA), and priority nodes within the IUA.

Throughout this chapter, basins management objectives for South African sub-basins will be presented through the (i) REC to be maintained (ii) WRC (iii) E-flow[9] as % of Natural Mean Annual Runoff and presented as a range across the Integrated Units of Analysis (IUA) in the Preliminary Risk Regions (PRR). Detailed RQO statements and descriptive management objectives are given for (i) water quantity (ii) habitat and biota and (iii) water quality in the specific Government Gazettes to which reference is made. Government Gazettes containing the RQO for the Marico, Crocodile, Matlabas, Mokolo and Letaba, Olifants are provided as Annexes to this document[10]. Table 3.5 provides a description of ecological classes ranging from natural unmodified dates to critical and irreversible changes (A – E).

[9] Also referred to as Ecological Water Requirements (EWR) in the Government Gazettes

[10] RQO documentation is not available for the Lephalale, Mogalakwena, Sand, Nzhelele, and Luvuvhu and Shingwedzi sub-basins in South Africa.

TABLE 3.4: TERMS AND DESCRIPTIONS FOR BASIN MANAGEMENT OBJECTIVES IN SOUTH AFRICA. (RSA, 2016). THESE CLASSES ARE USED TO INTERPRET THE GAZETTED OBJECTIVES

TERM	DESCRIPTION
WATER RESOURCE CLASS (WRC)	The representation of the attributes required of different water resources by the water resource custodian (the DWS)
CLASS I	Indicating high environmental protection and minimal utilisation
CLASS II	Indicating moderate protection and moderate utilisation;
CLASS III	Indicating sustainable minimal protection and high utilisation.
RECOMMENDED ECOLOGICAL CATEGORY (REC)	A category indicating the ecological management target for a water resource based on its eco-classification that should be attained.
RESOURCE QUALITY OBJECTIVES (RQO)	The Resource Quality Objectives that are both descriptive statements and numerical values for the biological, physical and chemical attributes of the significant water resources throughout the catchments. They are narrative and qualitative statements that describe the overall objectives for the Resource unit.
INTEGRATED UNIT OF ANALYSIS	A catchment that incorporates a social-economic zone, but is defined by a watershed
ECOLOGICAL RESERVE	Is the quantity and quality of the water required to satisfy basic human needs by securing a basic water supply and to protect the aquatic ecosystem in order to secure ecologically sustainable development and use of the relevant water resources.

TABLE 3.5: ECOLOGICAL CATEGORY DESCRIPTIONS (RSA, 2016). THESE CATEGORIES ARE USED TO INTERPRET THE GAZETTED CATEGORIES

ECOLOGICAL CATEGORY	GENERIC NARRATIVE RQO	INSTREAM AND RIPARIAN HABITAT NARRATIVE RQO	FISH, MACROINVERTEBRATE AND RIPARIAN VEGETATION NARRATIVE RQO	NUMERICAL RQO
A	Unmodified, near natural.	Very similar to natural reference conditions	Assemblage attributes as specified	≥ **A** (≥ 92%) A/B ≥ **A/B** (≥ 88%)
B	Largely natural with few modifications.	Largely natural with few modifications. The flow regime has been slightly modified and pollution is limited to sediment. A small change in natural habitats may have taken place. However, the ecosystem functions are essentially unchanged.	Assemblage attributes as specified	≥ **B** (≥ 82%) ≥ **B/C** (≥ 78%)
C	Moderately modified.	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	Assemblage attributes as specified	≥ **C** (≥ 62%) ≥ **C/D** (≥58%)
D	Largely modified	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	Assemblage attributes as specified	≥ **D** (≥ 42%) ≥ **D/E** (≥ 38%)
E	Seriously modified	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is	Assemblage attributes as specified	20-39%

ECOLOGICAL CATEGORY	GENERIC NARRATIVE RQO	INSTREAM AND RIPARIAN HABITAT NARRATIVE RQO	FISH, MACROINVERTEBRATE AND RIPARIAN VEGETATION NARRATIVE RQO	NUMERICAL RQO
		extensive.		
F	Critically / Extremely modified	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	Assemblage attributes as specified	0-19%

Mozambique The Mozambique's 'Water Act No. 16/91 provides statutory guidance on regulation of water resources. The following supporting policy documents were used to determine management objections and visions related to the flows in the Limpopo Basin in Mozambique.

1. Water Act No. 16/91- stipulates provisions for regulating public water resources and their use
2. National Water Resources Management Strategy, 2006, provides strategic actions for water resources in areas inkling flood and drought management as well as managing transboundary resources.
3. Flood Management Plan, 2018 which provides a detailed description of flood management

Zimbabwe The Zimbabwe National Water Act of 1998 is the overarching law for managing water resources. Nation Development Plans also contain management plans for water resources. Documents referenced for water management objectives are:

1. Zimbabwe National Act (20:24) of 1998
2. Environmental Management Act (20:27) of 2002
3. Zimbabwe National Water Policy, 2012
4. The National Transitional Stabilization Plan, 2018

5. The Mzingwane Catchment Council Strategic Plan 2019-2023
6. Mzingwane River System Outline Plan, 2009

3.7 PRELIMINARY RISK REGIONS – FLOW RELATED MANAGEMENT OBJECTIVES

This section presents flow related management objectives in each Preliminary Risk Region and associated sub-basins.

MARICO CROCODILE

TABLE 3.6: MARICO CRODODILE MANAGEMENT OBJECTIVES

SUB-BASIN	WRC	REC TO BE MAINTAINED[11]	E-FLOWS AS % OF NATURAL MEAN ANNUAL RUNOFF	VISIONS STATEMENTS / MANAGEMENT OBJECTIVES
Crocodile	II - III	B-D	7.48 -45.93	Available groundwater resources should be utilized in all areas and opportunities for conjunctive surface / groundwater utilization should be explored. (DWS, 2018)
Marico	I - III	B - D	7.96 – 76.32	Groot Marico flagged as FEPA PES for Marico to be maintained (DWA, 2013) Importance of implementing an Ecological Reserve monitoring programme (DWA, 2013) It is not in any way practical to release upstream flows for the management of low flows in the Limpopo. Water released from the tributaries might reach the main stem but would never get beyond the first weir. The low-flow status quo of the Limpopo main stem has

[11] Data for REC, WRC and E-Flows as % of Natural Mean Annual Runoff obtained from (RSA, 2015)

				changed irreparably, and a true Reserve can now never be achieved. Botswana does not have legal obligations to the Reserve of this common river, complicating the task. It is nevertheless recommended in the NFEPA report that a portion of the Marico River be protected in its current, relatively pristine condition.
Notwane	Cognizance shall be taken for the environment and ecosystem requirements to receive priority when planning and allocating water among competing uses and users (GoB, 2012)[12] Assess and operationalize an ecological reserve and requirements for all catchments and water resources infrastructure (GoB, 2012).			

[12] Basin management statements in the Botswana National Water Policy applies as no specific objectives were available.

OLIFANTS

TABLE 3.7: OLIFANTS MANAGEMENT OBJECTIVES

SUB-BASIN	REC TO BE MAINTAINED[13]	WRC	E-FLOWS AS % OF NATURAL MEAN ANNUAL RUNOFF	VISIONS STATEMENTS / MANAGEMENT OBJECTIVES
Upper Olifants	B - D	III	4.67 – 13.90	De Hoop Dam on the Steelpoort River, an important tributary of the Olifants River, Mpumalanga, as Phase 2A of the Olifants River Water Resource Development Project. Major pipelines for delivering water from de Hoop Dam (a) for domestic use on the Sekhukhune Plateau (b) to platinum mines in the Eastern Belt near Steelpoort (c) to augment supplies for mining and domestic use at Mokopane, and (d) for later augmentation of supplies for domestic and industrial use at Polokwane. These components are Phases 2B, 2C and 2D, to be followed by planned phases 2E to 2H, of the ORWRDP (DWA, 2013) Groundwater augmentation investigations underway, the implementation of groundwater schemes to be initiated as soon as possible (DWS, 2018)
Middle Olifants	B - D	III	3.81 - 13.90	
Steelpoort	B - D	III	7.43 - 20.78	
Lower Olifants	A - D	II	4.30 - 27.9	

[13] Data for REC, WRC and E-Flows as % of Natural Mean Annual Runoff obtained from (RSA, 2015)

UPPER LIMPOPO

TABLE 3.8: UPPER LIMPOPO MANAGEMENT OBJECTIVES

SUB-BASIN	REC TO BE MAINTAINED[14]	WRC	E-FLOWS AS % OF NATURAL MEAN ANNUAL RUNOFF	VISIONS STATEMENTS / MANAGEMENT OBJECTIVES
South Africa sub basins				
Mokolo	B-D	II	8.65-52.63	Provide assurance of supply to the Matimba and Medupi power Stations (DWA, 2013) Consideration of water transfers into the Mokolo Catchment (DWA, 2013) A number of new developments are expected in the Mokolo catchment, including possible extension of existing mines, development of gas fields and the development of petrochemical industries, which may negatively impact on the water quality in this catchment (DWS, 2016)
Matlabas	A-B/C	II	5.23-35.58	
Lephalale	There are no significant developments expected in the Lephalale catchment due to the limited water available and the high conservation importance of the Wilderness area in the middle reaches of the catchment (DWS, 2016).			
Mogalakwena	Additional water to support the rapid expanding mining activities in the vicinity of Mokopane needs to be augmented by transfers from the Flag Boshielo Dam in the adjacent Olifants River catchment (DWS, 2016)			
Botswana sub basins				
Bonwapitse Mahalapswe Lotsane Motloutse	Cognizance shall be taken for the environment and ecosystem requirements to receive priority when planning and allocating water among competing uses and users (GoB, 2012)[15] Assess and operationalize an ecological reserve and requirements for all catchments and water resources infrastructure (GoB, 2012)			

[14] Data for REC, WRC and E-Flows as % of Natural Mean Annual Runoff obtained from (RSA, 2017)

[15] Basin management statements in the Botswana National Water Policy applies as no specific objectives were available.

SHASHE

TABLE 3.9: SHASHE MANAGEMENT OBJECTIVES

SUB-BASIN	VISIONS STATEMENTS / MANAGEMENT OBJECTIVES
Shashe	Shashe West development of 1.50 MAR will be required to cater for the increases in water usage to the planning horizon, this includes a reserve of 3% of MAR. (ZINWA, 2009) Agriculture will be the predominant user taking up 75% of the developed yield. An environmental flow of 4% has been allowed (ZINWA, 2009) Tuli river catchment - a development of only 0.50MAR will be required to cater for the planning horizon, this includes a reserve of 4% of MAR. (ZINWA, 2009) Tuli-Manyange Dam 33 million m³ dam and 2 saddle dams with earth fill volume of 110 000 m³ to be 40% complete by 2020 (GoZ, 2018)

MIDDLE LIMPOPO

TABLE 3.10: MIDDLE LIMPOPO MANAGEMENT OBJECTIVES

SUB-BASIN	VISION STATEMENTS / MANAGEMENT OBJECTIVES
Mzingwane	A dynamic, sustainable and prosperous Catchment area by 2023. (MCC, 2018) A further 3 000ha has been proposed for irrigation and a canal is under construction. An environmental flow of 10% MAR has been allowed in Lower Mzingwane Catchment (ZINWA, 2009). Upper Mzingwane - Development to 2.40 MAR for the Mzingwane dams will be required to cater for the increased usage over the planning horizon. An environmental flow of 4% MAR has been allowed (ZINWA, 2009) It is therefore recommended that for the river systems in this area, as a whole, 15% of the gross MAR amounting to 82.84 million m^3/a be reserved for future use on a permanent basis by the private sector, and that the remaining run-off of the river system be reserved for the future development of national schemes. Intervention options proposed for additional water supply into the Sand catchment (South Africa) include the transfer of approximately 30 million m^3/a of water from Zhovhe Dam (Zimbabwe) to support the planned controversial Musina Special Economic Zone and the Limpopo Eco-Industrial Park by 2025 (DWS, 2016).

SUB-BASIN	VISION STATEMENTS / MANAGEMENT OBJECTIVES
Bubi	Environmental flows reserved at 4% of MAR (ZINWA, 2009). Additional potential yield of this catchment that could be made available for agricultural use until the early part of the next century is 8.2 million m^3/a (ZINWA, 2009).
Nzhelele	Approximately 25% of the MAR of 49 000 million m^3/a needs to remain in the rivers and estuaries to support ecological functioning of the catchments, depending on the specific river systems. (DWA, 2013)[16]
Sand	A joint water commission has been stablished to conduct studies to investigate potential supply from Zimbabwe into the Sand catchment for use in the Musina Special Economic Zone (DWS, 2018).

MWENEZI

TABLE 3.11: MWENEZI MANAGEMENT OBJECTIVES

SUB-BASIN	VISION STATEMENTS / MANAGEMENT OBJECTIVES
Mwenezi	Development level will need to be increased to 1.50 MAR to cater for an increase in the agricultural usage (ZINWA, 2009) Additional potential yield of this catchment that could be made available for agricultural use until the early part of the next century is 54.9 million m^3/a (ZINWA, 2009) 10% MAR has been allowed for environmental flows (ZINWA, 2009).

LUVUVHU

TABLE 3.12: LUVUVHU MANAGEMENT OBJECTIVES

SUB-BASIN	VISIONS STATEMENTS / MANAGEMENT OBJECTIVES
Luvuvhu	Investigate and implement groundwater developments. The Luvuvhu and Letaba Water Supply System (DWS, 2018) Investigate the possible increase of the Nandoni sub-system yield by improved utilising of downstream incremental flows (DWS, 2018).

[16] Basin management statements in the South Africa National Water Resources Strategy II applies as no specific objectives were available.

LETABA

TABLE 3.13: LETABA MANAGEMENT OBJECTIVES

SUB-BASIN	REC TO BE MAINTAINED[17]	WRC	E-FLOWS AS % OF NATURAL MEAN ANNUAL RUNOFF	VISION STATEMENTS / MANAGEMENT OBJECTIVES
Letaba	A-E	I - III	11.8 – 14.1	Groot Letaba Water Development Project (GLeWAP): Phase 2 Construction of Nwamitwa Dam in the Groot Letaba River to meet the projected growing primary requirements to the year 2025, to improve the water availability for the riverine ecosystem and to make provision for new resource poor farmers by 2020 (DWS, 2018) Investigate and implement groundwater developments. The Luvuvhu and Letaba Water Supply System (DWS, 2018)

The highest recommended ecological class in the sub-basin is A in the Lower Klein Letaba tributaries while the poorest REC of E is to maintained for two of the biophysical nodes in the middle Letaba.

SHINGWEDZI

TABLE 3.14: SHINGWEDZI MANAGEMENT OBJECTIVES

SUB-BASIN	VISIONS STATEMENTS / MANAGEMENT OBJECTIVES
Shingwedzi	Efficient use of water for economic development, water for environmental conservation (RdM, 2006). Approximately 25% of the MAR of 49 000 million m^3/a needs to remain in the rivers and estuaries to support ecological functioning of the catchments, depending on the specific river systems (DWA, 2013).

[17] REC, WRC and E-Flow as % of Natural Mean Annual Runoff obtained from (RSA, 2016)

LOWER LIMPOPO

TABLE 3.15: LOWER LIMPOPO MANAGEMENT OBJECTIVES

SUB-BASIN	VISIONS STATEMENTS / MANAGEMENT OBJECTIVES
Lower Limpopo	Improving the resilience and reducing risk of damage to the communities, infrastructure and livelihoods in the lower Limpopo River Basin (ADB, 2014). Efficient use of water for economic development, water for environmental conservation (RdM, 2006).

KEY MESSAGES

- Flow related regional (SADC) and basin wide (LIMCOM) policy frameworks on the Limpopo recognise the importance of maintaining ecological flows, however detail lacks on how exactly these E-flows will be implemented at basin level. Attention has mostly been paid to capacity building activities.
- Riparian countries uphold IWRM principles in their policies, however implementation of E-flows is addressed to varying degrees of detail and articulation.
    - Botswana's policy framework on E-flows is the least detailed with not much granular guidance provided. No guidance or management objectives were available in terms of protection and use of the individual sub-basins of the Limpopo.
    - Mozambique equally recognizes the importance of E-flows both in its water Law 16/91 and in its 2006 National Water Resources Management Strategy. Other basin management objectives are linked to flood mitigation and climate resilience.
    - South Africa leads the basin in terms of policy and legislation provisions on how E-flows will be implemented and protected even up to the catchment level. Management objectives for the individual sub-basins are available and directed towards implementing E-flows and the protection of ecological habitats. The priority of freshwater ecosystems has also been identified. Management objectives and vision for the sub-basins in South Africa range from ecological protection, economic productivity through irrigation, water availability and infrastructure development.
    - The Zimbabwe National Water Policy highlights the need to make provision for E-flows in catchment plans. A similar plan was developed for the Mzingwane and provides some guidance on E-flows and future uses of water resources in the sub-basin. Management Objectives largely linked to ensuring water availability for irrigation and economic productivity.

4. WATER RESOURCES

4.1 WATER RESOURCES AVAILABILITY PER RISK REGION

Water resources, refers to water in its various forms of liquid, vapour and solid, and in various locations (atmospheric, surface and subsurface), which have potential value to society's well-being and to sustainable economic development (United Nations, 2006). Water availability refers to total runoff, including groundwater recharge, also called internal renewable water. Plants, animals, ecosystems and humankind are sensitive to fluctuations in the storage, fluxes, and quality of available soil, surface and/or ground water and hence water availability and management are linked to poverty, hunger and diseases at local and national levels. In turn, these storage fluxes and quality are sensitive to climate change (e.g. manifested through rainfall variations, spread of certain diseases and other factors).

CLIMATE

The mean annual rainfall varies from 200 millimetres (mm) in the hot dry central Limpopo valley and Mozambique interior to 1 000-1 500 mm in the high mountain areas in South Africa, with a basin average of 530 mm (Environmentek, CSIR, 2003; LBPTC, 2010; Trambauer et al. 2015). The mean annual water input by precipitation to the Limpopo Basin totals approximately 230 000 million m^3 (Mainuddin et al. 2010). The annual number of rain days in the rainy season rarely exceeds 50 (Alemaw 2008) and the mean annual potential evaporation varies between 1 400 and 2 200 mm (Trambauer et al. 2015). The timing of the beginning and end of the effective precipitation is very variable, which makes the lower Limpopo a very high-risk dryland agricultural zone with crop failure in 75-90 per cent of the years (Environmentek, CSIR, 2003). The proportion of rainfall that becomes river runoff (runoff coefficient) is very small, about 4.3 and 1.7-2 per cent for the naturalized and observed discharges respectively, at Chókwe station in Mozambique (Mainuddin et al. 2010; Trambauer et al. 2015). The runoff ratio is very low in the west of the basin (i.e. there is less runoff) and generally increases to the south and east (Mainuddin et al. 2010).

This water input is partitioned amongst the major water uses in the basin as shown in Table 4.1 and Figure 4.1. The grassland, which includes shrub land and barren land, is the most extensive landuse that covers 57 per cent of the basin and uses most water followed by rainfed agriculture which covers 40 per cent of the basin and uses 40 per cent of the available water. Net runoff, which is runoff remaining after all the water uses in the basin have been satisfied and includes all other storage changes and losses is 3 595 million m^3 or 1.6 per cent of the total precipitation input (Mainuddin et al. 2010).

TABLE 4.1: RAINFALL PARTITIONING IN THE LIMPOPO BASIN (MAINUDDIN ET AL. 2010)

WATER USER	AREA COVERED (%)	WATER USE (MILLION M³/A)	WATER USE (%)
Grassland, shrub and barren land	57	120 000	52
Rainfed	40	90 000	39
Woodland and other	-	14 005	6
Irrigation	0.6	1 700	0.8
Domestic and industry	-	700	0.3
Net runoff		3 595	1.6

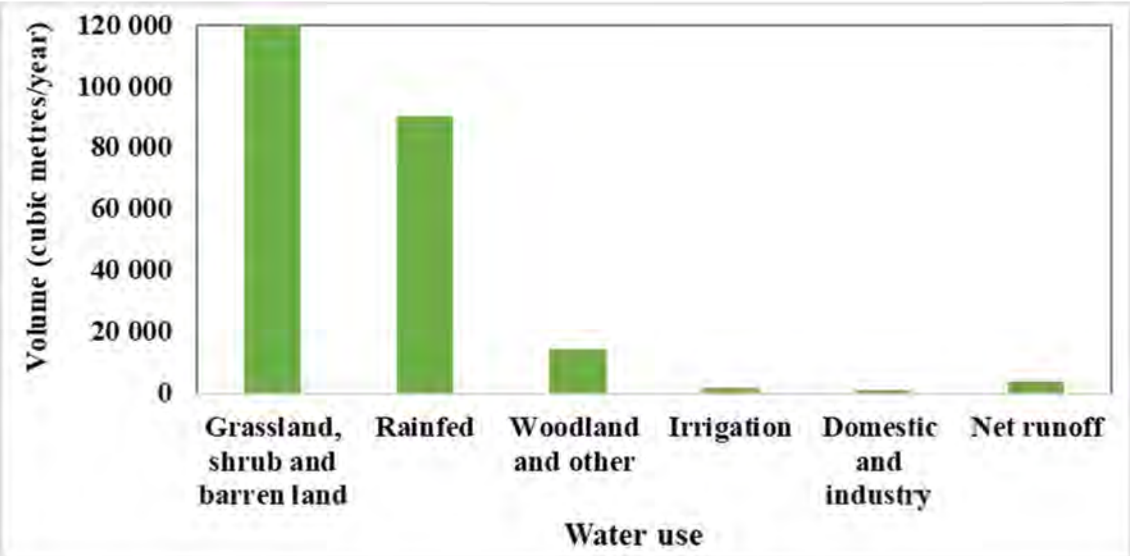

FIGURE 4.1: WATER USES FROM THE RAINFALL INPUTS OF 230 000 MILLION CUBIC METRES PER YEAR IN THE LIMPOPO BASIN (2010).

Most of the Limpopo basin countries are water stressed (below 1 700 cubic metres per capita per year) and Botswana, Mozambique and South Africa face chronic scarcity (below 1 000 cubic metres per capita per year) of water (SADC, 1999; Falkenmark et al. 2007) as shown in Table 4.2. In 2025 all the basin countries will experience chronic water scarcity as water availability per person will decrease (Table 4.2). The population projection for 2025 was exponetial based on average rate of population increase from 2000-2020 for Botswana (2.08%), Mozambique (3.76%), South Africa (1.31%) and Zimbabwe (1.99%) (African Development Bank, 2019).

TABLE 4.2: WATER AVAILABILITY AT COUNTRY LEVEL FO RTHE LIMPOPO BASIN RIPARIAN COUNTRIES (SADC, 2020)

COUNTRY	TOTAL WATER AVAILABLE (KM³)*	POPULATION 2020 (MILLIONS)	WATER PER PERSON IN 2020 (M³/PERSON/YEAR)	ESTIMATED POPULATION IN 2025 (MILLIONS)**	WATER PER PERSON IN 2025 (M³/PERSON/YEAR)
Botswana	1.6	2.3	696	2.6	627
Mozambique	17.0	29.5	576	32.7	519
South Africa	52.8	57.9	912	64.3	822
Zimbabwe	15.5	14.4	1 076	16.0	970

Notes:

*This is the total water available (surface plus ground water) that is generated within the geo-political boundaries of the riparian countries each year and excludes water that flows in from neighbouring riparian countries. Minor volumes of recycled water contribute to water available in South Africa.

**Population projections in 2025 have been adjusted to account for the current prevalence of HIV/AIDS in the respective countries.

CLIMATE CHANGE

Climate change is projected to have major physical (reduced water availability e.g., for irrigation) and economic impacts in the Limpopo River Basin because the basin is already water-constrained and there is a reliance on rural livelihoods (Aurecon, 2013a). Climate change modeling for each country was summarized in the respective national communications to the United Nations Framework Convention on Climate Change (UNFCCC). The modeling studies are of high quality in Botswana, Mozambique and South Africa, based on ensemble GCMs (and RCMs in South Africa), for two timeframes (~2050 and end century), while modeling work for Zimbabwe is based on one GCM and a timeframe of 2080 (Table 4.3). All parts of the countries are likely to experience increased seasonal rainfall variability.

TABLE 4.3: CLIMATE CHANGE EFFECTS IN BASIN COUNTRIES FROM THE GCMS (ONE WORLD, 2013)

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR IMPACTS
All	Limpopo river basin	Increase in temperature (min and max) and evapotranspiration and variability. In Botswana all areas are affected by 2046-2065, In Mozambique all areas in basin are expected to experience 1.5-3°C by 2046-2065, In South Africa an increase of 3°C by middle of 21st century and in Zimbabwe an average increase of 2°C and a decrease of rainfall by 68-158 mm per annum by 2080 (One World 2013). Other impacts expected in different areas include increased total annual rainfall, increased mean number of rain days, decrease in median daily rainfall and a decrease in its variance, earlier beginning of rainy season, earlier end of rainy season, late beginning of rainy season and later end to the rainy season, increased drought and flood frequency and severity (One World 2013). GCM-based modelling was used for the above results: Fifteen GCMs from the IPCC Fourth Assessment Report (AR4) were forced with both the SRES B1and A2 scenarios, for the period 2030-2060 relative to 1960-2000. GCM-based projections indicate increased temperature by between 1°C and 2°C than the baseline in the short term (2011- 2040), while long term rainfall is projected to decrease by up to 15%, especially in the north-eastern side of the basin (Aurecon, 2013a).
All	Limpopo river basin	The effects of climate change on water availability and use (especially for irrigation) were analysed, using a global hydrological model and the Water Simulation Module (WSM) of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). The analysis finds that while water resources of the Limpopo River Basin are already stressed under current (1971-2000) climate conditions, projected water infrastructure and management interventions are expected to improve the situation by 2050 if current climate conditions continue into the future. However, under the SRES A1B scenario, water supply availability is expected to worsen considerably by 2050. Given that expansion of irrigated areas has been suggested as a key adaptation strategy for Sub-Saharan Africa, such expansion will need to carefully consider future changes in water availability in African river basins (Zhu and Ringler, 2012).
Marico and Crocodile and a part of Upper Limpopo	Crocodile, Marico, Mahalapse, Lotsane	The effect of regional climate on river flow in the upper Limpopo Valley (21–24.5S, 26–30E) is demonstrated. The study finds that the annual cycle of gains from precipitation spikes upward in late summer (Jan–Mar), while losses from evaporation have a broad peak in early summer (Oct–Dec). Different formulations of the surface water balance yield a range of values from −0.21 to −1.69 mm/day, depending on how evaporation is quantified. The study also finds that there is little trend in Limpopo River flow during the period 1959–2014; however, CMIP5 model projections exhibit a decreasing trend in the surface water balance (Jury et al. 2016).
All	Limpopo river basin	Annual and seasonal variations of rainfall and temperature in time and space from 1979 to 2013 were analysed. The annual rainfall means varied between 160 and 1 109 mm, from west to east of the basin during the study period. Annual minimum and maximum temperature ranged from 8°C in the south to 20°C in the east of the basin, and 23°C in the south of the basin to 32°C in the east. Annual rainfall showed higher CV values (28% to 70% from east to west of the basin) than annual temperature.

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR IMPACTS
		Upward trends for both annual and seasonal rainfall are revealed in most parts of the basin except for the winter season, which shows a decreasing trend. Minimum temperature on an annual basis and for the winter and spring seasons have shown an increasing trend while it has shown a decreasing trend for the summer and autumn seasons. Maximum temperature has shown a decreasing trend on an annual, summer, autumn and spring basis but an increasing trend for winter (Mosase and Ahiablame, 2018).
All	Limpopo river basin	In the last few decades, the Limpopo has experienced a number of extreme rainfall events which have created considerable socio-economic and environmental impacts, especially among those dependent on rain-fed agriculture. CHIRPS, 0.05° gridded rainfall data was used to identify and analyse daily extreme events over the 1981–2016 period. Analysis of the top 20 events had suggested a pattern with rainfall generally decreasing from the eastern to western parts of the basin. The highest rainfall amounts were observed to occur over the regions where there are steep topographical gradients between the mountainous regions of north-eastern South Africa and the Mozambican flood plains. The monthly distribution of extreme events had shown that most of the events occurred during the late summer months (January–March). On inter-annual time-scales, most of the summers with above average number of events have coincided with La Niña conditions and, to a lesser extent, a positive subtropical South Indian Ocean Dipole (Rapolaki et al. 2019).
Shashe and a part of Middle Limpopo	Shashe and Mzingwane	Trends in various parameters of temperature (4 stations), rainfall (10 stations) and discharge (16 stations) from the Shashe and Mzingwane basins have been statistically analysed. It has been determined that rainfall and discharge in the study area have undergone a notable decline since 1980, in terms of the total annual water resources (declines in annual rainfall, annual unit runoff) and the temporal availability of water (declines in number of rainy days, increases in dry spells, increases in days without flow). The main rising risk is identified as an increasing number of dry spells (which is likely to decrease crop yields), and an increasing probability of annual discharge below the long-term average (which could limit water availability). Increasing food shortages are identified as a likely consequence of the impact of declining water resource availability on rain-fed and irrigated agriculture. Further, stresses on urban water supplies, especially to Zimbabwe's second-largest city of Bulawayo, which already experiences chronic water shortages, are also predicted (Love et al. 2010).

4.2 HYDROLOGY

RIVERS AND TRIBUTARIES

The most important rivers from a perspective of contributions to the Limpopo main-stem flow are the Crocodile and Olifants Rivers in South Africa and the Mzingwane River in Zimbabwe (Figure 4.2). There is only a single tributary in Mozambique, the Changane River which contributes only a small percentage of runoff to the Limpopo River due to the flat nature of the topography in Mozambique. This tributary has significant wetlands associated with it (Aurecon, 2013a).

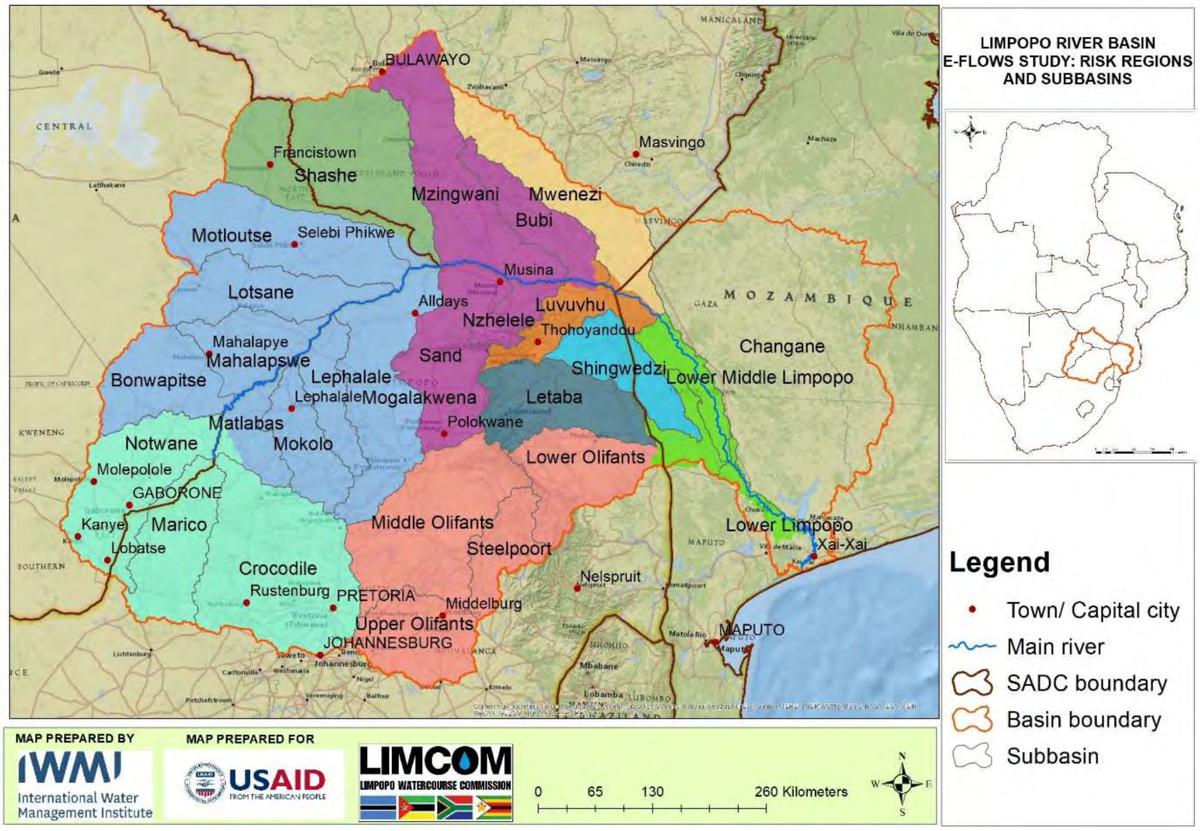

FIGURE 4.2: SUB-BASINS (AURECON, 2013A) IN EACH RISK REGION

MEAN ANNUAL RUNOFF

Runoff is that portion of precipitation which flows into rivers, lakes and oceans by surface drainage, while the portion that remains is either returned to the atmosphere through evapotranspiration or infiltrates the ground and percolates into groundwater. Mean Annual Runoff (MAR) expressed as an average depth of water in mm per unit area of the basin is important in the design of water supply systems, fisheries, hydroelectric power generation, and other water related projects. The annual river flows from some of the larger gauged catchments of the basin are shown in Figure 4.3 and Figure 4.4 for most recent study in 2010. The difference between natural and current flows in Figure 4.4 indicates the extent of development and effects of climate variability and change in each of the subbasins, while that between MAR amounts indicates the variations in mean annual precipitation, topography, landuse/type and latitude across the basin or catchment. The main runoff period is from December to May, while the peak runoff period is from February to March.

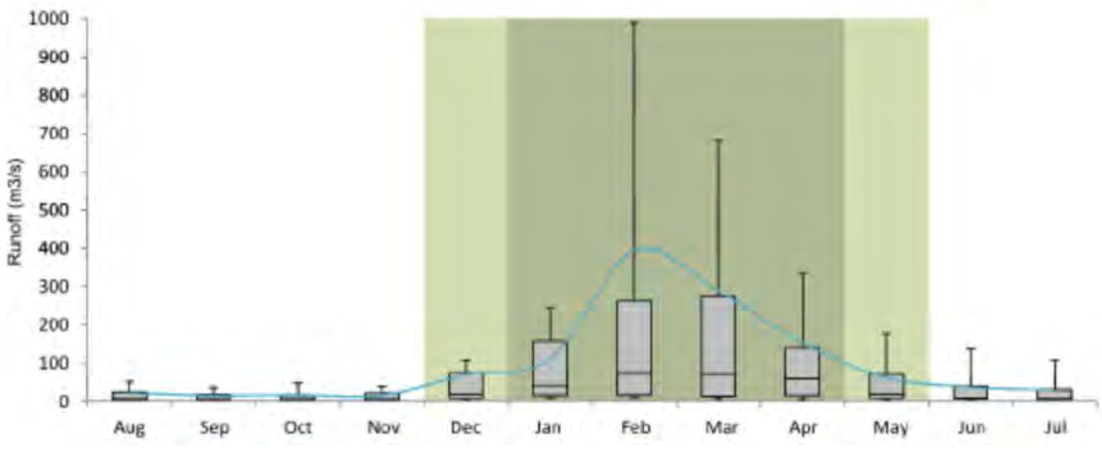

FIGURE 4.3: LIMPOPO RIVER FLOW REGIME FOR STATION 24 AT CHÓKWÈ (TRAMBAUER ET AL. 2015). BLUE LINE REPRESENTS THE AVERAGE OBSERVED RIVERFLOW AND THE WHISKERS OF THE BOXPLOTS REPRESENT THE 10TH PERCENTILE AND THE 90TH PERCENTILE.

ANNUAL RUNOFF

The past hydrological studies estimated the total surface MAR at the Limpopo River mouth and this is shown in Table 4.4. The current (C) and natural (N) flows for sub-basins in the basin are shown in Figure 4.4. Heavily water used subbasins show a huge difference between the current and natural flow figures. The total cumulative basin MAR at the mouth of the Limpopo River is 4 072 million cubic metres for current (2010) conditions which is 66 per cent of the 6 197 million cubic metres for natural basin conditions (Aurecon, 2013a). This indicates that the cumulative net human impacts on the surface water resources of the basin currently constitute about 34 per cent on average of the natural surface water resources.

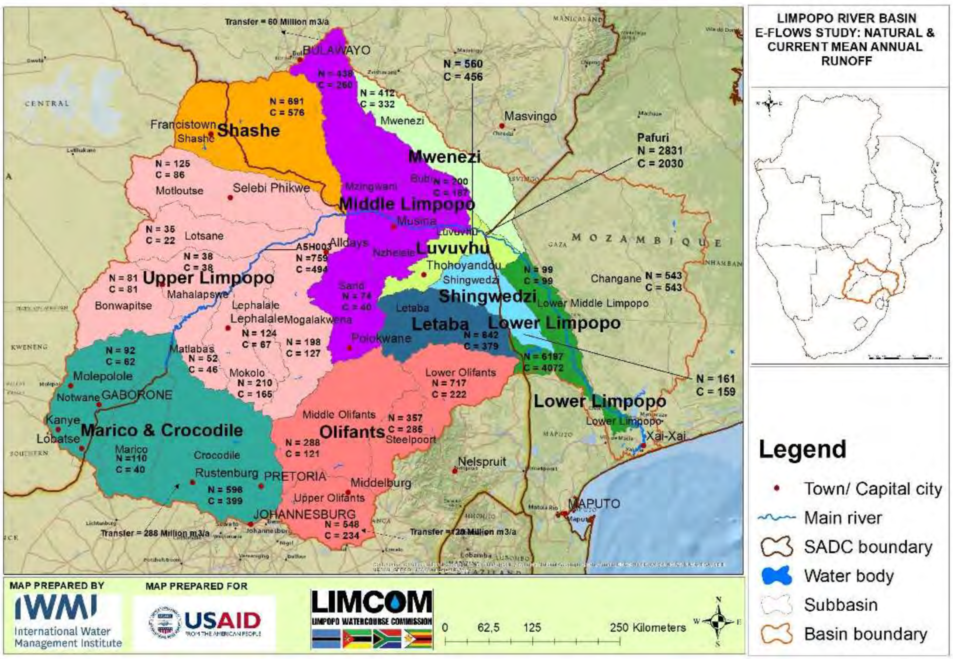

FIGURE 4.4: COMPARISON OF CURRENT (C) (2010) TO NATURAL (N) MEAN ANNUAL RUNOFF FOR SUB-BASINS IN MILLION M3/A (DATA SOURCE: AURECON, 2013A).

MAXIMUM FLOWS

Floods risk

The basin has experienced devastating flood events in the past such as those experienced in February 2000 and January 2012 (Aurecon, 2013a). Continued developments in the flood prone areas have increased the flood risks. Establishment of early warning systems and discouraging further development of flood prone areas have been implemented to reduce flooding impacts, but there is still an opportunity to operate the large dams in the basin as one system to manage floods and droughts. However, floods also bring fertile soil to the flood plain to support agriculture-based livelihoods and other ecosystem services.

The flood risk area (maps) for the 1:20, 1: 50 and 1:100 year floods and normal water levels were produced for the basin and municipalities and other land developers have been encouraged to incorporate the flood risk zones in their development and spatial plans and regulations (Table 4.4). The return period does not indicate regularity of occurrence but the average time interval in years, over a long period of time, between occurrences of flood flows which equal or exceed a given magnitude.

TABLE 4.4: FLOOD RISK AREAS, PEAKS AND RECURRENCE INTERVALS FOR THE LIMPOPO RIVER BASIN (AURECON, 2013A)

RISK REGION	TRIBUTARY / SUB-BASIN / MAIN-STEM GAUGING STATION	MEAN ANNUAL MAXIMUM FLOOD PEAK (MAMFP) (M3/S)	RECURRENCE INTERVAL FLOOD PEAK (M3/S)		
			1:20 Year	1:50 Year	1:100 Year
Shashe	Shashe	209	774	1 172	1 507
Marico and Crocodile	Tuli	413	1 527	2 311	2 972
Middle Limpopo	Mzingwane	729	2 697	4 082	5 248
	Bubi	423	1 564	2 367	3 043
Mwenezi	Mwenezi	693	2 563	3 879	4 987
Marico Crocodile	Marico	194	893	1 029	1 165
	Crocodile	164	752	867	981
Upper Limpopo	Matlabas	177	671	964	1 192
	Mokolo	156	591	848	1 049
	Lephalale	167	633	909	1 124
	Mogalakwena	118	448	644	796
Middle Limpopo	Sand	126	479	688	851
	Nzhelele	440	1 773	2 723	3 550
Luvuvhu	Luvuvhu	578	2 331	3 580	4 668
Letaba	Letaba	1 136	4 579	7 033	9 169
Shingwedzi	Shingwedzi	932	3 754	5 767	7 518
Olifants	Lower Olifants	960	3 456	6 432	9 888
Not a risky region	Changane	80	272	431	596
Middle Limpopo	A5H003/06 (Sterkloop)	225	675	1 013	1 373
	A7H004/08 (Beit Bridge)	2 583	7 749	11 624	15 756
	E33 (Combumune)	1 730	5 882	9 325	12 889

RISK REGION	TRIBUTARY / SUB-BASIN / MAIN-STEM GAUGING STATION	MEAN ANNUAL MAXIMUM FLOOD PEAK (MAMFP) (M3/S)	RECURRENCE INTERVAL FLOOD PEAK (M^3/S)		
			1:20 Year	1:50 Year	1:100 Year
Lower Limpopo	E35 (Chokwe)	1 952	6 637	10 521	14 542
	E38 (Xai-Xai)	1 799	6 117	9 697	13 403

MINIMUM FLOWS

Drought risk

The impacts of drought (Table 4.5) include the drying up of surface water sources and reducing the significant contribution of groundwater to sustain demands and environment.

TABLE 4.5: DROUGHT RISK FOR THE LIMPOPO RIVER BASIN

RISK REGION	INDICATOR	RATIONALE
All	Limpopo basin	A spatial analysis of drought characteristics in the Limpopo basin was undertaken where drought duration, frequency and severity were investigated and drought Severity-Area-Frequency (SAF) curves constructed. The entire Limpopo River Basin was subdivided into four homogeneous regions based on topographic and climate variations in the basin. Monthly and annual SAF curves and maps of the probability of drought occurrence were produced. The results indicated localized severe droughts with higher frequencies compared to moderate to severe low frequency droughts spread over wider areas in the basin. This investigation also revealed that the western part of the basin faced a higher risk of drought when compared to other regions of the Limpopo Basin in terms of medium-term drought patterns (Alemaw et al. 2013).
All	Limpopo basin	A $0.05^0 \times 0.05^0$ resolution PCRaster Global Water Balance (PCRGLOBWB) model has been used to analyze hydrological droughts in the Limpopo River basin in the period 1979–2010 with a view to identifying severe droughts that have occurred in the basin using hydrological and meteorological drought indicators. The indicators considered were able to represent the most severe droughts in the basin and to some extent identify the spatial variability of droughts. Results also show the importance of computing indicators that can be related to hydrological droughts, and how these add value to the identification of hydrological droughts and floods and the temporal evolution of events that would otherwise not have been apparent when considering only meteorological indicators. The study has also characterized drought severity in the basin, indicated by its time of occurrence, duration and intensity (Trambauer et al.

4.3 EXISTING INFRASTRUCTURE

DAMS

Reservoirs/dams are inland water bodies that temporarily store runoff and play a key role in social and economic welfare. They can also support the environment through releases of E-flows. Dams are constructed to impound or divert water in order to maintain a constant water supply for domestic, irrigation, hydroelectric power generation and recreational needs, and may also contribute to streamflow regulation under floods and droughts and may even be used to sustain downstream ecosystems (Figure 4.5). Storage dams in the Limpopo river system shown in Table 4.6 provide reliable supplies of clean water to people in both rural and urban settings, but can also have negative impacts on the environment or other demands if not properly managed (Limpopo Briefing Note, 2015). There are a total of 97 dams (total storage of 7 528 million m^3) of various sizes in the basin reported by Aurecon (2013), plus 3 additional recently constructed dams in Botswana (Dikgatlhong, Lotsane and Thune dams), with a total storage capacity of above 400 million m^3 (yield of 70 million cubic metres). Massingir Dam in the Olifants sub-basin in Mozambique has a capacity of 2 200 million m^3 and an annual discharge of 1 800 million m^3 and is the largest water body in the basin (Mainuddin et al. 2010).

Impact of Dams

The development of numerous large, medium and small dams including farm dams has altered the hydrology of the Limpopo River (Figure 4.5), from a perennial river to a seasonal river for about three quarters of its length (Boroto and Görgens, 1999; Ashton et al. 2001; Environmentek, CSIR, 2003). In addition to the decrease in total flows, there has been a shift in river regime flow with parts of the river having increased dry season flows due to waste-water discharge and irrigation return flows that have significantly affected the water-dependent and aquatic fauna and flora, riverine and floodplain woodlands and forests and mangroves. On the contrary, small reservoirs in the upsteam may release flows during times of shortage and contribute to base flow through underground aquifers and thereby help to maintain flows in rivers during the dry season (McMahon and Mein, 1986).

The catchments of Notwane and Marico (Marico Crocodile risk region) and Upper Olifants (Olifants risk region), and Mzingwane (Middle Limpopo risk region) and Mwenezi (Mwenezi risk region) store greater than 100 % of MAR in dam developments (Limpopo RAK, 2020), with significant hydrology alteration. On the contrary, the sub-catchments in Botswana, Lotsane, Bonwapitse, and Mahalapswe in Upper Limpopo risk region, South Africa (Lephalale –Upper Limpopo risk region), Steelpoort, Lower Olifants (Olifants risk region), Luvuvhu and Shingwedzi risk regions, all catchments in Mozambique (Lower Limpopo risk region), and Bubi (Middle Limpopo risk region) in Zimbabwe store 25 % or less of MAR within dams (Limpopo RAK, 2020).

TABLE 4.6: IMPACTS OF DAMS IN THE LIMPOPO RIVER BASIN

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR DAM IMPACTS
Marico Crocodile	Gaborone dam (144 Mm³) - second largest dam in Botswana. Located at 24.700161°S; 25.926381°E). Construction started in 1966 and completed in 1964. Raised by 7m between 1983 and 1985 to increase capacity, reaching a maximum height of 25 m.	The dam is one of the oldest in the basin and was built to provide urban water supply to the city of Gaborone, in conjunction with groundwater and water transfers. Dam is an earthcore fill structure with a final length of 3.6 km. Dam water releases also recharge the dolomitic aquifer in the lower Notwane river, which is abstracted from well points and boreholes.
Marico-Crocodile	Hartbeespoort dam (206 Mm³). Located at 25.744167°S; 27.899444°E. Dam is in Crocodile catchment in North West Province of South Africa. Contruction started in 1921 and completed in 1925 (renovated in 1969) and is the oldest dam in South Africa, as well as the Limpopo River basin. Dam is 59 m high.	Hartbeespoort dam provided water for irrigation and is a tourist attraction. However, it is impacted by high eutrophication as a result of high nutrients (phosphates and nitrates) from farming, industrial and sewage effluent from the Crocodile river. Recharge of groundwater from the polluted water will likely affect the groundwater quality. It is an arch dam.
Middle Limpopo	Zvohe Dam (133 Mm³) located at (21.8413⁰ S, 29.7114⁰ E) on Umzingwani (lower Mzingwane) river, constructed in 1995-1996. The river, located in Zimbabwe is ephemeral, flowing on average 191 days per year.	Managed releases from the dam supply the Beitbridge town and commercial agribusiness (citrus plantations) downstream. Water releases also recharge an alluvial aquifer in the lower Mzingwane river, which is abstracted from well points and boreholes. Flow regime changes downstream of the dam include the capture of all flows early in the rainy season, most low flows, many larger flows and the reduction in magnitude of some floods. These flow regime changes are thought to have contributed to the decline in active riverbed width and the abandonment of portions of the river channel on either side, which are colonized by vegetation, competing for water with the established riparian vegetation as well as with water users. These effects together with apparent loss in aquifer material indicate a likely decline in the extent of the alluvial aquifer and its specific yield. The riparian ecosystem, consisting of a stand of acacia woodland, is also likely to suffer (Love et al. 2007; Love et al. 2008). This dam is also expected to be under more pressure in future as it is ear-marked to supply water to the Musina-Makhado Special Economic Zone.
Middle Limpopo	Upper Insiza dam (8.829 Mm³) located on the Insiza river, which is a tributary of the Umzingwani (Mzingwane) river. The dam was constructed in 1967. The Insiza river, located in Zimbabwe, is ephemeral with no flow for 176-245 days per year.	The dam provides urban water supply to the city of Bulawayo. No significant difference was detected between the mean annual runoff or the annual maximum flood at gauging stations upstream and downstream of the dam. The amount of water stored during the wet season is thought to balance the releases made during the dry season. The highest floods occur from January to February, which coincides with the period when most dams spill due to earlier inflows from November to January, resulting in an insignificant impact on the annual maximum flood. However, the number of days with no flow is found to be lower at the downstream gauging station due to flow releases in the dry season. Changes in exceedance probabilities of daily flow levels have been

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR DAM IMPACTS
		observed, but are not reflected at the annual level (Kileshye Onema et al. 2006).
Middle Limpopo	Insiza Dam (173.491 Mm³). Located at (20.369886°S, 29.246752°E) on the Insiza river downstream of the Upper Insiza dam. The dam was constructed in 1973.	The dam provides urban water supply to the city of Bulawayo. The behavior of mean annual runoff, the annual maximum flood and the reasons for their behavior are observed to be the same as those for the Upper Insiza dam. However, in the case of this dam, no significant difference was observed in the number of days with no flow upstream and downstream of the dam. Changes in exceedance probabilities of daily flow levels
Middle Limpopo	Silalabuhwa Dam (23.454 Mm³) located at (20.75833°S, 29.36056°E) on the Insiza river downstream of the Insiza dam. The dam was constructed in 1966.	The dam provides urban water supply to the city of Bulawayo. The behavior of mean annual runoff, the annual maximum flood and the reasons for their behavior are observed to be the same as those for the Upper Insiza and Insiza dams. Similar to Upper Insiza dam, the number of days with no flow is found to be lower at the downstream gauging station due to flow releases in the dry season. Changes in exceedance probabilities of daily flow levels were observed, but are not reflected on the annual time scale (Kileshye Onema et al. 2006).
Middle Limpopo	Mutshedzi Dam (216 Mm³). Located at 22.948611°S; 30.161111°E. Dam is located on the Mutshedzi River, a tributary of the Nzhelele River. Built in 1990, and is 22.5m high.	Mutshedzi Dam provides water supply mainly for irrigation purposes. The hazard potential of the dam was ranked significant including flow alterations. It is a gravity dam with a 160m long wall.
Upper Limpopo	Letsibogo Dam (100 Mm³). Located 21.844819°S; 27.734608°E. Construction started in 1997 and completed in 2000, It is 28 m high. Dam is on the Motloutse River in Botswana	Letsibogo Dam provides provide water to the industrial town of Selebi-Phikwe (BCL Limited involved in copper and nickel mining) and surrounding local areas, with potential for use in irrigation around Mmadinare village. Now it also supplies Gaborone, the capital of the country, via a 400 km pipeline, as well as major villages along the pipeline route (Kjetil, 1994).
Upper Limpopo	Lotsane Dam (42 Mm³), Located at 22.591976°S; 27.61443°E. Completed in 2012. It is 30 m high. Dam is on the Lotsane River in Botswana	Lotsane Dam provides water supply to 22 villages of Tswapong North and irrigation water for a 250 hectares horticulture operation near Maunatlala. Dam is an earthfill embankment of 1.5 km long.
Upper Limpopo	Thune Dam (90 Mm³). Located at 22.271098°S; 28.800686°E. Construction started in 2010 and completed in 2013. It is 33.6 m high. Dam is on Thune river, upstream from its confluence with the Motloutse river, Botswana.	Thune Dam provides water supply to several villages in the Bobirwa area, and irrigation water to an agricultural project near Mathathane. Other areas of water supply include the villages of Bobonong, Motlhabaneng, Mathathane, Tsetsebjwe, Mabolwe, Semolale, Gobojango, Lepokole and Molalatau. Dam is a mass concrete, Clay core rock fill structure of 1.7 km long.

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR DAM IMPACTS
Shashe	Dikgatlhong Dam (400 Mm³) -largest dam in Botswana, Located at 21.549008°S; 27.981034°E. It is located near the Robelela village on the Shashe River in Botswana. Construction started in 2008 and completed in 2011. It is 41 m high.	The dam provides water supply to Greater Gaborone, Mahalapye, and Palapye. Water from two dams – Letsibogo and Dikgalthong – is channelled through pipelines called North-South Water Carriers, which transport water for domestic use in the urbanized southern portion of the country namely Gaborone, Palapye, Dikgatlhong dam is a zoned earthfill structure 4.5 kilometres long (LBPTC, 2010)
Shashe	Shashe Dam (85 Mm³). Located at 21.366988°S; 27.428268°E. Construction began in 1970 and completed in1973, It is 27m high. Dam is on the Shashe River in Botswana.	Shashe Dam provides water supply to Francistown for domestic use and industrial city of Selebi-Phikwe. The dam embankment 3.5 km long (Gabathuse and Maganu-Edwin, 2011).
Olifants	Loskop Dam (362 Mm³) -is largest in South African part of the basin. Located at 25.416944°S; 29.350277°E. Dam was built in 1939 and renovated in 1979. It is 54 m high. Dam is on the Olifants river, Mpumalanga, South Africa.	Loskop Dam provides water supply for irrigation purposes (e.g., summer tobacco and cotton and winter wheat, as well as table grapes and vegetables). The dam is situated in the Loskop Dam Nature Reserve and has altered the flows in the river, and its hazard potential was ranked high (LBPTC, 2010). It is a combined gravity and arch type dam, 105m long.
Olifants	De Hoop Dam (348 Mm³) -second largest in South African part of the basin. Located at 24.95750°S; 29.956389°E. Construction started in 2007 and completed in 2014. Dam is on the Steelpoort River, South Africa.	De Hoop Dam provides water supply to people of the Nebo Plateau, Greater Tubatse, Mooihoek and Jane Furse. It is a gravity dam with 1 km long wall.
Lower Limpopo	Massingir Dam (2 800 Mm³) - is the largest dam in the basin, with a flooded area of 150 km². Located at 23.879167°S; 32.144444°E. Construction started in 1971 and completed in 2006. It is 46 m high. Dam is on the Rio dos Elefantes (Olifants or Lepelle) river, Gaza Province, Mozambique. Dam was rehabilitated from 2003-2006 and mobile flood gates were further repaired in 2009 (LBPTC, 2010).	Massingir Dam provides water supply to irrigation schemes of the Limpopo Valley downstream at Chokwe and a 25 megawatts hydro-electric power plant. Dam is located within Limpopo National Park, which is part of the Great Limpopo Transfrontier Park. Flooding affects the breeding ground for the Nile crocodiles and some fish species.

FIGURE 4.5: DAMS WITH STORAGE CAPACITY OF >30 MILLION CUBIC METRES AND RELATED BULK INFRASTRUCTURE FOR WATER SUPPLY IN THE LIMPOPO BASIN (AURECON, 2013A).

Dam water use by power stations is regarded as a strategic water use for the countries. A total of 736 million m^3/a is required by all the existing and new thermal power stations in the basin. No water is transferred out of the basin but a total volume of 695 million m^3/a is transferred into the basin from other basins, i.e., the Vaal, Usuthu and Komati basins (Table 4.7).

TABLE 4.7: INFRASTRUCTURE IN THE RIPARIAN COUNTRIES (AURECON, 2013A).

TYPE OF INFRASTRUCTURE	BOTSWANA	MOZAMBIQUE	SOUTH AFRICA	ZIMBABWE	TOTAL
Large Dams*	13	2	57	28	100
Power Stations - Thermal	1		11		12
Power Stations – Hydro			1		1
Water transfer schemes – Intra-basin	1		9		10
Water transfer schemes – Inter-basin			5	1	6

*Large dam as defined by the International Commission on Large Dams (ICOLD). Total storage of all dams is estimated at 7 928 million m^3, including recently three constructed dams in Botswana with total capacity of 400 million m^3 (2020).

POWER STATIONS

Of the 12 thermal power stations currently in the basin (Aurecon, 2013a), 11 of them are located in South Africa, with a total water use of 223 million m^3/a, while one station, the Morupele power station is in Botswana (Table 4.8). Most of the power plants are located near the major coal fields near Johannesburg and Pretoria in South Africa. There is only a small hydro-power station in Lydenburg in South Africa. The planned thermal and hydro-electric power stations in the basin are shown in Table 4.9.

TABLE 4.8: THERMAL POWER STATIONS IN THE BASIN (AURECON, 2013A)

<table>
<tr><th>NAME OF POWER STATION</th><th>COUNTRY</th><th>SUB-BASIN</th><th>POWER GENERATION CAPACITY (MW)</th><th>WATER REQUIREMENTS (MILLION M3/YEAR)</th></tr>
<tr><td>Morupele A</td><td>Botswana</td><td>Mahalapswe</td><td>132</td><td>3</td></tr>
<tr><td>Arnot</td><td>South Africa</td><td>Upper Olifants</td><td>2 232</td><td>37</td></tr>
<tr><td>Duvha</td><td>South Africa</td><td>Upper Olifants</td><td>3 450</td><td>52</td></tr>
<tr><td>Hendrina</td><td>South Africa</td><td>Upper Olifants</td><td>1 865</td><td>33</td></tr>
<tr><td>Kriel</td><td>South Africa</td><td>Upper Olifants</td><td>2 850</td><td>46</td></tr>
<tr><td>Matla</td><td>South Africa</td><td>Upper Olifants</td><td>3 450</td><td>54</td></tr>
<tr><td>Kendal</td><td>South Africa</td><td>Upper Olifants</td><td>3 840</td><td>3</td></tr>
<tr><td>Komati</td><td>South Africa</td><td>Upper Olifants</td><td>525</td><td>4</td></tr>
<tr><td>Kusile #</td><td>South Africa</td><td>Upper Olifants</td><td>4 800</td><td>15</td></tr>
<tr><td>Medupi 1#</td><td>South Africa</td><td>Mokolo</td><td>4 764</td><td>15</td></tr>
<tr><td>Matimba</td><td>South Africa</td><td>Mokolo</td><td>3 690</td><td>159</td></tr>
<tr><td>Kempton Park</td><td>South Africa</td><td>Crocodile</td><td rowspan="3" colspan="2">28</td></tr>
<tr><td>Johannesburg</td><td>South Africa</td><td>Crocodile</td></tr>
<tr><td>Pretoria</td><td>South Africa</td><td>Crocodile</td></tr>
</table>

Note: # - now operational (2020). Data is based on information from 2011, 2012 and 2020.

TABLE 4.9: PLANNED THERMAL AND HYDRO-POWER STATIONS

NAME OF POWER STATION/ DAM	TYPE OF POWER STATION	COUNTRY	SUB-BASIN	POWER GENERATION CAPACITY (MW)	WATER REQUIREMENTS MILLION M³/A	WATER USE
Morupele B	Thermal	Botswana	Lotsane	600	18	Consumptive
Mmamabula	Thermal	Botswana	Mahalapswe	1 200	± 40	Consumptive
Exaro Private	Thermal	South Africa	Mokolo		3	Consumptive
Medupe II	Thermal	South Africa	Mokolo	4 764	15	Consumptive
Massingir Dam	Hydro	Mozambique	Lower Olifants	28	2 488	Non-consumptive
Manyuchi Dam	Hydro	Zimbabwe	Mwenezi	5	Unknown	Non-consumptive

WATER TRANSFERS

Water transfers are important as a way to balance the water demands and water availability in the basin (Table 4.10). The return flows, from the water transfers can contribute to the environmental water requirements in the receiving basins. Transfers are either classified as intra-basin, where water transfers occur within the Limpopo basin or inter-basin, where water transfers occur from one river basin to another, especially in the South African part of the basin. There is more water transferred into the Limpopo basin than out of it. The largest suppliers of water into the basin are Vaal River System, Orange-Senqu basin, the Komati and Usuthu basins.

TABLE 4.10: WATER TRANSFER SCHEMES IN THE LIMPOPO RIVER BASIN

NAME	PURPOSE OF WATER TRANSFER SCHEME	RIVERS/ TRIBUTARIES INVOLVED		COUNTRIES INVOLVED	TRANSFER VOLUME (MILLION M³/A)
		TRANSFER FROM	TRANSFER TO		
	Inter Transfers				
Usuthu – Vaal Grootdraai Dam	Power stations in Olifants Catchment	Vaal River System	Olifants River	South Africa	36
Rand Water Supplies	Water Supply to Johannesburg, Pretoria and	Vaal System (Augmented from Senqu System)	Crocodile River (West)	South Africa	523
Komati Scheme	Power Stations in the Olifants Catchment	Komati River Nooitgedacht & Vygeboom Dams)	Olifants River	South Africa	85
Usuthu – Vaal Scheme	Power Stations in the Olifants Catchment	Usuthu River (Jericho and other dams)	Olifants River	South Africa	51
	Intra Transfers				
Ebenezer GWS	Water supply to Polokwane 1	Groot Letaba River System (Ebenezer Dam)	Sand River	South Africa	12
Dap naude Transfer	Water supply to Polokwane 2	Groot Letaba System (Dap Naude Dam)	Sand River	South Africa	6
Havecroft Weir transfer	Water supply to Polokwane 3	Olifants River (Havecroft Weir)	Sand River	South Africa	9
Olifants River Water	Water supply to Mogalakwena	Olifants River (Flag Boshielo Dam)	Sterk River	South Africa	40
Gravelotte Supply	Water Supply to Gravelotte mine	Groot Letaba River System (Tzaneen	Olifants River	South Africa	2
Thabina Dam Water	Water supply to villages in the	Groot Letaba River System (Thabina	Olifants River	South Africa	1
Makhado Water Supply	Water Supply to Makhado	Luvuvhu/Mutale River System	Sand River	South Africa	2
Bela-Bela Water Supply	Water Supply to Bela	Apies/Pienaars River System	Mogalakwena River System	South Africa	3
Tshwasa Water	Water supply to Gaborone	Marico River	Notwane River	South Africa & Botswana	9
Bulawayo Water Supply	Water Supply from the Mzingwane catchment in Zimbabwe to Bulawayo	Mzingwane River from the following dams: • Upper Ncema • Lower Ncema • Mzingwane • Inyakani • Insiza • Mtshabezi	Bulawayo in Zambezi catchment	Zimbabwe	No data

NAME	PURPOSE OF WATER TRANSFER SCHEME	RIVERS/ TRIBUTARIES INVOLVED		COUNTRIES INVOLVED	TRANSFER VOLUME (MILLION M3/A)
		TRANSFER FROM	TRANSFER TO		
North-South Carrier	Supply to Gaborone and other towns	Lower Shashe	Ngotwane	Botswana	45

YIELD IN THE CATCHMENT

The water yield is an amount of freshwater derived from unregulated flow (m^3s^{-1}) measurements for a given geographic area over a defined period and is generated from a combination of base flow, interflow and overland flow originating from groundwater, precipitation and/or snowmelt (McMahon and Mein, 1986). The water yield modelling for all current-day storages and run-of-river abstraction points in each risk region /at the Sub-Basin rivers' confluences with the Limpopo main-stem and at a few critical Limpopo main-stem points is shown in Figure 4.6. The 1:5 year yield (Aurecon, 2013a) was approximated by the annual draft that caused 18 annual failures out of a 91-year data series (i.e., 1:5 year recurrence interval - 80% assurance of supply on an annual basis). The downstream yields incorporated the upstream impacts of 1:5 year recurrence interval of failure drafts. At each yield point a monthly distribution of the annual draft appropriate to the relevant types of water use was employed. Besides climate change, topography, land use/ land cover change and management can have a significant effect on catchment water yields and hence affect water allocation to different uses in the basin, including environmental water requirements.

Other benefits of water yield assessment include providing reliable information on availability and interaction of water resources (surface and ground water) to plan their extraction and uses, reflects the management of catchment physical properties required to improve the water yield and provides information on whether to develop conservation measures at head catchment to the tail catchment.

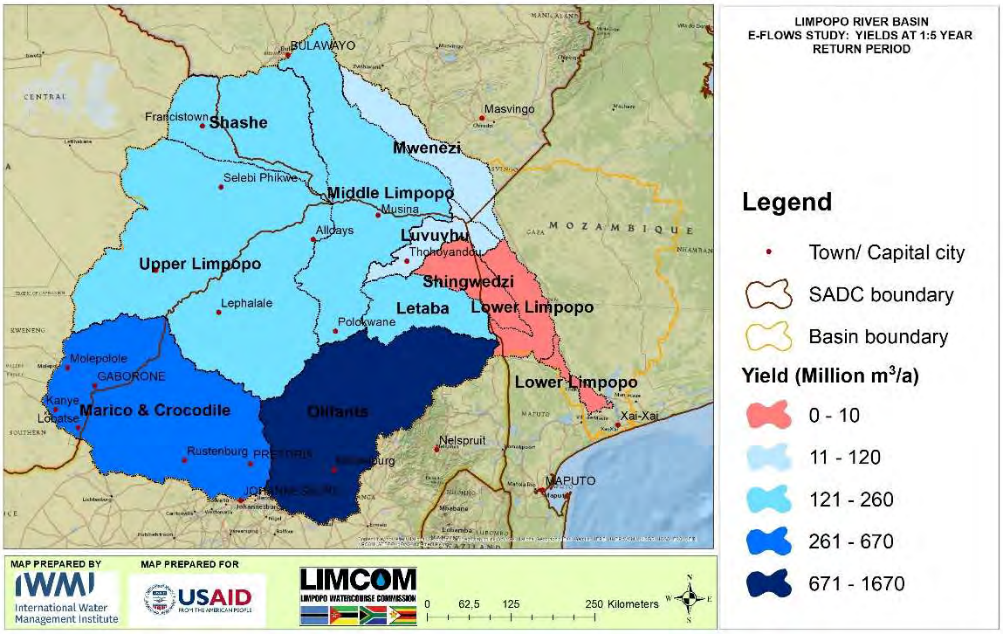

FIGURE 4.6: 2020 YIELDS AT 1:5 YEAR RETURN PERIOD OF FAILURE (80 PERCENT ASSURANCE) AT RISK REGION SCALE

PLANNED WATER SUPPLY PROJECTS

Future water supply sources from Gwayi and Zambezi Rivers are being considered for Bulawayo, while Mapai Dam in Gaza province, southern Mozambique, with a capacity of 11 200 million cubic metres is planned for irrigation water supply in the Lower Limpopo in Mozambique (Boroto, 2001). This dam will exceed the total capacity of all dams in the basin (Aurecon, 2013a), and will supply water for agriculture, livestock, agro-processing, mitigation of floods and droughts, electricity production of 18.36 Megawatts at an early stage, and could be doubled in the future and other developments of the Limpopo Basin (ADB, 2014; Frey, 2018). Future water demand was estimated at 50 million m^3/a based on DTI (2009) mining guidelines and steel plant water needs, with approximately 30 million m^3/a being transferred from Zhovhe Dam in Mzingwane catchment (Middle Limpopo risk region) in Zimbabwe into the Sand catchment (South Africa) to support the planned Musina Special Economic Zone and the Limpopo Eco-Industrial Park which includes the Electro Metallurgical Special Economic Zone (EMSEZ) between Musina and Makhado by 2025 (DWS, 2016, 2018). The Zhovhe dam and the Mzingwane river are both located on the Tuli Karoo Aquifer, shared by Botswana, South Africa and Zimbabwe. However, there are concerns that this special project will negatively impact the water and environmental resources in this water scarce region (Munnik, 2020). The Mokolo Crocodile West Augmentation Project (MCWAP) is planned to bring water for sulphur dioxide scrubbers on Eskom's Medupi power station, (their installation are a contractual obligation to the World Bank), and to expand coal mining and electricity generation (Munnik, 2020). The water will come from the heavily eutrophied (due to wastewater effluent) Hartebeespoort dam on the Crocodile River in Marico-Crocodile risk region.

4.4 LANDUSE/ LANDCOVER

The regulating capacity of the vegetation (Figure 4.7) is generally very small compared to the soil (McMahon and Mein, 1986). Forests are generally known for a high soil infiltration capacities, enhancing base flow, but reduce both dry and wet season flows, which has consequences for downstream water supply. Land-use in the basin includes large bulk water supply dams, smaller farm dams, rainfed and irrigated cropland, and National Parks/conservation areas. Grassland-Cropland mosaics and Savannah are by far the dominant land-cover categories. Land use and vegetation influence rainfall runoff, possible sedimentation of rivers and dams, and groundwater potential.

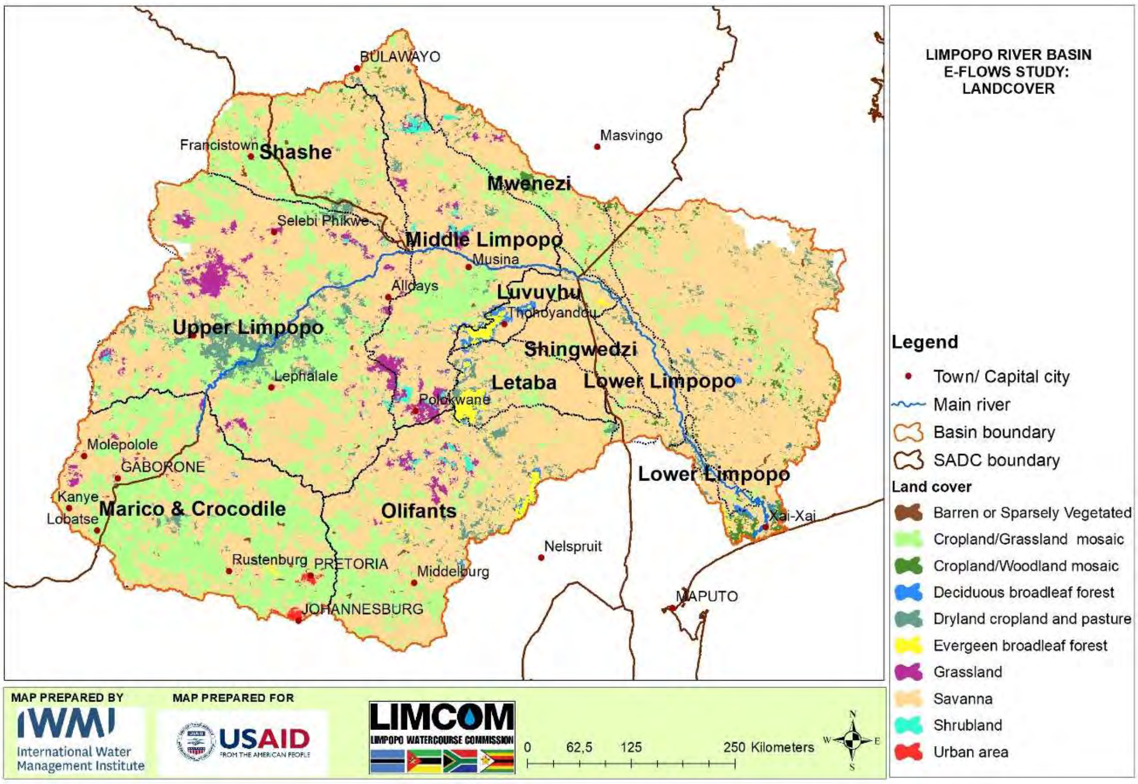

FIGURE 4.7: DISTRIBUTION OF LAND-COVER IN THE LIMPOPO RIVER BASIN (DATA SOURCE: AURECON, 2013A)

4.5 SURFACE WATER BALANCE EVALUATIONS (DEMAND VS AVAILABILITY)

Water use can either be consumptive (e.g., crop transpiration) or non-consumptive such as water use for hydro-power generation. The blue water uses in the basin indicate that irrigation is the highest water use followed by domestic (Figure 4.8).

There is need to quantify water supply from surface water and groundwater sources which was also not quantified for some of the water demands.

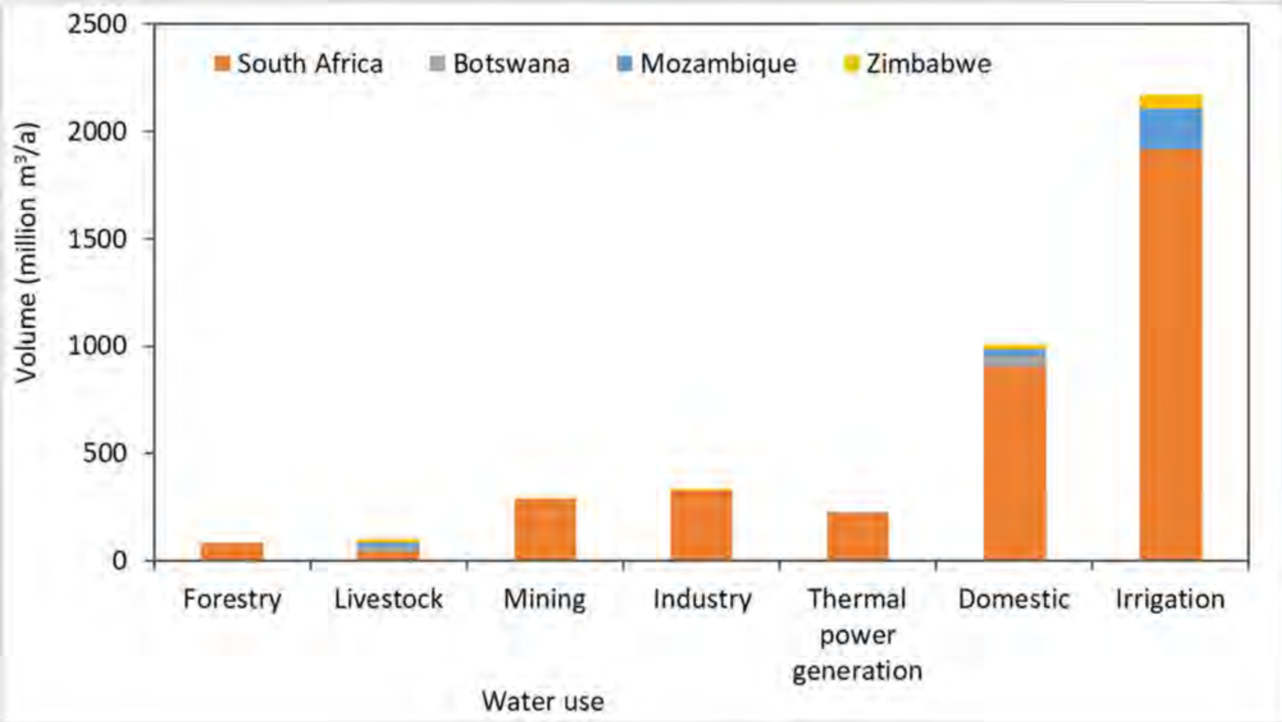

FIGURE 4.8: WATER USES IN THE BASIN (AURECON, 2013A)

The South African livestock water requirements are low. The contribution of game farming currently needs to be investigated but traditionally utilises minimal water and protects ecosystems. Most of the basin is in a stressed to very stressed condition when the water demands and availability are compared (Figure 4.9), hence meeting environmental water requirements may be challenging.

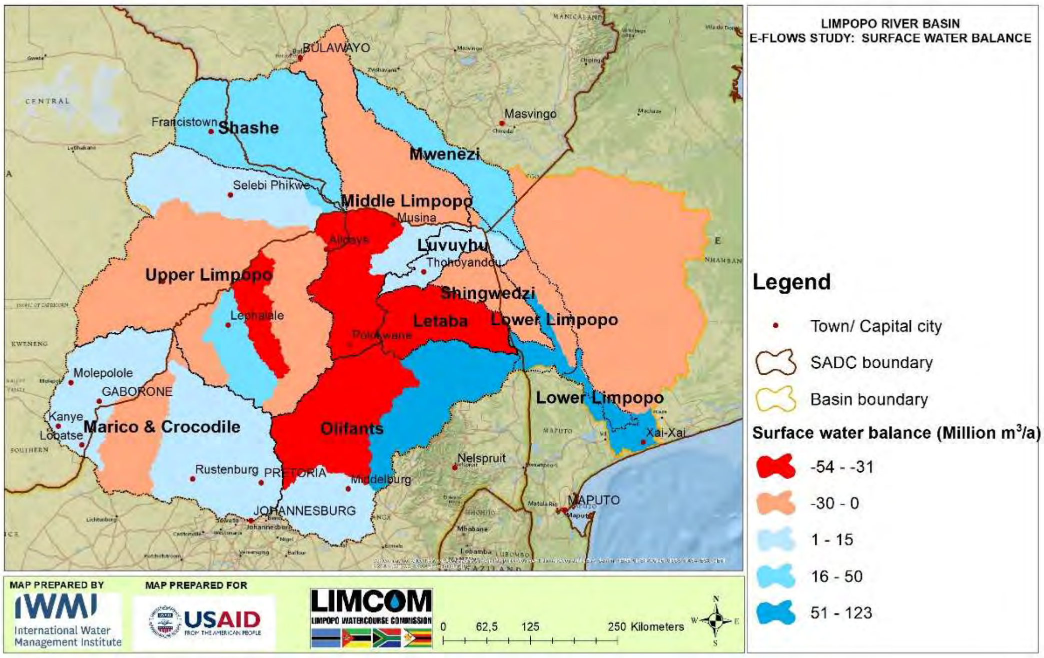

FIGURE 4.9: WATER BALANCE IN RISK REGIONS (SOURCE: LBPTC, 2010)

PROJECTED WATER DEMANDS IN THE BASIN COUNTRIES

The projected water demands due to population increase, economic development are shown in Figure 4.10, with South Africa having the largest projection.

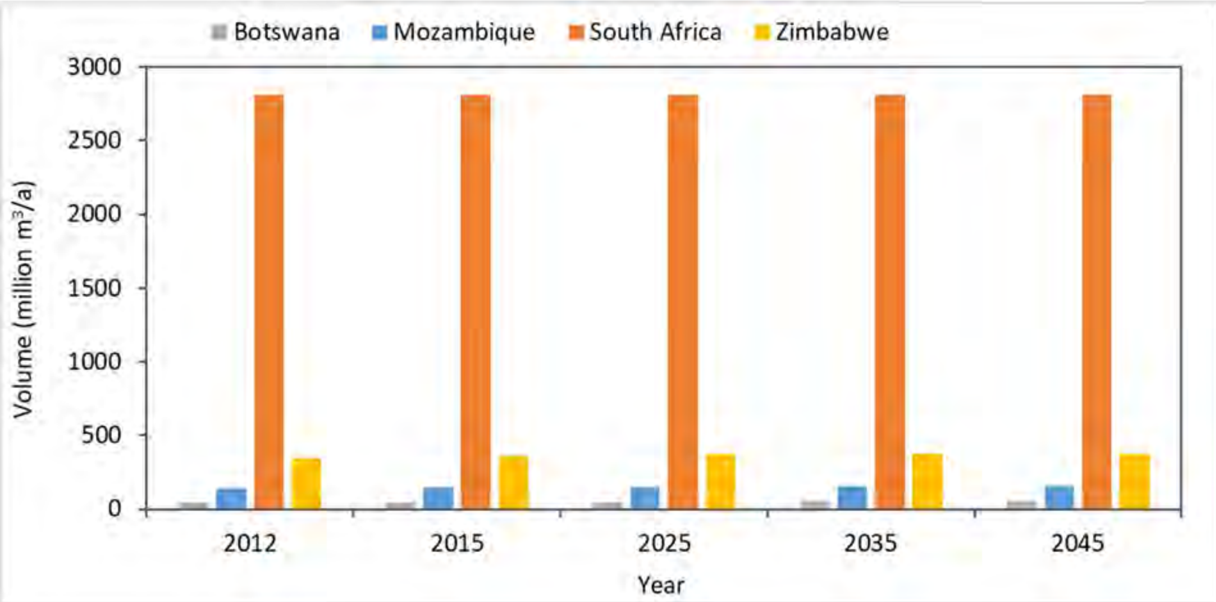

FIGURE 4.10: PROJECTED WATER USES IN THE BASIN (FROM AURECON, 2013A)

4.6 GEOLOGY

Geology influences soil type, rainfall runoff, possible sedimentation of rivers and dams,

groundwater potential and recharge, and agricultural potential. The distribution of geology shows high coverage by crystalline rock such granite, gneiss in the basin is shown in Figure 4.11.

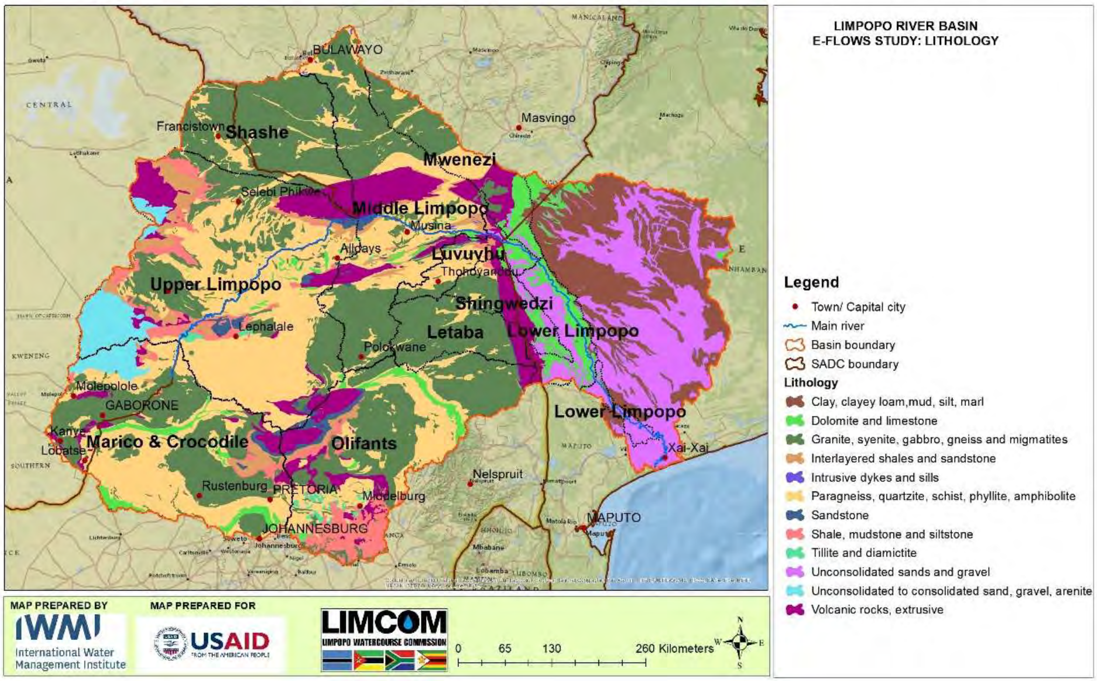

FIGURE 4.11: GEOLOGY OF THE LIMPOPO RIVE RBASIN (DATA SOURCE: AURECON, 2013A)

SOILS

Soil physical properties play a major role on the timing and seasonality of water yield, which consequently affect the river flows and environmental flow requirements. The Mozambique portions are predominantly Solonetz soils, which are defined by an accumulation of sodium salts and with a sub-surface layer that also contains a significant amount of accumulated clay (Figure 4.12). The Zimbabwe Risk Regions mainly have the Luvisols soil type, which is characterized by distinctive textural differences between the A and B horizons, where clay has generally been transported from the A to the B horizon. The Botswana portions of the LRB risk regions are dominated by Arenosols, which are sandy-textured soils that lack any significant soil profile development. In the South African risk regions, the soil types are immensely varied.

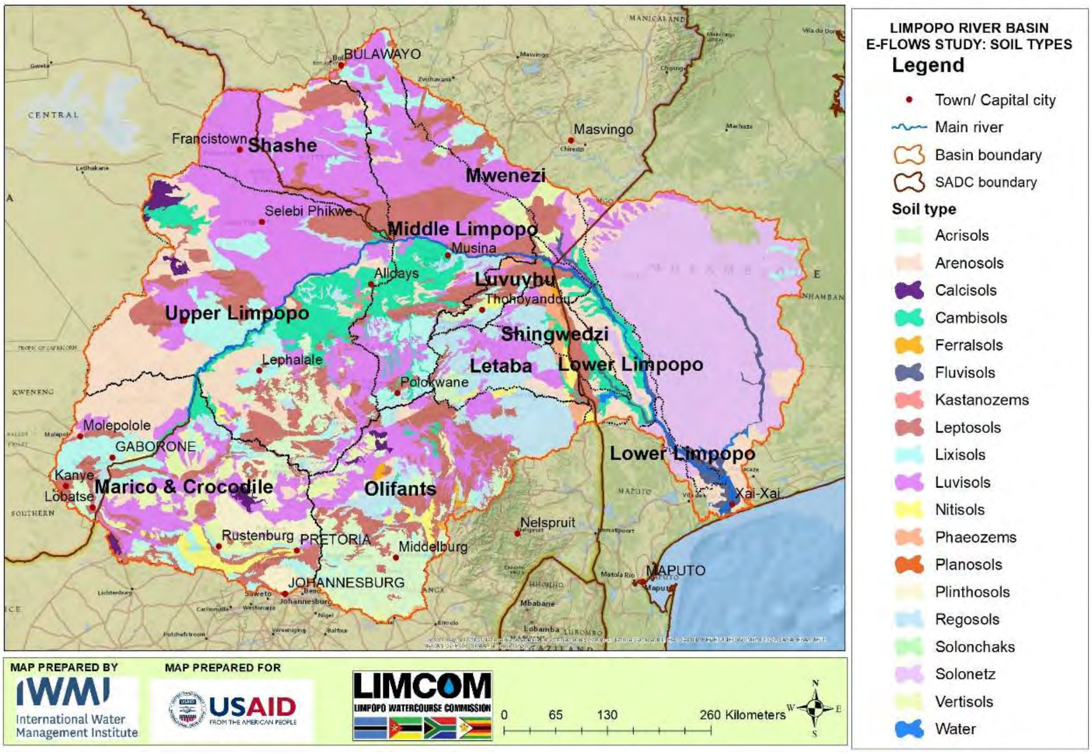

FIGURE 4.12: SOIL TYPES IN THE LIMPOPO RIVER BASIN (AURECON, 2013A)

4.7 HYDROGEOLOGY/GROUNDWATER

When precipitation is lacking, groundwater and reservoir storage can supplement water supplies. With the increasing water demand and frequency of droughts in the basin, groundwater resource is increasingly becoming more important, especially in sustaining the groundwater dependent ecosystems. This section describes the groundwater status, potential and role in the sub-basins of the Limpopo River basin as a whole in sustaining ecosystems. Generally the boundaries of the groundwater catchment and the flow directions within the aquifers follow surface water catchments and flow directions (Aurecon, 2013a), with a good correlation (>90%), with exceptions in the lower Limpopo and Bonwapitse sub-catchments due to the predominant inter-granular aquifers in these catchments. The lithology and structural features such as faults and dykes are shown in Figure 4.13.

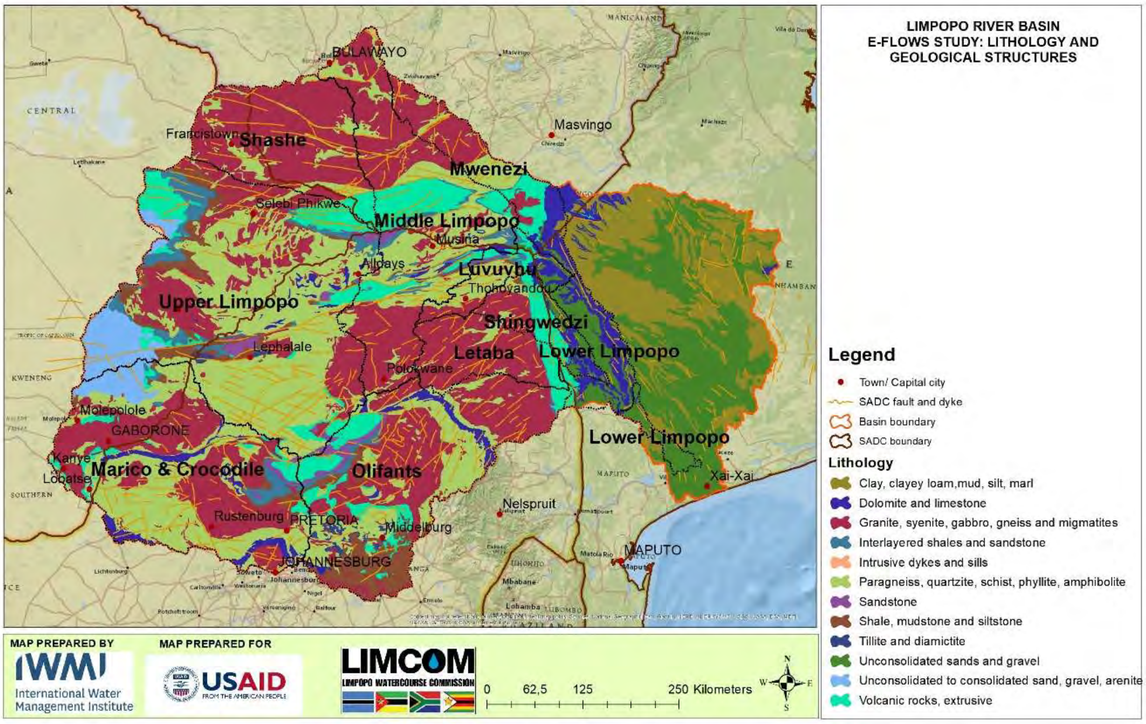

FIGURE 4.13: GENERAL HYDROLOGICAL MAP FOR THE LIMPOPO RIVER BASIN (AURECON, 2013A)

AQUIFER TYPES

The Limpopo River basin is nearer to become a "closed basin", as most of the water resources have been allocated to existing water demands (Munnik, 2020). There are several water transfers into the basin and any new water use will require additional transfers – unless more groundwater from different types of aquifers in the basin is used. The basin was classified into four aquifer types namely fractured, inter-granular, karst and low permeability. The low permeability (low yielding) aquifers are the most predominant aquifer type across the basin (approximately 63%), while fractured (moderate to high yielding) aquifers constitute approximately 19% of the basin (Figure 4.13). Karst aquifers (moderate to high yielding) constitute approximately 4% of the basin, while (moderate to high yielding) inter-granular aquifers make up the remaining 14% (Aurecon, 2013a).

GROUNDWATER SUPPLY POTENTIAL

Groundwater supply potential includes recharge and storage volume components. An understanding of the supply potential of an aquifer is crucial to the sustainable management of groundwater resources. Due to data limitations the estimated supply potential of the basin does not include the groundwater in storage but only represents the volume of water entering the aquifers as recharge. The mean yield per borehole from all risk regions/ sub-catchments of the basin is 3 ℓ/s. The highest average yields were observed in the Bonwapitse catchment of Botswana with approximately 7 ℓ/s, while the lowest average yields of 0.9 ℓ/s were observed in the Mzingwane catchment in Zimbabwe (Aurecon, 2013a). The recharge values indicate volume of water entering the aquifers and thus give an indication of the maximum groundwater quantity available for abstraction. For sustainable groundwater use, abstraction should not exceed the rate of recharge to prevent unacceptable decline in the hydraulic head or deterioration in water quality in the aquifer.

The fractured or karst aquifers are more productive compared to low permeability aquifers (Figure 4.14).

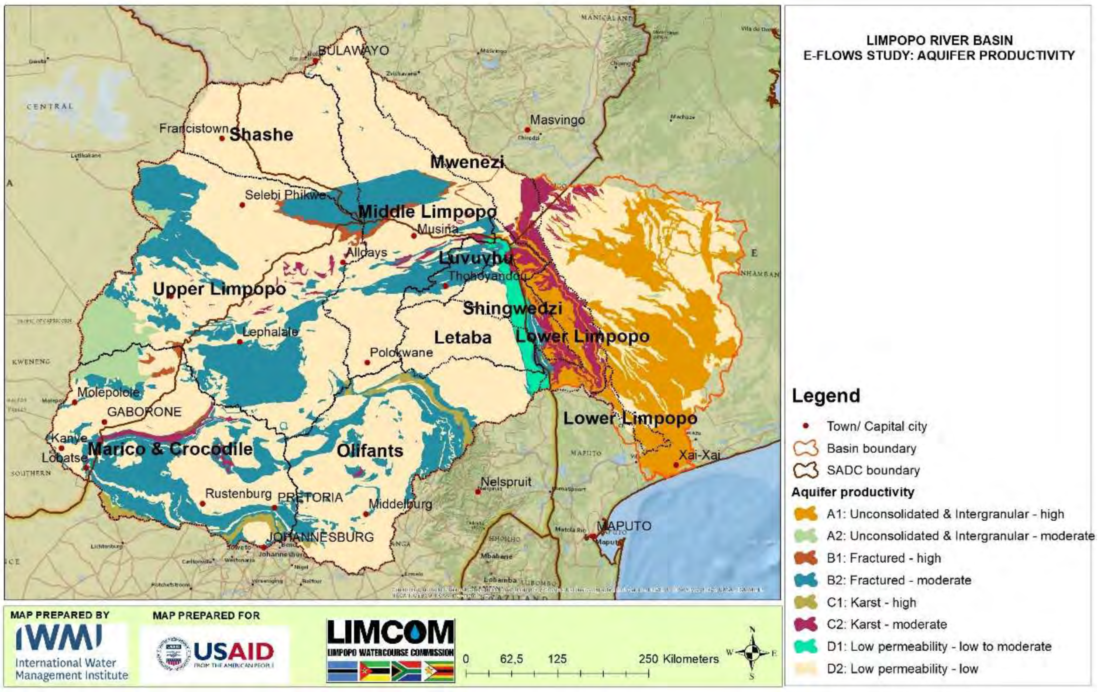

FIGURE 4.14: AQUIFER TYPES AND PRODUCTIVITY IN THE LIMPOPO RIVER BASIN

TRANSBOUNDARY AQUIFERS

Geographically there are local (within country) and transboundary (intersects political boundaries) aquifers within the Limpopo River Basin (Figure 4.15). Therefore for transboundary aquifers there are at least two governance structures managing the single resource. Management through a transboundary water management institution such LIMCOM is required to harmonise governance to prevent inequality exploitation of the resource by one state which in turn would negatively impact the availability of the resource (quantity and quality) to other states.

There are three transboundary aquifers in the basin and these include the Tuli Karoo Basin (shared among South Africa, Zimbabwe and Botswana), Ramotswa dolomite basin (shared between South Africa and Botswana) and the Limpopo Basin Transboundary Aquifer, shared among South Africa, Mozambique and Zimbabwe. The Ramotswa dolomite basin is a karstic aquifer with high productivity and mainly supplies commercial farms in South Africa and Gaborone City in Botswana, while Tuli Karoo has both alluvial and sandstone aquifers, with sandstone aquifer as most productive (Tuli Karoo TDA, 2019). The alluvial aquifers associated with the Limpopo River and its tributaries are important in areas where river flow is not permanent, and they need to be sufficiently protected against overexploitation, pollution and destruction from sand mining (Figure 4.16) in river beds (http://www.sardc.net/en/wp-content/uploads/Limpopo/en/Limpopo3.pdf).

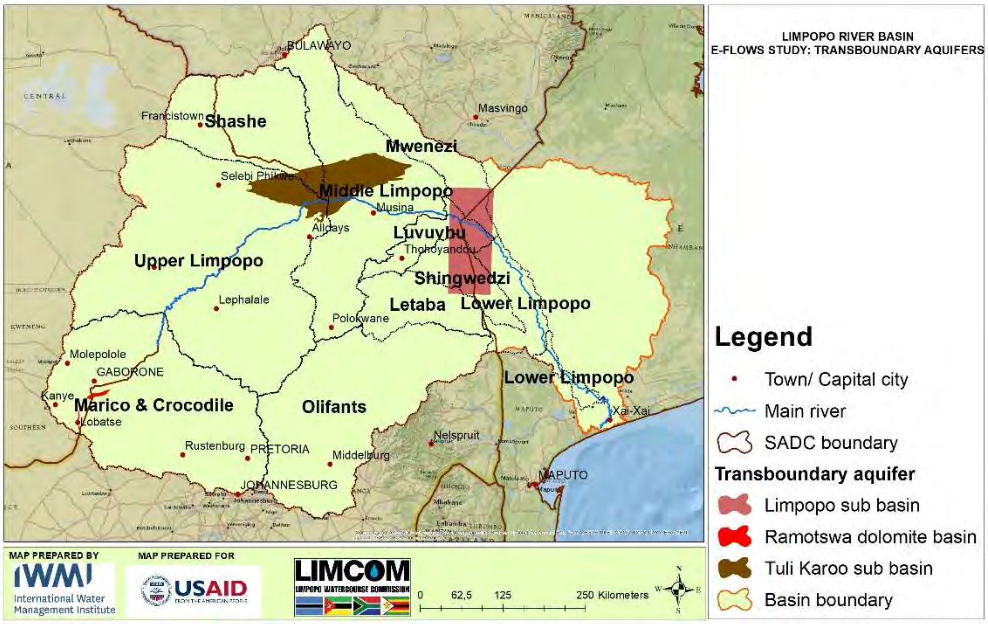

FIGURE 4.15: TRANSBOUNDARY AQUIFERS IN THE LIMPOPO RIVER BASIN (AURECON, 2013A)

FIGURE 4.16: SAND ABSTRACTION FROM THE GA-SELATI RIVER – A TRIBUTARY OF THE OLIFANTS RIVER

BOREHOLES/WELLS AND GROUNDWATER LEVELS

There were 75 480 boreholes from the SADC borehole database (Aurecon, 2013a), with only 30 percent or 22 790 boreholes with data on borehole yields. The highest density of boreholes is in South Africa (Table 4.11).

TABLE 4.11: BOREHOLE CHARACTERISTICS BY BASIN COUNTRY

COUNTRY	NUMBER OF BOREHOLES	PROPORTION OF BOREHOLES WITH YIELD DATA (%)	PROPORTION OF BOREHOLES WITH WATER LEVELS (%)
Botswana	2 631	69	88
Mozambique	1 077	72	93
South Africa	70 000	28	50
Zimbabwe	1 758	25	68

Intersecting a buffer area of 20m away from both perennial and non-perennial rivers, a total of 443 boreholes were identified from the database (Figure 4.17). This indicates the number of boreholes most likely to be tapping from the river or supplying the river with base flow during dry periods to sustain the environmental water requirements.

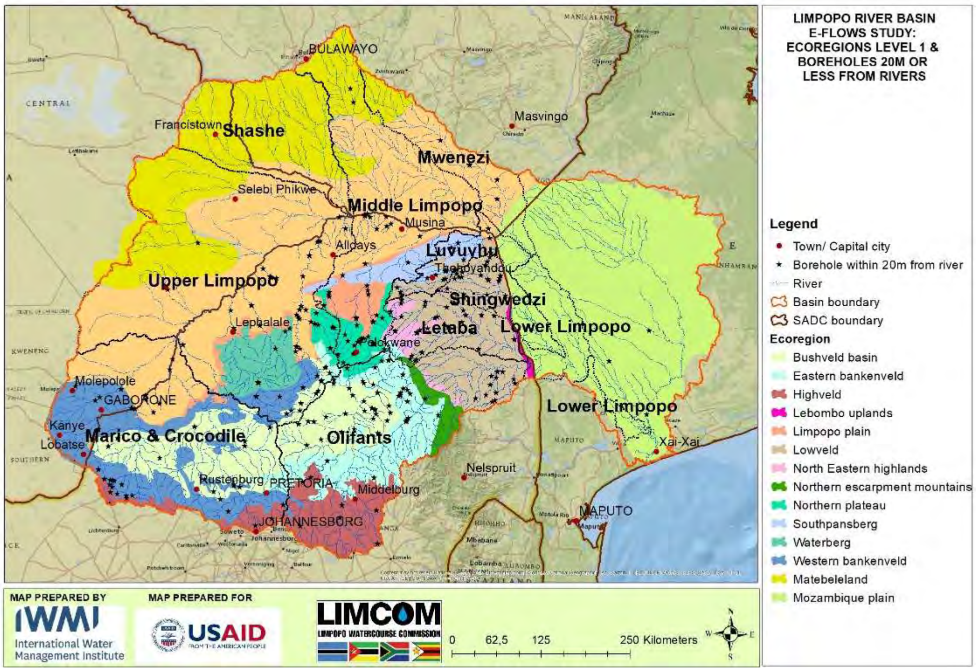

FIGURE 4. 17: BOREHOLES WITHIN 20M BUFFER FROM A RIVER (DATA FROM AURECON, 2013A)

GROUNDWATER RECHARGE

Groundwater recharge is the downward movement of water and reaching the water table to replenish groundwater resource. This replenishment indicates possible total available water for abstraction from groundwater without significant drop in groundwater levels. The quantity of recharge depends on geology, extend of groundwater abstraction, rainfall and landcover/landuse. The coefficients of recharge estimations were based on the SADC hydrogeological map, which was based on the large scale, SADC 1:2 500 000 geological map (SADC-HGM, 2011). Hence, it is possible that small local areas of hydrogeological significance were masked. Annual groundwater recharge estimates calculated from mean annual precipitation (MAP) for each risk region are shown in Figure 4.18 (Aurecon, 2013a). For sustainable management purposes groundwater abstraction should be smaller than aquifer replenishment to prevent significant groundwater level drawdown. Land use changes in rural and urban areas will continue to affect groundwater recharge and quality.

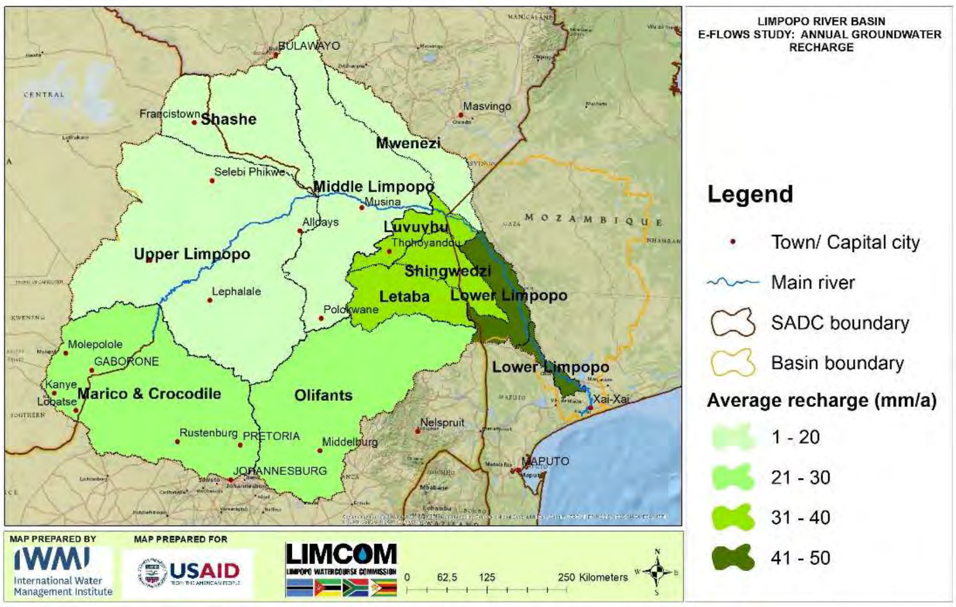

FIGURE 4. 18: GROUNDWATER RECHARGE BASED ON ANNUAL RAINFALL (DATA FROM AURECON, 2013A)

POTENTIAL BOREHOLE WATER SUPPLY AND GROUNDWATER BALANCE

The potential borehole water supply and groundwater balance was based on Aurecon (2013) calculations. A simple groundwater balance indicates the volume of water available in the groundwater resource taking into account current abstraction yields. The groundwater balance is based on groundwater recharge from rainfall, number of boreholes identified from different databases per catchment, and the average groundwater abstraction rates (ℓ/s) of boreholes identified in the sub catchments. Total abstraction (million m^3/a) per catchment was based on the number of boreholes and average yields (m^3/d) assuming a 12 hour duty cycle per borehole. The conservative groundwater resource (million m^3/a) based on recharge to the aquifer, assumed 50 % is available, while the other 50% is not accessible. The groundwater balance was calculated by subtracting groundwater abstraction from the conservative resource, with a positive value denoting a surplus and a negative value denoting a deficit. Based on the forgoing assumptions, the groundwater resources within the catchment are largely underutilised in areas with surplus, while sub catchments with deficit include Crocodile, Lephalale, Levuvhu, Marico, Sand, Mogalakwena and the Middle Olifants sub catchments (Figure 4.19). Areas with deficit indicate possible over abstraction that affects water-users dependent on the resources and the riparian habitats dependent on base flow contributions. Based on the water balance development of well fields to augment the surface water supplies in the Limpopo River Basin should be carefully considered to ensure protection of basE-flows and to check validity of the above assumptions. The water balance is indicative as there are uncertainities including the number of boreholes within the databases is reflective of the number of active boreholes in the catchment, i.e. new boreholes may not be in te database and old boreholes may no longer be in use. Note must be taken of limitations such as accessibility, well field development cost and sustainability. Artificial or managed recharge must be considered in areas where suitable aquifers for recharge exist to increase the groundwater resource renewal. Example, includes artificial recharge done in Botswana and Zimbabwe (Mzingwane catchment) by building weirs across riverbeds to contain groundwater in a sandy aquifer (Aurecon, 2013a; Dabane Trust, 2019). The alluvial aquifers can be dammed to increase water availability during the dry period, resulting increased access to clean water – as the dam acts as a large natural slow sand filtration system through an aerobic filtration process of sedimentation (Hussey, 2007). Sand dams (Figure 4.20) have proved to be effective in enhancing groundwater recharge.

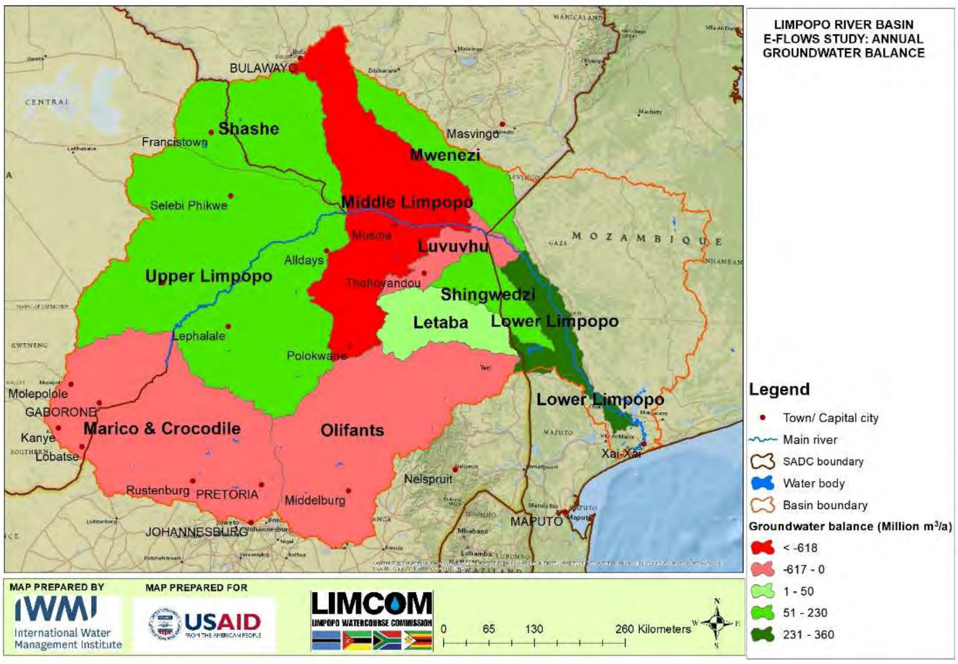

FIGURE 4.19: GROUNDWATER BALANCE BY RISK REGION (DATA SOURCE: AURECON, 2013A)

FIGURE 4.20: SAND DAM IN MZINGWANE CATCHMENT, ZIMBABWE (DABANE TRUST, 2019)

PLANNED WATER SUPPLY PROJECTS (SURFACE AND GROUNDWATER INFRASTRUCTURE E.G., DAMS, ETC.)

The proposed Electro Metallurgical Special Economic Zone (EMSEZ) threat in Makhado (South Africa Limpopo Province) is both a huge risk to water demand, quality and quantity and the environment in the Limpopo valley (Munnik, 2020). This development will likely reduce the water availability for uses and environmental water requirements. Future water supply sources from Gwayi and Zambezi Rivers are being considered for Bulawayo, while Mapai Dam with a capacity of 11 200 million cubic metres is planned for irrigation water supply in the Lower Limpopo in Mozambique (Boroto, 2001).

WATER QUALITY

The water quality in aquifers and rivers is impacted by location due to natural inputs of salt and nutrients from the geology and surrounding landscape and anthropogenic activities. The regulation of river flow by dams and weirs, the abstraction of water and effluent discharge (municipal, industrial and accidential mine spills) have influenced the quality of water in the basin which is exacerbated in that many rivers are receiving fewer floods and flow events that would naturally clean and flush the river system.

GROUNDWATER QUALITY

Groundwater quality describes the chemical and physical parameters of groundwater. The groundwater quality is important where groundwater is used for portable purposes or for industry or irrigation purposes. The quality is also important under groundwater-surface water interaction, especially during dry periods, droughts as groundwater can contaminate surface water, and vice versa, thereby affecting the groundwater depend ecosystems. Groundwater resources quality was reported to be one of the main factors restricting groundwater development in South Africa (LPTC, 2010). Of the problems associated with water quality, high concentrations of total dissolved solids, nitrates and fluoride are considered to be the most common and serious problems on a regional scale.

Electrical Conductivity

Electrical conductivity (EC) is an indication of salinity and gives an indication of the impact of geology as well as human influences on water resource quality. The EC results reported by Aurecon (2013) indicate that the groundwater water quality across the South African portion of the basin is generally within the WHO water quality parameters. Botswana, however, shows many zones of poor water quality, which seem unrelated to geology and perhaps, are a result of human impact. The large zone of poor water quality in terms of conductivity across Mozambique was attributed to the depositional history of fossil sea bed in the area. There were very few data points within the Zimbabwe portion of the basin to make meaningful interpretation (Aurecon, 2013a).

Fluoride

Fluoride in groundwater is from natural sources. Fluoride has beneficial effects on teeth at low concentrations in drinking-water, however excessive exposure to fluoride in drinking-water, or in combination with exposure to fluoride from other sources, can give rise to a number of adverse effects. These range from mild dental fluorosis to crippling skeletal fluorosis, which may result in death. Occurrences of elevated fluoride were reported throughout the basin in Aurecon (2013), but no specific sites were mentioned. Hence, future water quality should look at this water quality variable.

Nitrates

The presence of nitrates in drinking water is typically associated with pollution from agricultural activities, pit latrines, wastewater treatment, raw sewerage and mine water polluted by explosives. There are local occurrences of high nitrate, poor groundwater quality, in all catchments occurring within both South African and Botswana portions of the basin (Aurecon, 2013a), while no nitrate data was available from Zimbabwe or Mozambique.

SURFACE WATER QUALITY

Sediment

Sediment movement through the LRB is a particularly important component of this study as it reduces dam capacity and affects the water quality and consequently affects provision of ecosystems and environmental sustainabiltiy. The loss in storage reduces the ability of the reservoirs to meet water demands such as domestic and industrial, irrigation requirements, recreation, hydropower production, flood control, environmental water requirements, resulting in socio-economic, environmental and aesthetic losses. High sediment loads are transported during flood events in non-perennial rivers. The retention of sediment by large dams could also affect the equilibrium conditions of the lower river reaches and estuary (Aurecon, 2013a). Sediment movement is also an indicator of catchment management, especially landuse planning. The average annual storage loss (0.6%) due to sedimentation in the Limpopo Basin (in South Africa) is slightly lower than the international average annual storage loss (0.8%) (ICOLD, 2009). An understanding of the specific river and reservoir sediment loads, sediment yields and mass balance is essential for the formulation of appropriate solutions for the basin.

The total annual average sediment outflow (tonnes) from subcatchments within the Limpopo River basin observed and computed at selected river gauging stations or dam locations are shown in Figure 4.21**.** Sediment yield values for station numbers 28 and 34 were obtained from the Joint Limpopo Basin Study (1991), while data for Massingir Dam was obtained from Sedimentation Study (2002). An analytical method from Msadala et al. (2012) was used to estimate the loads at the other stations.

Many mines are reaching the end of their economic lives and the mine shafts or tailings will start filling up with water and will ultimately decant. This water will be polluted and the volumes will be large enough to impact significantly on the regional water quality, thereby affecting the quantity, quality and timing of the environmental flows in the basin.

To reduce the negative impact of water quality in the basin, mine water reclamation schemes have already been constructed in the South Africa side of the basin and are supplying water for potable use to the local municipalities, thereby supplying future water demands, especially in the upper areas of the Olifants catchment. Planned thermal power stations for energy production from coal will need water for cooling. However, new coal plants use air-cooling and may result in reduced water pollution.

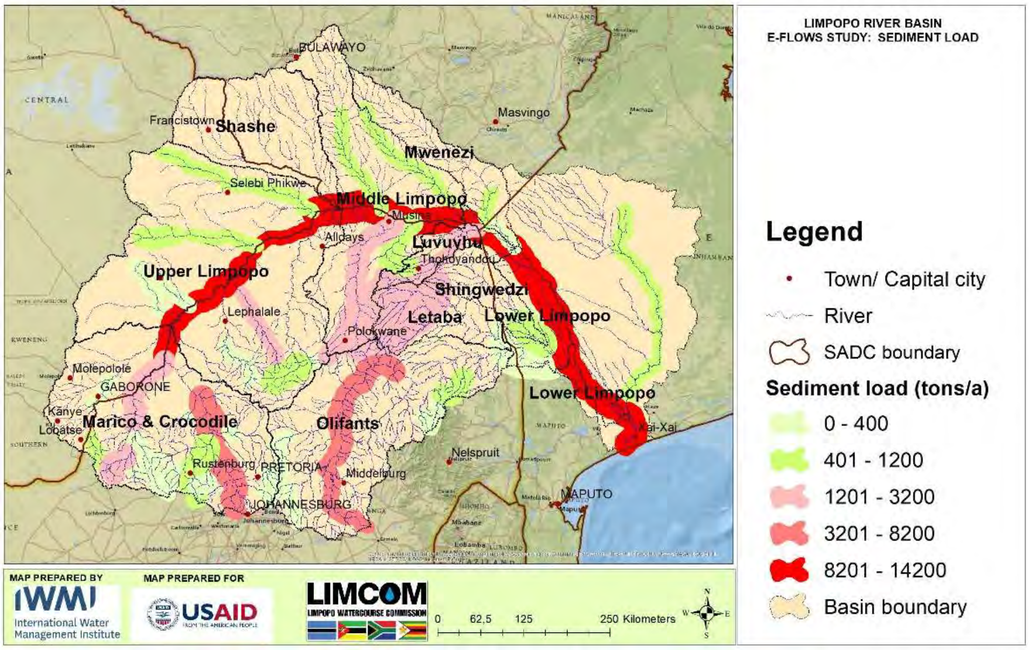

FIGURE 4. 21: ANNUAL SEDIMENT LOADING RATES (TONNES) IN THE LIMPOPO RIVER BASIN (DATA SOURCE: AURECON, 2013A)

The potential surface water pollutants and sources are presented by risk regions in Table 4.12. Mining, poorly performing wastewater treatment plants and agricultural return flows laden with nutrients and chemicals are the main culprits in polluting the basin.

TABLE 4.12: POTENTIAL SURFACE WATER POLLUTANTS AND SOURCES BASED ON LIMPOPO BASIN RISK REGIONS (AURECON, 2013A)

RISK REGION	SUBBASIN	POLLUTANTS	LOCAL SITE	POLLUTANT SOURCE
Marico Crocodile	Marico catchment	Elevated nutrient, salinity and turbidity, erosion - sediments	Marico Bosveld Dam, Klein Marico River catchment, Lower Marico River	Slate mining and agricultural return flows, urbanisation
	Crocodile catchment	Nutrient, salts enrichment and salinity, sediments, microbiological, acid mine drainage	Upper Crocodile River - urbanisation in Johannesburg and Pretoria metropolitan areas, Hex River, Apies Pienaars (13-point source discharges from industries and wastewater treatment	Poor effluent from wastewater treatment works (WWTWs), agricultural return flows, flow regulation in the catchment, high density settlements, failing sewerage infrastructure, mining
Upper Limpopo	Mokolo catchment	Elevated nutrient and salinity levels especially phosphates, future acid mine drainage	Lower Crocodile catchment	Irrigation return flows, rapid and uncontrolled growth of informal settlements in the upper Mokolo River (around Vaalwater and Alma without proper sanitation
	Lephalale catchment	Elevated pH, phosphates and sulphates	Agriculture and wastewater plants	Agriculture and poor effluent wastewater treatment works in Witpoort town
	Mokgalakwena catchment	Elevated nitrate and turbidity	Platinum mines and poor wastewater plants	Poor effluent from wastewater treatment works from towns of Nylstroom, Dimune, Nylsvlei, Mokupane and Naboomspruit, large platinum mines (blasting and runoff) in the upper catchment
Middle Limpopo	Sand catchment	Elevated nutrient levels in the river	Coal mines and agriculture	Coal mines with potential for acid mine drainage and sulphate contamination, sand mining, intensive agriculture and effluent from three wastewater treatment works
	Nzhelele catchment	Elevated nutrient levels in the river and dam	Along the river	Agriculture (citrus) both up and downstream of the Nzhelele Dam, poor effluent from wastewater treatment works, forestry around Louis Trichardt and associated industries
	Limpopo	Microbiological – Outbreak of cholera	Limpopo River and abstraction boreholes for Musina town	Collapsed BeitBridge town's wastewater infrastructure
Luvuvhu	Luvuvhu catchment	Elevated nutrient concentrations	Thohoyandou, and Kruger National Park	Intensive agriculture of sub-tropical fruits and afforestation in the upper catchment, the urban sprawl and wastewater treatment plants in Thohoyandou, the lack of formal wastewater treatment for the

RISK REGION	SUBBASIN	POLLUTANTS	LOCAL SITE	POLLUTANT SOURCE
Shingwedzi	Shingwedzi catchment	Elevated pH values, phosphates and salinity	Kruger National Park and the Transfrontier Park	Subsistence agriculture in the floodplain and informal urban settlements
Olifants	Olifants	High salt, sulphate concentrations	Mines and electricity generation plants	Mining, power generation, industries in the upper areas of
		high salt concentrations	Lower reach of Elands and Moses Rivers	Irrigation return flows and concentration effect due to
		Elevated pH	Along the river	Localized acid mine drainage from defunct coal mines
		Unacceptable phosphate	Selati, Phalaborwa	Sewage return flows and effluents from the mining and industrial activities
		High organic, nutrient and microbiological	Loskop Dam	WWTWs (Emalahleni and Steve Tshwete Municipalities)
		Pesticides and herbicides	Elands and Moses River catchments	Intensive agricultural activities
		unacceptably high levels of heavy metals e.g.	Loskop Dam (fish deaths)	Mining and industrial activities
Letaba	Letaba catchment	Turbidity, fertilizers, pesticides, herbicides, microbiological, litter	Wastewater treatment works at Tzaneen, Giyani and Letsitele. Along Klein Letaba Lower catchment main land-use is irrigation agriculture and afforestation	Diffuse sources: Afforestation in the upper catchment, agricultural runoff from intensive cultivated lands, mainly bananas and citrus, dense communities close to rivers (Letsitele), animal grazing and watering. Point sources: Effluents from wastewater treatment works at
		High nutrients, river regulation and high water temperatures	Along the length of the Letaba River, Letsitele River	Dense settlements and agriculture above the Middle Letaba Dam and upper Klein Letaba River
		Electrical conductivity and total dissolved solids	Along the length of the Letaba River	Afforestation and runoff from the intensive agriculture
		High sediment loads	Molototsi River	Rural settlements with subsistence flood plain agriculture and livestock overgrazing e.g., Ka-Dzumeri.

Seven water quality variables (Table 4.13) are presented to describe the fitness for water use in the Limpopo River Basin based on different types of water quality aspects encountered in the basin (Aurecon, 2013a). Green is good, blue is tolerable, orange is poor and red is unacceptable (Table 4.14). Other water quality variables including bacterial and agrochemical pollution could not be assessed due to lack of spatial data. The water quality along the rivers is presente in Figure 4.22. Acid mine drainage from both disused and existing mines is noted from the Botswana, South Africa and Zimbabwe (Aurecon, 2013a). The Olifants River is highly polluted upstream but as it flows through Kruger National Park it comes out as relatively good. The site considered (Mamba Weir) is in the Kruger National Park after the Phalaborwa barrage (Table 4.14).

TABLE 4.13: OVERVIEW OF SURFACE WATER QUALITY IN THE LIMPOPO RIVER BASIN USING THE 75TH PERCENTILE VALUES AND CLASSIFYING THE QUALITY USING DOMESTIC AND AGRICULTURAL GUIDELINE VALUES (AURECON, 2013A).

RISK REGION	SUBBASIN	STATION	EC	PH	PH	FLUORIDE	IRON	SULPHATE	ORTHO-PHOSPHATE	NITRATE
			MS/M	LOWER	UPPER	MG/L	MG/L	MG/L	MG/L	MG/L
	Botswana									
Marico-Crocodile	Notwane	Makgophana Bridge	71.00	6.94	7.35	0.79	1.78	28.06	11.410	65.420
Upper Limpopo	Mahalapye	All points	38.00	7.03	7.60	0.27	0.54	9.00	4.200	13.400
Upper Limpopo	Motloutse	All points	138.00	6.73	8.38	0.09	0.35	529.34	0.000	21.270
Upper Limpopo	Letlhakane	All	338.70	6.95	7.33	2.00	1.86	238.00	0.500	105.920
Upper Limpopo	Mozambique									
Lower Limpopo	Limpopo	E-31 at Pafuri	42.50	6.70	7.90			53.27		5.000
	Limpopo	E-33 at Combumu	60.80	6.80	7.94			42.80		6.810
	Limpopo	E-372 at Ald.	62.60	6.90	8.04			53.80		5.000
	Limpopo	E-36 at Sicacate	84.20	7.20	7.86			113.79		5.000
	Limpopo	E-38 at Xai-Xai	78.40	6.90	8.00			66.97		5.000
Olifants	Olifants/Elephants	E-546 d/s of	53.90	7.07	7.80			151.86		5.000
	South Africa									
Marico-Crocodile	Marico	A3R004Q01 at	29.25	8.23	8.48	0.41		17.67	0.031	0.040
	Crocodile	A2H132Q01 at Paul	83.90	7.95	8.37	0.48		82.59	0.259	1.609
Upper Limpopo	Matlabas	A4H004Q01 at	9.79	7.28	7.77	0.24		1.50	0.005	0.025
	Mokolo	A4H013Q01 at	11.10	7.57	7.70	0.35		1.50	0.005	0.025
	Lephalale	A5H008Q01 at Ga-	16.19	7.40	7.94	0.34		6.22	0.200	0.550
	Mogalakwena	A6R002Q01 at Glen	24.32	7.71	7.98	0.36		6.05	0.031	0.070
Middle Limpopo	Nzhelele	A8R001 at Nzhelele	33.63	8.12	8.35	0.23		3.01	0.006	0.055
Luvuvhu	Luvuvhu	A9H011Q01 at Pafuri	18.40	7.76	8.04	0.21		3.00	0.018	0.050
Shingwedzi	Shingwedzi	B9H002Q01 at	26.70	7.67	7.90	0.23		3.81	0.131	0.031
Letaba	Letaba	B8H018Q01 at	50.90	7.95	8.55	0.26		8.61	0.018	0.067
Olifants	Olifants	B7H015Q01 at Mamba	56.00	8.08	8.45	0.43		67.14	0.015	0.511
Upper Limpopo	Limpopo (upper)	A5H006Q01 at	58.20	7.92	8.16	0.47		54.00	0.057	0.179
Middle Limpopo	Limpopo (middle)	A7H008Q01 at Beit	63.60	8.17	8.42	0.43		52.00	0.200	0.225
	Zimbabwe									
	Mzingwane (upper)	BR11	25.6	7.06	7.74		0.53	22	0.1	0.249

RISK REGION	SUBBASIN	STATION	EC	PH	PH	FLUORIDE	IRON	SULPHATE	ORTHO-PHOSPHATE	NITRATE
			MS/M	LOWER	UPPER	MG/L	MG/L	MG/L	MG/L	MG/L
Middle Limpopo	Mzingwane (middle)	BR16	24	7.62	8.07		0.29	12	0.064	0.371
	Mzingwane (lower)	BL8 (Zhovhe	23.3	7.74	8.06		0.113	21.5	0.056	0.111
	Mtshabezi	BR15	19.2	7.3	7.74		0.28	19	0.04	0.22
	Limpopo (middle)	BR19	62.7	7.34	7.98		0.275	53	0.244	0.55

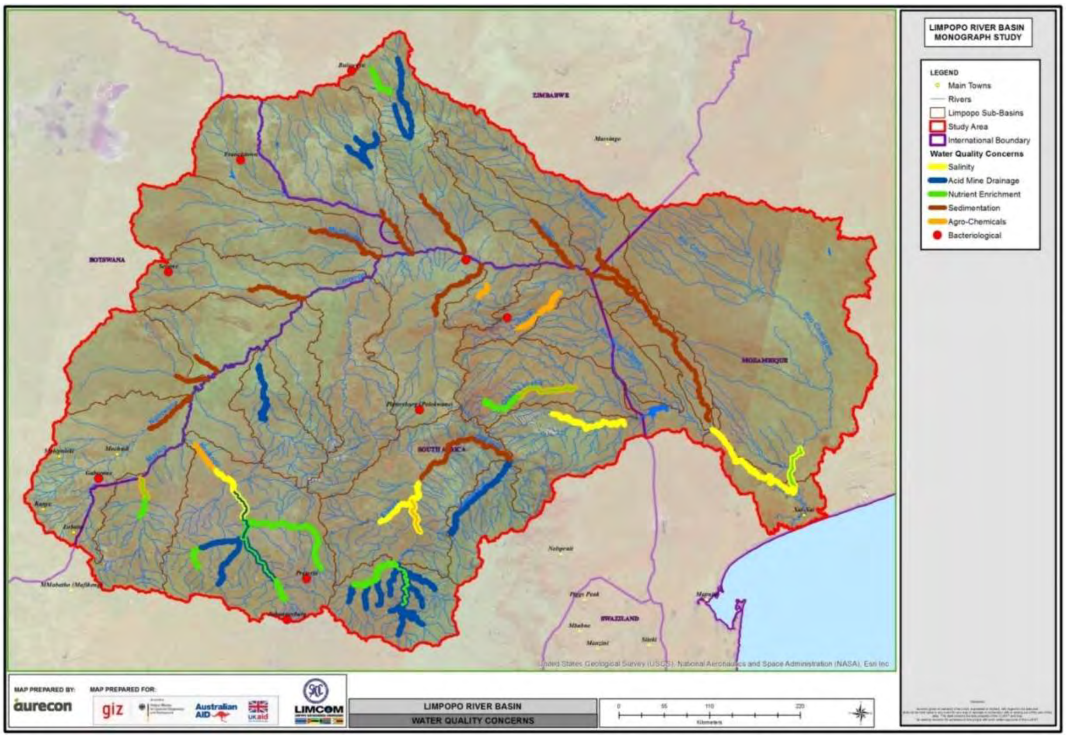

FIGURE 4. 22: WATER QUALITY POLLUTANTS IN THE BASIN (AURECON, 2013A)

TABLE 4.14: CLASSIFICATION OF WATER'S FITNESS FOR DIFFERENT USES

VARIABLE	UNITS	GOOD	TOLERABLE	POOR	UNACCEPTABLE	SENSITIVE USER
EC	mS/m	40	150	370	>370	Irrigation & Domestic
pH (lower)		6.5		<6.5		Domestic
pH (upper)		8.5		>8.5		Domestic
Fluoride	mg/l	0.7	1.0	1.5	>1.5	Domestic
Iron	mg/l	0.5	1.0	5.0	>5.0	Domestic
Sulphate	mg/l	200	400	600	>600	Domestic
Nitrate	mg/l	0.7	1.75	3.0	>3.0	Aquatic
Ortho-phosphate	mg/l	0.025	0.075	0.125	>0.125	Aquatic

KEY MESSAGES

- Planned thermal power stations for energy production from coal will need water for cooling. However new coal plants use air cooling and may result in reduced water pollution.
- Understanding of groundwater and surface water can show where there are opportunities and associated risks thereby ensuring effective investment and mangement of the resource to avoid conflicts between water uses including environmental water requirements. The planned Musina Special Economic Zone and the Limpopo Eco-Industrial Park by 2025, with an estimated water demand of 50 Mm^3/a will put more pressure on water resources and environment in the Sand catchment.
- Land use and land use changes in rural and urban areas will continue to affect water resource quantity and quality (i.e., groundwater recharge, groundwater and surface water quality)
- Groundwater will increasingly contribute to resilience and adaptation to climate change
- Equitable water access and balancing urban and rural needs with ecosystem requirements under a changing climate is important.
- By far the largest available water quality data sets are for rivers in South Africa and therefore water quality of tributaries outside of South Africa (i.e., Botswana, Zimbabwe and Mozambique) are poorly studied.
- Due to the size of the Limpopo Basin, the major tributaries drain regions with vastly different water qualities that represent different geological and anthropogenic contributions to the water quality.
- The water quality at sites of a particular tributary closest to the confluence with the main stem of the Limpopo River, would represent the cumulative water quality impacts (or assimilative capacity of the tributary of upstream water quality perturbations) of that particular tributary.

- The majority of water quality variables that are routinely monitored and subsequently included in Environmental Water Requirement studies are limited variables representing salts (i.e. electrical conductivity, major anions and cations), nutrients (nitrites, nitrates, ammonium and phosphates), other anions (e.g. F- and SO_4^{-2}) and pH.
- There is a distinct lack in the routine monitoring of variables that pose the greatest water quality threats. These include stressors from extensive mining activities in the catchments of the major tributaries (metals, acid mine drainage, salinization), agricultural activities (agrochemicals, salinization, sedimentation) and sprawling urban and rural communities (microbial pollution, salinization, sedimentation).

5. ECOSYSTEMS

The Limpopo River Basin is exceptionally rich in biodiversity and, as such, has a wide variety of genes, species and ecosystems (Petrie et al. 2014). Ecosystems (aquatic, terrestrial vegetation biomes, ground water) perform many important water-related roles in the basin and the environment at large, including nutrient recycling, water purification, attenuation of floods, ground water recharge, providing habitats for wildlife and other ecosystem services (Ozment et al. 2015). River discharge is a key aspect of the support of water-related ecosystems, with E-flows specifically designed to ensure that these ecosystems are sustained. This chapter is a general description of the diverse water-related ecosystems that exist within the Limpopo River Basin.

Note that later deliverables of this project will include specialist ecological reports. This report provides a general introduction from a risk region perspective where possible.

5.1 CONSERVATION AREAS

Some of Africa's largest and most renowned conservation areas are found in the Limpopo river basin. These include:

1. Kruger National Park
2. Great Limpopo Transfrontier Park
3. Gonarezhou National Park
4. Banhine National Park
5. Mapungubwe National park.

There are several additional adjacent smaller reserves, wildlife management areas, privately owned conservation areas and game farms. See Figure 5.1 below showing the conservation areas in the Limpopo River basin.

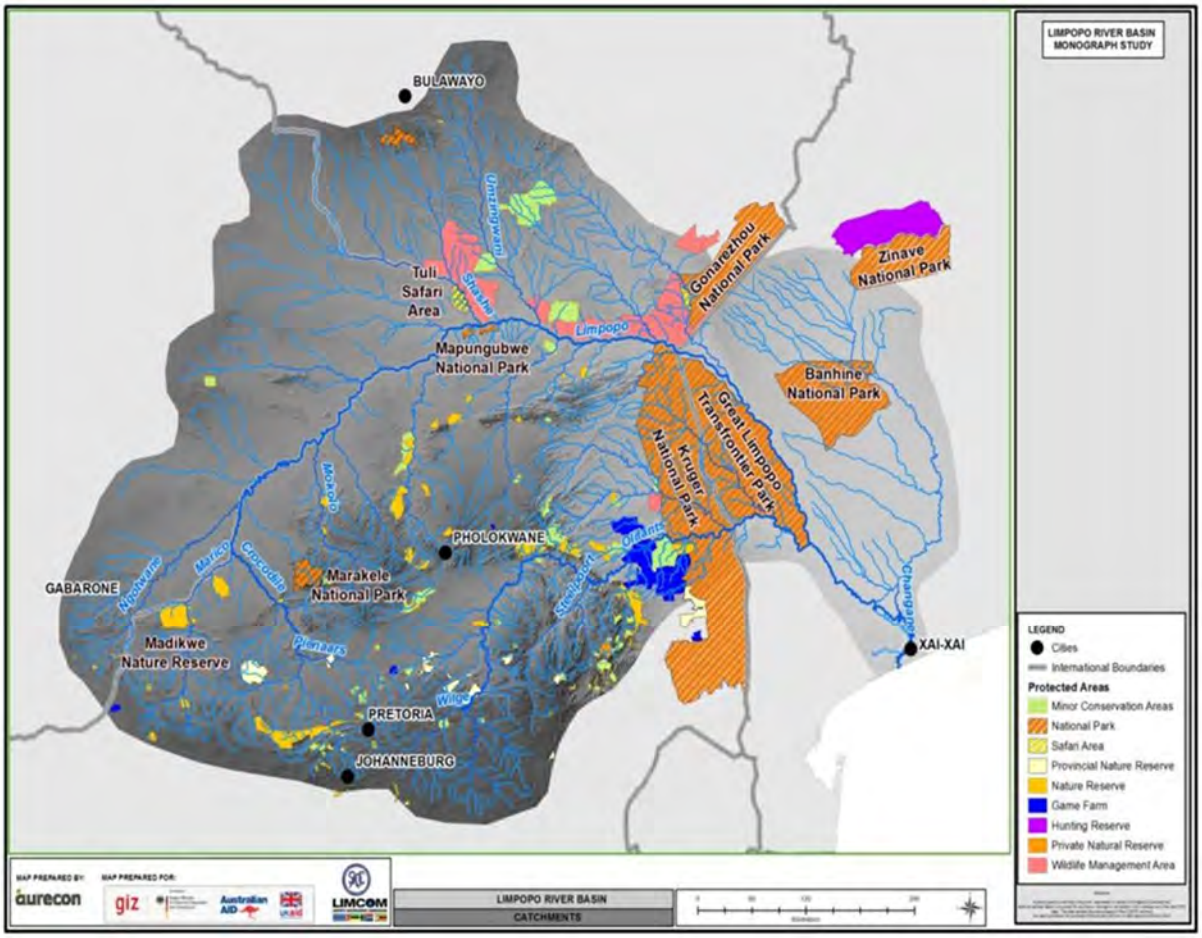

FIGURE 5. 1: CONSERVATION AREAS IN THE LIMPOPO RIVER BASIN (AURECON, 2013A)

5.2 WETLANDS

Wetlands play a key role in the hydrology of the river basin and provide a number of socio-economic development benefits including among others: flow regulation; erosion control; floodplain farming; plant and animal products; conservation; tourism and recreation; water quality amelioration; carbon sinks (Limpopo RAK, 2020).

Most of the larger wetlands in the Limpopo River basin are located in Mozambique along the Lower Limpopo and Changane Rivers. This predominance is driven mostly by climate, soil and hydrological conditions i.e., the flat topography, high rainfall and geology. Many other much smaller wetlands are distributed throughout the basin but fine scale wetland data for these smaller wetlands is only available for South Africa and show (Figure 5.2) a high density of wetlands in the upper catchments of the Olifants, Letaba and Luvuvhu Rivers (Aurecon, 2013a)

IWMI (2003) described a range of wetlands in the basin as follows; in the upper catchment predominantly dambos (seasonally or permanently saturated areas, also referred to as pans), while in the lower catchment in Mozambique there are large floodplains in the Chokwe area. Dambos and pans are common in the upper Olifants catchment in South Africa; the Mwenezi, Shashe, Tuli, Umzingwane and Bubi catchments in Zimbabwe; and the tributaries of the Changane catchment in Mozambique.

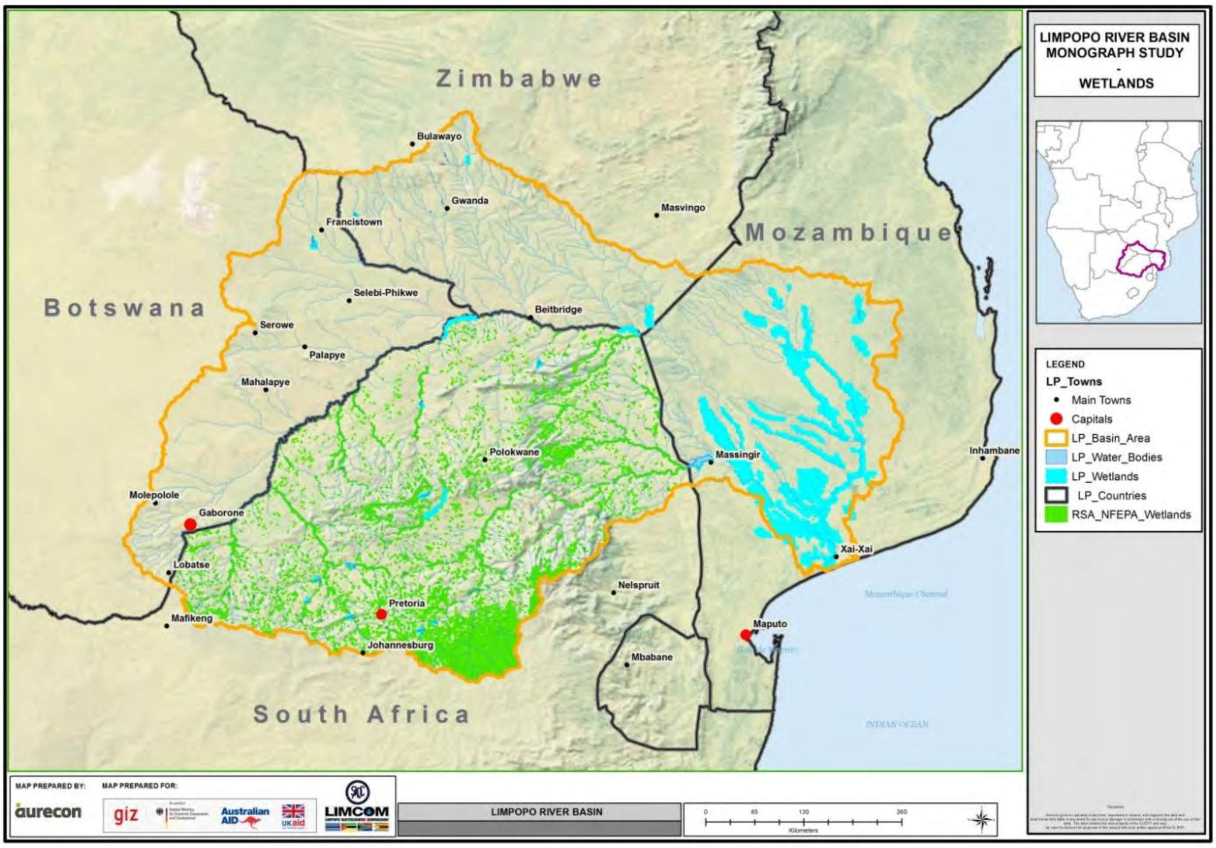

FIGURE 5.2: LOCATION OF WETLANDS IN THE LIMPOPO RIVER BASIN (AURECON, 2013A)

Much of the population in the basin is concentrated near wetlands and many people use them for pasture to feed livestock and to grow wetland crops, while springs and shallow wells provide potable water. Many of the areas around wetlands are converted into agricultural fields and water from wetlands may be withdrawn for irrigating crops. Masiyandima et al (2005) provided examples of the extensive conversion and alteration of wetlands to support livestock and arable agriculture with examples from the Intunjambili wetland in Tuli, Botswana, the Motlapitsi wetland in the Olifants River, South Africa and the Chibuto wetland on the Changane River in Mozambique.

Ramsar designated wetlands

Only three Ramsar designated wetlands are found in the Limpopo River basin, namely;

1. Makuleke Wetlands
2. Nylsvley Nature Reserve
3. Verloren Valei Nature Reserve

Ecosystems of these RAMSAR sites are presented in Table 5.1.

TABLE 5.1: RAMSAR SITES IN THE BASIN. INFORMATION ADAPTED FROM RAMSAR 2010 AS QUOTED IN LIMPOPO RAK

RAMSAR SITE	LOCATION & COORDINATES	STATUS/TYPE & SIZE	DESCRIPTION OF THE ECOSYSTEMS
Malukele Wetland R.S. no. 1687	Limpopo, South Africa 22°23'S 031°11'E	National Park 7 757 ha	Luvuvuhu Risk Region: Vlei type flood plain with riverine forests, riparian floodplain forests, floodplain grasslands, river channels and flood pans.
Nylsvley Nature Reserve R.S. no 952	Northern Province, South Africa 24°39'S 028°42'E	Nature reserve 3 970 ha	Upper Limpopo Risk Region: Riverine floodplains, flooded river basins, and seasonally flooded grassland. Had the endangered roan antelope Hippotragus equis, and the area serves as a breeding ground for eight South African, red-listed waterbirds
Verloren Valei Nature Reserve R.S. no1110	Mpumalanga, South Africa 25°17'S 030°09'E.	Nature Reserve. 5 891 ha	Olifants Risk Region: Comprising >30 wetlands (14% of the site's area), permanent freshwater marshes, with the emergent vegetation waterlogged for most of the season, acting as a sponge in the upper catchment of important river systems in South Africa and Mozambique. These support high botanical diversity, are one of the last areas with suitable Wattled Crane *Bugeranus carunculata* breeding habitat, and contain a significant number of vulnerable and threatened plant, butterfly, and mammal species.

5.3 GENERAL BIODIVERSITY

The General Assembly of the United Nations on the program of further implementation of agenda 21 decided under biological diversity 66(a) that urgent and decisive action is needed to conserve and maintain genes, species and ecosystems, to sustainably manage, use and benefit from biological resources (UNGA, 1997). Aquatic species are generally seen as an important cause of habitat alteration and have caused a loss of aquatic biological diversity in many places around the world (FAO, 2004). The Southern African Research and Documentation Centre (SARDC, 2020) describes the biodiversity found in the Limpopo River Basin as rich in diversity with endemic as well as migratory biota occupying the varied ecosystems of all riparian countries of the basin. Table 5.2 presents the number of species in each riparian country of the basin as per World Resources (2000-2001) statistics. Fish are unfortunately not listed. Petrie and colleagues also noted that the Limpopo River Basin is exceptionally rich in biodiversity (Petrie et al. 2014). Biodiversity hotspots and species within the basin are discussed below.

TABLE 5.2: NUMBER OF SPECIES IN EACH RIPARIAN COUNTRY (WORLD RESOURCES 2000-2001). BRACKETS INDICATE THE NUMBER OF THREATENED SPECIES. (*SOURCE:* SARDC, 2020)

COUNTRY	TOTAL MAMMAL SPECIES	TOTAL BIRD SPECIES	TOTAL REPTILE SPECIES	TOTAL AMPHIBIAN SPECIES	TOTAL PLANT SPECIES
Botswana	164 (5)	386 (7)	157 (0)	38 (0)	215 (0)
Mozambique	179 (13)	498 (14)	167 (5)	62 (0)	5 692 (57)
South Africa	255 (33)	596 (16)	315 (19)	108 (9)	23 420 (1 875)
Zimbabwe	270 (9)	532 (9)	153 (0)	120 (0)	4 440 (73)

Biodiversity Hotspots

There are two recognized Biodiversity Hotspots areas identified in the Limpopo basin: small remnants of the Coastal Forests of Eastern Africa hotspot that extends mainly to the north; and the Maputoland-Pondoland-Albany that extends from the south and ends its range at the Limpopo mouth (Table 5.3 and Figure 5.3).

TABLE 5.3: BIODIVERSITY HOTSPOTS IN THE LIMPOPO BASIN

COASTAL FORESTS OF EASTERN AFRICA	Tiny and fragmented in the Limpopo basin but part of the Coastal Forest of Eastern Africa which has 40 000 cultivated varieties of African violet, home to a variety of primate species including three endemic and highly threatened monkey species and two endemic species of bush-babies, subsistence agriculture and commercial farming consume more and more of the region's natural habitat.
MAPUTOLAND-PONDO-ALBANY **RANGING FROM THE COAST AT XAI TO THE NORTHERN DRAKENSBERG/STRYDPOORTBERG AREA**	An area of an area of 274 136 km^2 running down the eastern seaboard of Southern Africa. A mix of grasslands, bushveld and forest. Contains warm temperate forests, home to nearly 600 tree species being the highest tree richness of any temperate forest on the planet. Flanks the Great Escarpment stretching along the coastline of eastern South Africa from Port Elizabeth to the Limpopo River mouth.

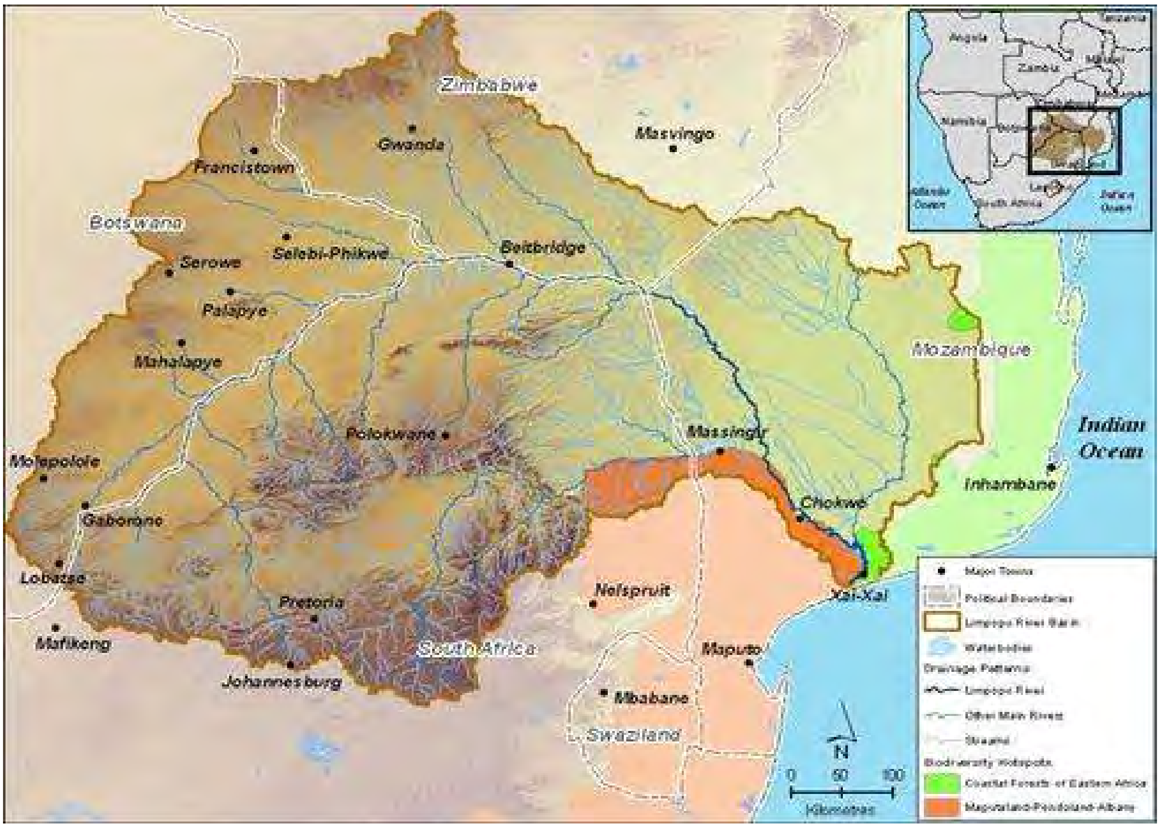

FIGURE 5.3: BIODIVERSITY HOTSPOTS IN THE LIMPOPO RIVER BASIN. (SOURCE: CONSERVATION INTERNATIONAL, 2010). THE DARKER ORANGE AREA IS THE PORTION OF THE MAPUTO PONDOLAND ALBANY HOTSPOT AREA WITHIN THE PONGOLA.

5.4 LAKES

Defined as permanent waterbodies greater than 0.25 ha in surface area and more than 2m deep (Kalff, 2002), the Limpopo River Basin has only one natural lake, Lake Pave on the Lumane River. This lake is about 80 ha in size and is fed by small streams that are in turn fed by several swampy areas which usually do not run dry. Due to the stable water supply including ground water flows from the highland areas that infiltrate the sandy bottom of the lake, there is not much fluctuation in water levels during the dry period, while levels can rise >1m higher than normal during the rainy periods e.g., 1.0m and 1.5m during the floods of 2013 and 2000, respectively.

5.5 ARTIFICIAL LAKES/DAMS

The large number of dams and their associated artificial lakes (see Figure 4.5) provides aquatic habitats that to some extent mimic those found in natural lakes (a large body of deeper water, with slow flow, temperature gradients and a different sediment and nutrient profile compared to rivers) even though there are a number of notable differences. However, these ecosystem types are not natural for the Limpopo basin and the presence of these dams and artificial lakes in general contributes negatively to the river ecosystems. Particular negative impacts include river discontinuity, interruption of sediment movement, water quality changes, downstream flow changes, impacts on faunal migrations both up and downstream, lake (lentic) habitats supporting different and unnatural biodiversity, reduced stream power downstream with associated loss of sediment scour and riparian zone influence.

Most of the large dams in the basin are found in South Africa (~160 dams) and are located mostly in the Crocodile, Upper Olifants and Middle Olifants catchments, 15 of these dams have storage capacities above 100 Mm^3 while 34 have capacities between 10 Mm^3 and 100 Mm^3 (FAO, 2004). Mozambique has two major dams with the Massingir Dam located on the Elephantes River (right next to Massingir town) having the largest storage capacity at 2800 Mm^3. Zimbabwe has more than 2000 small dams in the basin with around 21 medium or large dams. Botswana has six large storage dams with an estimated total storage capacity of 355 Mm^3 and another approximately 100 smaller dams (FAO, 2004). There are many other privately owned small dams (heights and capacity less than 10 m and 5 Mm^3, respectively) within the basin.

Many of the dams in the basin are highly polluted (e.g., Loskop, Witbank on the Olifants river) due to the progressive worsening of water quality, especially in the South African portion of the basin due to urbanization and industrialization (Ashton, 2007). Due to this pollution, there is an advanced and at times dramatic reduction in the numbers and abundance of several sensitive species of insects, amphibians, fish, reptiles and aquatic mammals in the worst affected dams and associated river systems (O'Keeffe et al. 1989; Darwall et al. 2009)

5.6 ESTUARY

According to the Limpopo river basin monograph (Aurecon, 2013a), estuaries potentially play a critical role in determining water allocation in a catchment. For a reasonable functionality to be retained in an estuary, some river reaches in the catchment will have to be maintained in high ecological categories to offset those in worse condition, thus ensuring a reliable river flow arriving at the estuary.

The Limpopo River has an elongated estuarine zone fed by a catchment of greater than 400 000 km^2 that enters the sea near to Xai in Mozambique (Aurecon, 2013a). The estuary has saline and fresh water in an interface between freshwater and marine environments, which spreads through the dune-field at the coast some 35 kilometers upstream from the river mouth. River flow in the system is highly seasonal with the highest flows occurring during the wetter summer months having a pronounced impact on physico-chemical conditions. The estuary is characterized by mangrove communities on both banks for up to 20 kilometers from the lower reaches, with Avicenna marina interspersed with Phragmites australis reed beds, and relatively small sections of shoreline mudbanks (utilised extensively by subsistence fishers). The E-flows assessment carried out in 2013 on the basin identified the following botanical communities within the estuarine zone; Open surface water area (potential habitat for phytoplankton), Submerged macrophytes, Intertidal sand and mudflats (potential habitat for intertidal benthic microalgae), Macro-algae, Salt marsh Mangrove communities, including landward edges, Reedbeds (nearly uniform occurrences of *Phragmites*) but including some adjacent sedge communities), Open vegetation mainly comprising grasses, but including some nested reeds and sedges, Sand thicket and Coastal forest and the presence of other alien plant species including *Eucalyptus* sp. mainly on dunes of the north bank, water Hyacinth (*Eichhornia crassipes*) and alien trees including *Casuarina equisetifolia* (mainly in closer proximity to the mouth), *Terminalia catappa* and *Psidium guajava*, the latter two as only scattered trees, however the presence of these alien species has been considered to be small (Aurecon, 2013a).

Under the same 2013 E-flow study for the basin, a total of 35 macrobenthic taxa were recorded, dominated by polychaete worms which contributed 10 taxa (families, genera and species) plus some unidentified individuals. The number of taxa increased from five at the mouth site to a maximum of 13 in the middle reaches before declining to two at the top three sites. Due to the lack of information on fish, the study used the records of the entire basin and reference communities to suggest that category II estuarine dependent marine species dominate the Limpopo's estuarine fish fauna (Aurecon, 2013a).

FIGURE 5.4: LANDSAT IMAGE SHOWING MANGROVE COMMUNITIES IN THE LIMPOPO RIVER ESTUARY. (SOURCE - USGS/HATFIELD, 2010)

5.7 RIVER ECOSYSTEMS

The Limpopo river has 24 major known tributaries and flows north of its origin, beginning at the confluence of the Marico and Crocodile Rivers in the Limpopo Province of South Africa, and forms the border with Botswana where it arcs east, is joined by the Shashe river to form the border with Zimbabwe. From here, it flows down the Great Escarpment and east into Mozambique at Pafuri, across the coastal plateau to the Indian Ocean at Xai (Limpopo RAK, 2020).

Three logical reaches (upper, middle and lower) of the Limpopo river basin were identified by FAO (1997) in its description of the basin's hydrology. I) the upper Limpopo river down to Shashe confluence at the South Africa-Botswana-Zimbabwe border, II) the middle Limpopo River between Shashe confluence and the Luvuvhu confluence at the South Africa-Zimbabwe-Mozambique border at Pafuri, III) the Lower Limpopo River downstream of Pafuri to the river mouth in the Indian ocean (FAO, 1997). FAO (2004) ranked the tributaries of the Limpopo River from each riparian country according to decreasing mean annual runoff (MAR) which are summarized in the Table 5.4 below.

TABLE 5.4: TRIBUTARIES OF THE LIMPOPO RIVER BASIN RANKED ACCORDING TO DECREASING MAR. (SOURCE – FAO, 2004)

COUNTRY	MAIN TRIBUTARY (MOST IMPORTANT)	OTHER MAJOR TRIBUTARIES ACCORDING TO DECREASING MAR
Botswana	Shashe river	Motloutse, Lotsane, Notwane, Bonwapitse and Mahalapswe Rivers
South Africa	Olifants River and the Crocodile-Limpopo part of the Limpopo River Basin	Shingwedzi and Letaba Rivers (tributaries to Elephantes river), Luvuvhu (which joins the Limpopo River at Pafuri), Mokolo, Mogalakwena, Marico, Lephalala, Nzhelele, Sand and Matlabas Rivers.
Zimbabwe	Shashe and Umzingwane Rivers	Mwenezi and Bubi Rivers as other major tributaries
Mozambique	Elephantes	Chokwé, Changane (an intermittent tributary) and Lumane Rivers

In other parts of the basin on the Mozambique side, the Limpopo River, which used to be a perennial river, can fall dry for up to eight months per year mostly as a result of abstractions in the upper catchment area (GOM-DNA, 1995 as quoted in FAO (2004)).

The Olifants River, which becomes the Elephantes and joins the Limpopo river in Mozambique, has the largest catchment area and is also the largest contributor of flow to the Limpopo River, while the Luvuvhu River has the highest unit runoff and also has a high ratio of denaturalized to naturalized MAR (86 percent), indicating a relatively low level of development in the catchment (FAO, 2004).

Many of the rivers in the basin are seasonal in that they only flow during the wet season. This situation has worsened over time (see hydrology chapter). Since the mainstem Limpopo River itself has also become seasonal in some areas, the changes come with major ecosystem changes as many of the ecosystem processes that existed before can no longer function.

FISH

The fish of the Limpopo River Basin have historical connections to the Congo Basin resulting in a high regional aquatic diversity (Stankiewicz et al. 2005) with many unique species and those with high conservation value (IUCN Red List status). At least 83 species of fish have been recorded in the basin (FAO, 2004) with 48 of these species being found in the Limpopo River and the others only recorded in its tributaries. Among these species of fish found in the Limpopo River; cyprinids, catfish, *Tilapia*, exotic trout and several brakish-water species (found in the estuary) provide a source of income and protein to the basin people. A large number of mollusk species that can be harvested are also found in the basin (Darwall et al. 2009) but due to the characteristics of the system, the Limpopo Systems has relatively low endemicity.

FIGURE 5.5: FISHING IN A TRIBUTARY OF THE OLIFANTS RIVER

AQUATIC MACRO-INVERTEBRATES

Urban waste-water treatment works generating treated effluent that enters the basin system mostly via the Crocodile River gives rise to large nutrient loads causing a highly modified habitat template for macroinvertebrates particularly within the upper reaches of the system. There is abundant growth of algae obstructing instream habitat with remnant available habitat in areas where instream flow is sufficiently strong. The benthic algal mats provide excellent habitat, however, for Corbiculids (basket clams) which in many areas dominate the aquatic biota. Once base flows weaken outside of the main stream flow, the algal mats completely dominate and cover the habitat. This nutrient signal gradually weakens down the length of the Limpopo, although is still evident as far as Chokwe (Aurecon, 2013a).

There is lack of species level information (distribution and ecology) on Aquatic macro-invertebrates at the basin level. Most of the collected data in the catchment is family based (SASS5) with broad insights into their ecological requirements. Based on family based biotic indices the headwaters of streams draining mountain catchment areas are generally in good condition due to their natural flow providing good instream habitat and thus healthy invert communities. Examples are streams draining the; Soutpansberg mountains (upper Luvuvhu, Dzindi, Mukhase, Mutale, Mutshindudi) (River Health Programme, 2001b); Wolkeberg mountains (upper Ga-Selati, Makhutsi, Letsitele, Groot Letaba, Debegeni, Politsi) (River Health Programme, 2001a and 2001b); Drakensberg (Treur, upper Blyde, upper Lisbon, Belvedere Creek, Klaserie) (River Health Programme, 2001a; Diedericks, 2018a, 2019a, 2019b, 2019c); Waterberge (Mothlabatsi, Thongwane, Sterkstroom) (River Health Programme 2001a; Diedericks and Koekemoer, 2012) Magaliesgerg (Groot Marico) (River Health Programme, 2005) Witwatersrand mountain range (upper Skeerpoort, Sterkstroom in Upper Crocodile-west) (River Health Programme, 2005); Upper Groot Marico (dolomitic eyes) (River Health Programme, 2005).

Streams impacted by weirs, dams, over-abstraction, urban runoff and high waste water loading, with poorly managed commercial forestry areas, agricultural return flow, lack of well-managed riparian buffers, poorly managed mining, all provide for severely modified conditions for habitat and invertebrates communities. (River Health Programme, 2001a, 2001b; 2005).

VEGETATION

Particular points of interest include:

1) The catchment is dominated by 2 vegetation Biomes: Savanna (more than 60%) on the western side and Indian Ocean Coastal Belt on the eastern side (Mucina and Rutherford, 2006; 2012). A small amount of Grassland Biome occurs in the southern regions and supports a high density of seep wetlands, which are vital for base flow maintenance. Several reaches of lowland rivers are characterized by a zonal Lowveld Riverine Forest, a critically endangered vegetation unit.

2) The major impacts on vegetation are removal and invasion by alien species. Vegetation removal is comprised mainly of (Aurecon, 2013a):

    a. Mining

    b. Agriculture

    c. Urbanization

3) Alien plant species had a notable impact on natural vegetation in the Basin. Highly invasive species (see section below) invaded banks and open water and reduced natural vegetation cover and abundance and resulted in impacts on general biodiversity.

4) Several large National Parks occur within the basin, as well as numerous other protected areas. These provide refugia for vegetation communities and species and also provide clues to the reference conditions associated with vegetation. Sites within these areas will provide more realistic assessments of water requirements for vegetation.

AQUATIC INVASIVE ALIEN SPECIES

Introduced (invasive alien) species including aquatic weeds are widespread in southern Africa, especially where there are human disturbances (Environmentek, CSIR, 2003). Invasive aquatic species, such as water hyacinth/*Eichhornia crassipes*, red water-fern/*Azolla filiculoides* and parrot's feather/*Myriophyllum aquaticum* provide conditions, which increase the prevalence of water-borne diseases, adversely affect water quality and aquatic life and block river courses, increasing the damage done by floods (UNEP, 2002). The impacts of alien (terrestrial) plants include crowding out the native riverine vegetation, displacing or affecting populations of aquatic organisms and fauna and trap sediment, use more water than the natural vegetation that they replace, deplete soil moisture, reduce groundwater recharge, spring flows and river base flows (Le Maitre et al. 2000; Environmentek, CSIR, 2003). The most aggressive invader, *Chromolaena odorata* is rapidly spreading northwards into southern Mozambique and its impact will increase in the Limpopo basin. The Limpopo basin especially, its South African tributaries, has been invaded by Australian wattles/*Acacia* species, guavas/*Psidium guajava*, bugweed/*Solanum mauritianum*, lantana/*Lantana camara*, jacaranda/ *Jacaranda mimosaefolia*, syringe/*Melia azedarach*, amongst others (Versfeld et al. 1998; Environmentek, CSIR, 2003). These species are likely to have been widely dispersed by the floods of February 2000. Water hyacinth *Eichhornia crassipes* was noted in the estuary during the Monograph study of 2013 but in small quantities, presumably originating in upstream dams in South Africa where it is common. There are several operational programs in the basin countries to control alien species but the process is expensive and takes several years to complete.

5.8 AQUATIC ECOREGIONS

Aquatic ecoregions are areas of similar ecological character. The concept is that any river ecosystem within a single ecoregion would have common characteristics to any other river in that ecoregion. This allows a comparison between these supposedly similar rivers, and also extrapolation from one site to the next with some confidence. Different levels of ecoregion may be mapped, commencing with coarse differentiation and going to finer levels. Within South Africa (Kleynhans et al. 2005), these were mapped for both Level 1 (coarse resolution) and Level 2 (finer resolution) but not for the other riparian countries. In this project Level 1 ecoregions are presented for the entire basin. Level 2 detail was not immediately possible due to lack of mapped information and local experts who could attest to the ecoregion types.

The Level 1 aquatic Ecoregions have been mapped for south Africa (Kleynhans et al. 2005), and in this project the methods applied for developing them were applied for the other basin riparian countries (Figure 5.6). Where possible data sets that could be applied at the regional or country level for all riparian countries were used. Predominantly the data sets used to develop Figure 5.6 include:

1. vegetation type (which is a good indicator of geology, soil type and climate),
2. altitude
3. contours and rainfall isohyets
4. hydrology
5. climate
6. soil
7. Google earth

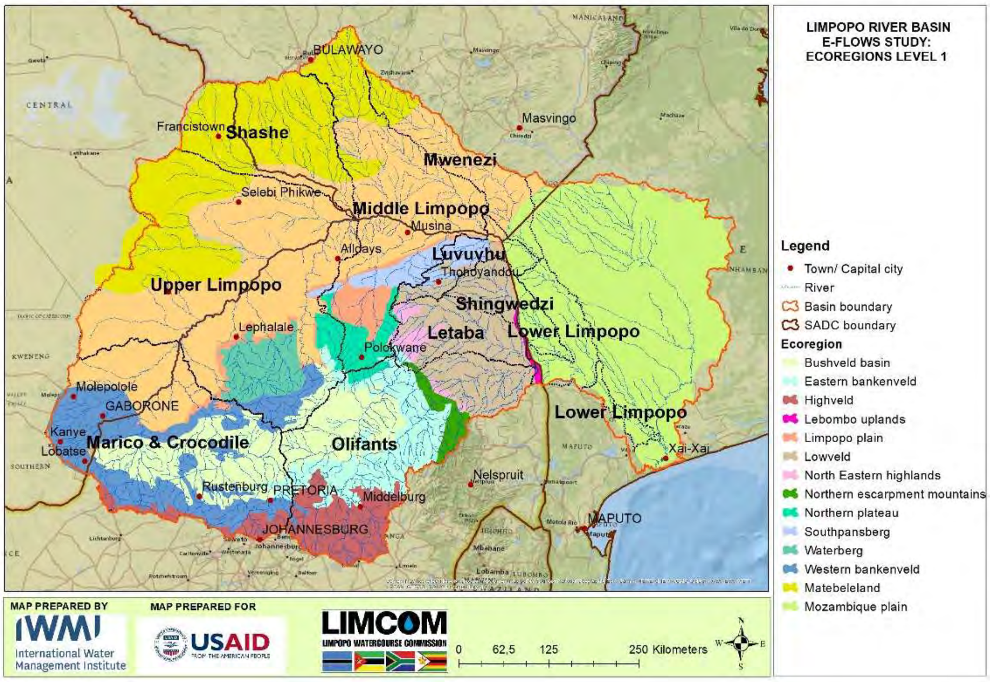

FIGURE 5.6: AQUATIC ECOREGIONS OF THE LIMPOPO RIVER BASIN

5.9 PRESENT ECOLOGICAL STATE

Ecological State or Condition refers to the state of ecological systems, and includes their physical, chemical, and biological characteristics and the processes and interactions that connect them. The present ecological state (PES) describes the present condition of these ecosystems derived in a quantitative way. Data has been used to develop the PES of the rivers in the South African portions of the Limpopo basin, but also for all the E-flow sites used in the Monograph. Table 5.5 provides a guide to the Ecological Categories that are used in this report, while Table 5.6 provides the achieved PES categories for the Rivers in the basin as developed by the South African Department of Water and Sanitation. Table 5.7 provides the PES for the E-flow sites monitored during the Monograph study and also for existing sites in South Africa that contributed to this overall evaluation (Aurecon, 2013). This latter table also provides the Recommended Ecological Condition (REC) which is a statement of management objective, and a measure of the Ecological Importance and Sensitivity (EIS).

TABLE 5.5: ECOLOGICAL CATEGORIES FOR PES

ECOLOGICAL CATEGORIES	NAME	DESCRIPTION
A	Natural	Unmodified natural: Modifications to the natural abiotic template should be negligible to small.
B	Good	Largely natural with few modifications: Only a small risk of modifying the natural abiotic template and exceeding the resource base should be allowed.
C	Fair	Moderately modified: A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed.
D	Poor	Largely modified: Large risk of modifying the abiotic template and exceeding the resource base may be allowed.
E	Seriously modified	Seriously modified
F	Critically modified	Critically or extremely modified

TABLE 5.6: PES OF THE RIVERS IN THE RISK REGIONS OF THE LIMPOPO RIVER BASIN

	OLIFANTS, LETABA, SHINGWEDZI, RSA						
	PRESENT ECOLOGICAL STATE (KM)						
SECONDARY	CAT A	CAT B	CAT C	CAT D	CAT E	CAT F	LENGTH KM
B1 OLIF Upper Olif	0.0	138.0	395.0	345.0	235.0	2.0	1115.0
B2 OLIF Wilge	0.0	55.8	245.5	150.1	24.6	0.0	475.9
B3 OLIF Midd Olif	6.3	294.3	476.9	476.3	67.9	0.0	1321.8
B4 OLIF Steelpoort	0.0	166.7	572.3	329.3	64.3	0.0	1132.6
B5 OLIF Midd Olif	14.9	22.4	307.7	591.3	130.1	28.8	1095.2
B6 OLIF Bllyde	0.0	183.4	207.7	93.0	0.0	0.0	484.1
B7 OLIF Low Olif	108.4	625.3	678.8	167.3	147.2	0.0	1727.1
KM TOTAL: OLIF (B1-B7)	129.7	1 485.9	2 884.0	2152.3	669.1	30.8	7351.7
B8 LETABA	256.9	260.8	643.2	599.5	66.3	0.0	1826.7
B9 SHINGWEDZI	225.6	201.9	251.0	25.5	0.0	0.0	704.0
	PRESENT ECOLOGICAL STATE (CATEGORIES AS % OF STREAM LENGTH)						
SECONDARY	CAT A% LENGTH FOR SECONDARY	CAT B % LENGTH FOR SECONDARY	CAT C % LENGTH FOR SECONDARY	CAT D % LENGTH FOR SECONDARY	CAT E % LENGTH FOR SECONDARY	CAT F % LENGTH FOR SECONDARY	
B1 OLIF	0.0	12.4	35.4	30.9	21.1	0.2	
B2 OLIF	0.0	11.7	51.6	31.5	5.2	0.0	
B3 OLIF	0.5	22.3	36.1	36.0	5.1	0.0	
B4 OLIF	0.0	14.7	50.5	29.1	5.7	0.0	
B5 OLIF	1.4	2.0	28.1	54.0	11.9	2.6	
B6 OLIF	0.0	37.9	42.9	19.2	0.0	0.0	
B7 OLIF	6.3	36.2	39.3	9.7	8.5	0.0	
Total % for Secondaries B1-B7	1.8	20.2	39.2	29.3	9.1	0.4	
B8 LETABA	14.1	14.3	35.2	32.8	3.6	0.0	
B9 SHINGWEDZI	32.0	28.7	35.7	3.6	0.0	0.0	
	LIMPOPO, RSA						

NGOT/MAR/CROC	PRESENT ECOLOGICAL STATE (KM)						
SECONDARY	CAT A	CAT B	CAT C	CAT D	CAT E	CAT F	LENGTH KM
A1(Ngotwane)	0.0	12.8	42.7	152.1	0.0	0.0	207.6
A2 (Crocodile)	0.0	458.0	1 362.0	1 287.9	534.4	14.3	3656.7
A3 (Marico)	5.6	239.8	1 065.8	346.5	0.0	0.0	1657.7
KM TOTAL: NGOT/MAR/CROC	5.6	710.6	2 470.5	1 786.5	534.4	14.3	5521.9

	PRESENT ECOLOGICAL STATE (CATEGORIES AS % OF STREAM LENGTH)					
SECONDARY	CAT A% LENGTH FOR SECONDARY	CAT B % LENGTH FOR SECONDARY	CAT C % LENGTH FOR SECONDARY	CAT D % LENGTH FOR SECONDARY	CAT E % LENGTH FOR SECONDARY	CAT F % LENGTH FOR SECONDARY
A1(Ngotwane)	0.0	6.2	20.6	73.3	0.0	0.0
A2 (Crocodile)	0.0	12.5	37.2	35.2	14.6	0.4
A3 (Marico)	0.3	14.5	64.3	20.9	0.0	0.0
Total % for Secondaries	0.1	12.9	44.7	32.4	9.7	0.3

UPPER LIMPOPO	PRESENT ECOLOGICAL STATE (KM)						
SECONDARY	CAT A	CAT B	CAT C	CAT D	CAT E	CAT F	LENGTH KM
A4 MOKOL	23.1	270.2	966.3	359.9	18.3	0.0	1637,9
A5 LEPHAL	0.0	156.4	199.5	259.9	0.0	0.0	615,8
A6 MOGAL	29.6	235.2	843.1	718.1	74.6	0.0	1900,5
KM TOTAL: NGOT/MAR/CROC	52.7	661.8	2 008.9	1 337.9	92.9	0.0	4154,2

	PRESENT ECOLOGICAL STATE (CATEGORIES AS % OF STREAM LENGTH)					
SECONDARY	CAT A% LENGTH FOR SECONDARY	CAT B % LENGTH FOR SECONDARY	CAT C % LENGTH FOR SECONDARY	CAT D % LENGTH FOR SECONDARY	CAT E % LENGTH FOR SECONDARY	CAT F % LENGTH FOR SECONDARY
A4 MOKOL	1.4	16.5	59.0	22.0	1.1	0.0
A5 LEPHAL	0.0	25.4	32.4	42.2	0.0	0.0
A6 MOGAL	1.6	12.4	44.4	37.8	3.9	0.0

Total % for Secondaries	1.3	15.9	48.4	32.2	2.2	0.0

MIDDLE LIMPOPO	PRESENT ECOLOGICAL STATE (KM)						
SECONDARY	CAT A	CAT B	CAT C	CAT D	CAT E	CAT F	LENGTH KM
A7 SAND	66.6	306.8	740.8	312.6	0.0	0.0	1426,7
A8 Nzhelele Nwanedi	0.0	55.8	245.5	150.1	24.6	0.0	475,9
A9 LUVUVH	94.1	83.5	486.7	214.0	5.9	0.0	884,1
KM TOTAL: SAND/NZHEL/LUVUVH	160.7	446.0	1 472.9	676.6	30.5	0.0	2786,7

	PRESENT ECOLOGICAL STATE (CATEGORIES AS % OF STREAM LENGTH)					
SECONDARY	CAT A% LENGTH FOR SECONDARY	CAT B % LENGTH FOR SECONDARY	CAT C % LENGTH FOR SECONDARY	CAT D % LENGTH FOR SECONDARY	CAT E % LENGTH FOR SECONDARY	CAT F % LENGTH FOR SECONDARY
A7 SAND	4.7	21.5	51.9	21.9	0.0	0.0
A8 Nzhelele Nwanedi	0.0	11.7	51.6	31.5	5.2	0.0
A9 LUVUVH	10.6	9.4	55.0	24.2	0.7	0.0
Total % for Secondaries	5.8	16.0	52.9	24.3	1.1	0.0

TABLE 5. 7 PRESENT ECOLOGICAL STATE (PES) AND RECOMMENDED ECOLOGICAL CONDITION (REC) AND ECOLOGICAL IMPORTANCE AND SENSITIVITY (EIS) FO RTHE BASIN (AURECON, 2013)

EWR SITE	RIVER	QUAT CATCHMENT	RRR	PES	EIS	REC	NMAR ($10^6 M^3$)	%EWR (REC)	LATDD	LONGDD
LmEWR1r	Limpopo at Spanwerk	A41D	1	B/C	High	B/C	591.49	27.60	-23.9447	26.9308
MAR_EWR 1	Kaaloog-se-Loop: Below gorge	A31A	1	B	Very high	B	10.539	76.32	-25.7770	26.4330
MAR_EWR 2	Groot Marico: Upstream confluence with Sterkstroom	A31B	1	B	Very high	B	42.08	50.26	-25.6690	26.4350
MAR_EWR 3	Groot Marico: Downstream Marico Bosveld Dam	A31F	1	C/D	High	C/D	65.083	23.62	-25.4610	26.3920
MAR_EWR 4	Groot Marico: Downstream Tswasa Weir	A32D	1	C	High	C	153.251	7.96	-24.7060	26.4240
MAR_EWR 5	Klein Marico Downstream Klein Maricopoort Dam	A31E	1	C	Moderate	C	29.8	4.67	-25.5160	26.1590
MAR_EWR 6	Polkadraaispruit before confluence with Marico	A31B	1	B/C	Moderate	B	9.866	31.87	-25.6469	26.4893
MAT_EWR 1	Matlabas Zyn Kloof	A41A	1	B	Very high	A	5.23	57.07	-24.412	27.60324
MAT_EWR 2	Matlabas at Haarlem East (A4H004)	A41C	1	C	High	B/C	32.8	33.23	-24.1601	27.47971
MAT_EWR 3	Mamba River Bridge	A41B	1	B/C	Moderate	B/C	9.54	35.49	-24.2127	27.50718

EWR SITE	RIVER	QUAT CATCHMENT	RRR	PES	EIS	REC	NMAR (10^6M^3)	%EWR (REC)	LATDD	LONGDD
MAT_EWR 4	Matlabas at Phofu	A41C	I	B	Moderate	B	35.58	33.42	-24.0516	27.35922
CROC_EWR 1	Crocodile: Upstream of the Hartbeespoort Dam	A21H	I	D	Moderate	D	231.1	24.07	-25.80040	27.896
CROC_EWR 2	Jukskei: Heron Bridge School	A21C	I	E	Moderate	D	139.9	29.19	-25.95390	27.9621
CROC_EWR 3	Crocodile: Downstream of Hartbeespoort Dam in Mount Amanzi	A21J	I	C/D	High	C/D	143.3	25.02	-25.71680	27.8431
CROC_EWR 4	Pienaars: Downstream of Roodeplaat Dam	A23B	I	C	High	C	28.2	20.98	-25.41550	28.312
CROC_EWR 5	Pienaars/Moretele: Downstream of the Klipvoor Dam in Borakalalo National Park	A23J	I	D	High	C	113	11.82	-25.12657	27.80457
CROC_EWR 6	Hex: Upstream of Vaalkop Dam	A22J	I	D	Moderate	D	26.9	14.96	-25.52140	27.3749
CROC_EWR 7	Crocodile: Upstream of the confluence with theBierspruit	A24C	I	D	Moderate	D	463.4	9.14	-24.88661	27.51743
CROC_EWR 8	Crocodile downstream the confluence with	A24H	I	C	Moderate	C	559.9	14.22	-24.64476	27.32569

EWR SITE	RIVER	QUAT CATCHMENT	RRR	PES	EIS	REC	NMAR (10^6M^3)	%EWR (REC)	LATDD	LONGDD
	Bierspruit in Ben Alberts Nature Reserve									
CROC_EWR 9	Magalies: Downstream of Malony's Eye	A21F	1	B	Very high	B	14.7	45.58	-26.01689	27.56581
CROC_EWR 10	Elands: Upstream Swartruggens Dam	A22A	1	C	High	B/C	10.1	30.48	-25.72655	26.72044
CROC_EWR 11	Sterkstroom: Upstream Buffelspoort Dam	A21K	1	C	High	C	14	28.41	-25.80739	27.47848
CROC_EWR 12	Buffelspruit before confluence with Plat	A23G	1	B/C	Moderate	B/C	3.14	35.85	-24.8304	28.22240
CROC_EWR 13	Elands downstream Lindleyspoort Dam	A22E	1	C	Low	C	18.77	21.90	-25.4811	26.69039
CROC_EWR 14	Waterkloofspruit downstream Rustenburg Nature Reserve	A22H	1	B/C	Low	B/C	5.469	28.27	-25.4811	26.69039
CROC_EWR 15	Lower Magalies before confluence with Skeerpoort	A21F	1	C/D	Low	C/D	21.899	21.18	-25.8969	27.59820
CROC_EWR 16	Rietvlei upstream Rietvlei Dam	A21A	1	C	Low	C	4.788	27.83	-26.0189	28.30442
MOK_EWR 1a	Mokolo at Vaalwater	A42C	2	C/D	High	B	84.84	22.60	-24.2894	28.0924

EWR SITE	RIVER	QUAT CATCHMENT	RRR	PES	EIS	REC	NMAR (10^6M^3)	%EWR (REC)	LATDD	LONGDD
MOK_EWR 1b	Mokolo at Tobacco	A42E	2	B/C	High	B	135.03	17.60	-24.1783	27.9777
MOK_EWR 2	Mokolo at Ka'ingo	A42F	2	B/C	Very high	B	196.2	19.80	-24.0650	27.7872
MOK_EWR 3	Mokolo below Mokolo Dam in the Gorge	A42G	2	B/C	Very high	B	214.5	12.50	-23.9680	27.7269
MOK_EWR 4	Mokolo: Malalatau	A42G	2	C	Very high	B	253.3	16.50	-23.7712	27.7553
LmEWR2r	Limpopo at Poachers Corner	A71L	4	B/C	Moderate	B/C	1 683	30.90	-22.1842	29.4052
LmEWR4r	Limpopo at Pafuri	Mozambique	5	C	Moderate	C	2 792	30.90	-22.4596	31.5030
LUV_EWR	Mutshindudi	A91G	5	C	High	B/C	47.47	29.86	-22.9147	30.48838
LmEWR3r	Mwanedzi at Malapati	Zimbabwe	6	C	Moderate	B/C	282.73	22.00	-22.0639	31.4231
Olifants_EWR1	Olifants	B11J	7	E (D)	Moderate	C	184.52	18.60	-25.75944	29.31250
Olifants_EWR2	Olifants	B32A	7	C	High	B	500.63	23.80	-25.49567	29.25411
Olifants_EWR3	Klein Olifants	B12E	7	D	Moderate	C	81.54	27.00	-25.67358	29.31680
Olifants_EWR4	Wilge	B20J	7	C	High	B	175.5	29.90	-25.61994	28.99881
Olifants_EWR5	Olifants	B32D	7	C	High	C	570.98	19.10	-25.30400	29.42200

EWR SITE	RIVER	QUAT CATCHMENT	RRR	PES	EIS	REC	NMAR (10^6M^3)	%EWR (REC)	LATDD	LONGDD
Olifants_EWR6	Elands	B31G	7	E (D)	Moderate	D	60.3	17.90	-25.11600	28.95650
Olifants_EWR7	Olifants	B51G	7	E (D)	Moderate	D	726.52	12.70	-24.52889	29.54639
Olifants_EWR8	Olifants	B71B	7	E (D)	Moderate	D	813.04	15.20	-24.23889	30.08194
Olifants_EWR9	Steelpoort	B41J	7	D	High	D	120.17	15.20	-24.77500	30.16500
Olifants_EWR10	Steelpoort	B41K	7	D	High	D	336.63	12.10	-24.49650	30.39900
Olifants_EWR11	Olifants	B71J	7	E (D)	High	D	1 321.8	13.70	-24.30719	30.78608
Olifants_EWR12	Blyde	B60J	7	B	High	B	383.7	34.50	-24.40861	30.82639
Olifants_EWR13	Olifants	B72D	7	C	Moderate	B	1 760.7	23.60	-24.12667	31.01694
Olifants_EWR14a	Ga-Selati	B72H	7	C	Moderate	C	52.2	31.20	-23.99139	30.68333
Olifants_EWR14b	Ga-Selati	B72K	7	E (D)	Moderate	D	72.74	24.80	-24.02250	31.14667
Olifants_EWR16	Olifants	B73H	7	C	Very high	B	1 916.9	21.60	-24.05117	31.73231
TREUR	Treur	B60C	7	A/B	Very high	A/B	49.28	45.40	-24.70967	30.81792
DWARS	Dwars	B41H	7	B/C	High	B/C	31.43	25.90	-24.84392	30.09189

EWR SITE	RIVER	QUAT CATCHMENT	RRR	PES	EIS	REC	NMAR ($10^6 m^3$)	%EWR (REC)	LATDD	LONGDD
NPS	Noupoortspruit	B11G	7	C/D	Moderate	C/D	4.28	25.90	-29.7554	30.60588
OLI-EWR1	Upper Klein Olifants	B12C	7	C	Low	C	44.46	28.90	-25.81690	29.5904
OLI-EWR2	Upper Steelpoort	B41B	7	C	Moderate	C	63.46	29.80	-25.38310	29.8383
OLI-EWR3	Kranspoortspruit	B32A	7	B	Very high	A/B	4.71	30.50	-25.43760	29.4758
OLI-EWR4	Klip	B41F	7	C	Moderate	B/C	5.2	27.50	-25.22490	30.0523
OLI-EWR5	Watervals	B42G	7	C	Moderate	C	36.39	23.50	-24.89120	30.3105
OLI-EWR6	Upper Spekboom	B42D	7	C	High	B/C	28.04	28.10	-25.00940	30.5003
OLI-EWR7	Klaserie	B73A	7	B/C	High	B	25.54	33.10	-24.54270	31.0349
OLI-EWR8	Ohrigstad	B60H	7	C	Moderate	C	65.49	21.50	-24.54030	30.7223
LmEWR6r	Shingwedzi d/s Kanniedood Dam	B90H	9	B/C	Moderate	B	81.63	28.80	-23.1441	31.4728
LmEWR5r	Limpopo at Combomune	Mozambique	10	C	Moderate	C	3 087	26.20	-23.4717	32.4438
# LmEWR7r	Limpopo at Chokwe	Mozambique	10	C	Moderate	C	5572	20.60	-24.5002	33.0104
EWR1	Elephantes below Massingir Dam	Mozambique	10	C	High	$ C	ND	14.77	-23.88005	32.253306

EWR SITE	RIVER	QUAT CATCHMENT	RRR	PES	EIS	REC	NMAR (10^6M^3)	%EWR (REC)	LATDD	LONGDD
[#] EWR2	Limpopo at Chokwe	Mozambique	10	C	High	[$] C	ND	14.05	-24.29825	32.818611
LmEWR8r	Changane	Mozambique	-	B/C	Moderate	B/C	434.7	21.80	-24.11416	33.78387
Estuary	Limpopo at mouth	Mozambique		C	Highly important	B	ND		N/A	N/A

6. E-FLOW HYDROLOGY

This chapter contains a summary of the discharge in the basin and provides a first indication of how this will impact on the E-flows when they are determined.

Figure 6.1 summarises the rainfall in the basin. Figure 4.4 earlier gave a summary of the runoff resulting.

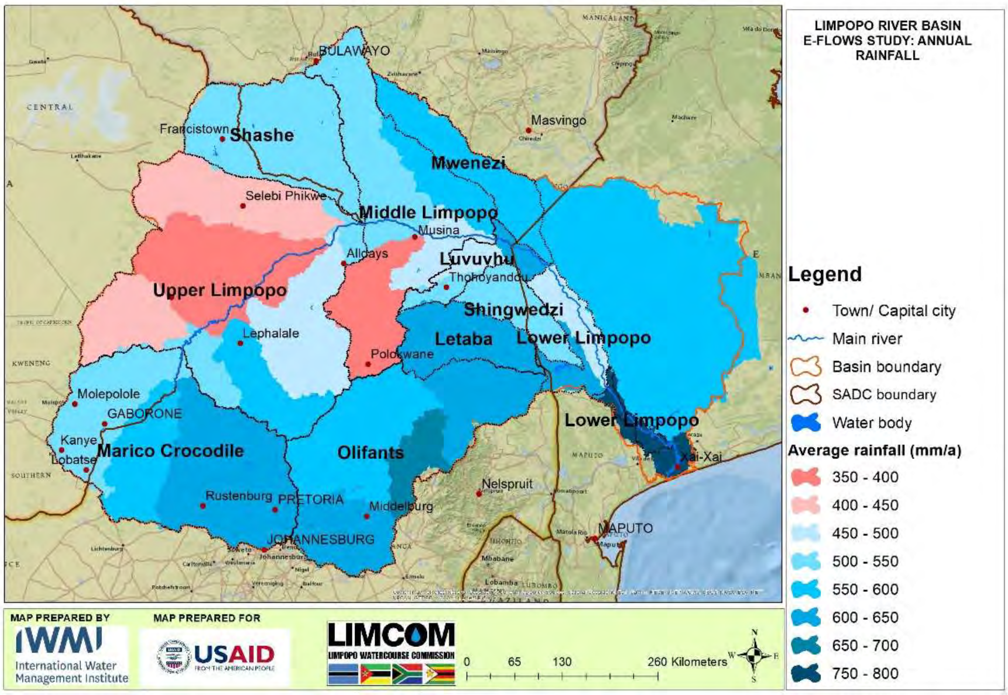

FIGURE 6.1: ANNUAL RAINFALL IN THE LIMPOPO BASIN

Figure 6.2 illustrates the hydrometric monitoring stations coupled with an indication of the PES.

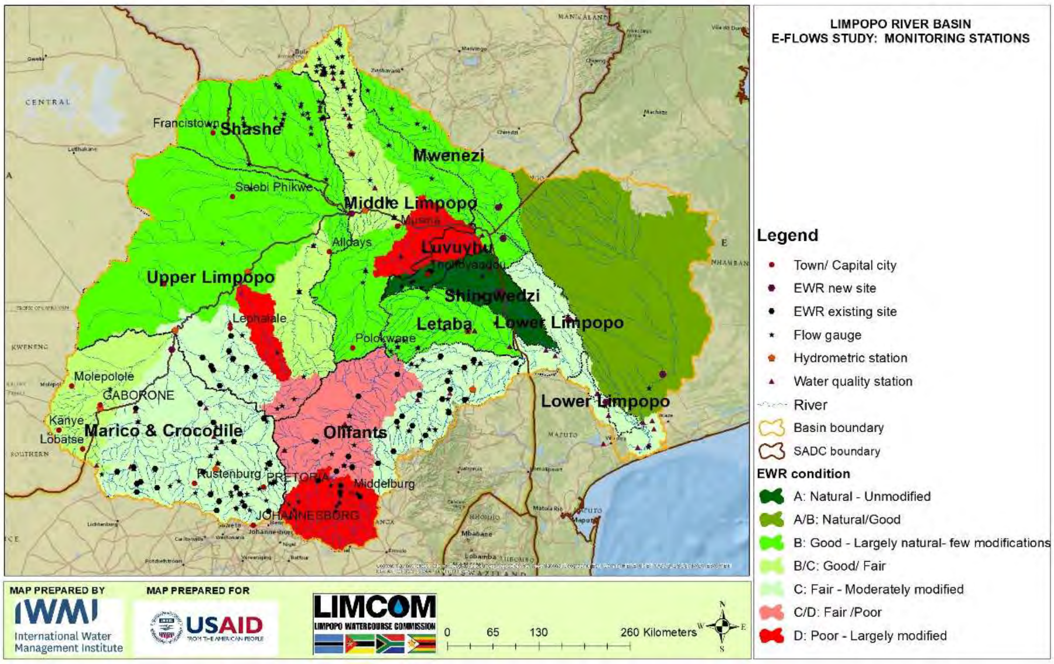

FIGURE 6.2: HYDROMETRIC AND E-FLOW MONITORING SITES IN TEH BASIN

Table 6.1 provides a detailed evaluation of the hydrology per risk region, in terms that may impact on the E-flows still to be determined. Such an evaluation considers the nature of the river discharge, its seasonality, fluctuations in flow, flood and drought characteristics.

TABLE 6.1: SUMMARISING HYDROLOGICAL ASPECTS RELATED TO ENVIRONMENTAL FLOWS BY RISK REGION BASED ON PUBLISHED LITERATURE

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR FINDINGS
Documented Effects of Dams		
Middle Limpopo 4	Zvohe dam (133 Mm^3) located at (21.8413 S, 29.7114 E) on Umzingwani (lower Mzingwane) river, constructed in 1995-1996. The river, located in Zimbabwe is ephemeral, flowing on average 191 days per year.	Managed releases from the dam supply the Beitbridge town and commercial agribusiness (citrus plantations) downstream. Water releases also recharge an alluvial aquifer in the lower Mzingwane river, which is abstracted from well points and boreholes. Flow regime changes downstream of the dam include the capture of all flows early in the rainy season, most low flows, many larger flows and the reduction in magnitude of some floods. These flow regime changes are thought to have contributed to the decline in active riverbed width and the abandonment of portions of the river channel on either side, which are colonized by vegetation, competing for water with the established riparian vegetation as well as with water users. These effects together with apparent loss in aquifer material indicate a likely decline in the extent of the alluvial aquifer and its specific yield. The riparian ecosystem, consisting of a stand of acacia woodland, is also likely to suffer (Love et al. 2007; Love et al. 2008).
Middle Limpopo 4	Upper Insiza dam (8.829 Mm^3) located on the Insiza river, which is a tributary of the Umzingwani (Mzingwane) river. The dam was constructed in 1967. The Insiza river, located in Zimbabwe, is ephemeral with no flow for 176-245 days per year.	The dam provides urban water supply to the city of Bulawayo. No significant difference has been detected between the mean annual runoff or the annual maximum flood at gauging stations upstream and downstream of the dam. The amount of water stored during the wet season is thought to balance the releases made during the dry season. The highest floods occur during January to February, which coincides with the period when most dams spill due to earlier inflows from November to January, resulting in insignificant impact to the annual maximum flood. However, the number of days with no flow is found to be lower at the downstream gauging station due to flow releases in the dry season. Changes in exceedance probabilities of daily flow levels have been observed, but are not reflected at annual level (Kileshye Onema et al. 2006).
Middle Limpopo	Insiza dam (173.491 Mm^3) located at (20.369886 S, 29.246752 E) on the Insiza river downstream of the Upper Insiza dam. The dam was constructed in 1973.	The dam provides urban water supply to the city of Bulawayo. The behavior of mean annual runoff, the annual maximum flood and the reasons for their behavior are observed to be the same as those for the Upper Insiza dam. However, in the case of this dam, no significant difference has been observed in the number of days with no flow upstream and downstream of the dam. Changes in exceedance probabilities of daily flow levels have been observed, but are not reflected at annual level (Kileshye Onema et al. 2006).

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR FINDINGS
Middle Limpopo 4	Silalabuhwa dam (23.454 Mm^3) located at (20.75833 S, 29.36056 E) on the Insiza river downstream of the Insiza dam. The dam was constructed in 1966.	The dam provides urban water supply to the city of Bulawayo. The behavior of mean annual runoff, the annual maximum flood and the reasons for their behavior are observed to be the same as those for the Upper Insiza and Insiza dams. Similar to Upper Insiza dam, the number of days with no flow is found to be lower at the downstream gauging station due to flow releases in the dry season. Changes in exceedance probabilities of daily flow levels have been observed, but are not reflected at annual level (Kileshye Onema et al. 2006).
Environmental Flow Assessments and Constraints		
Parts falling within Zimbabwe in Risk Regions Upper Limpopo, Shashe and Mwenezi	Part of Shashe, Mzingwane, Mwenezi, Bubi	An Eflow assessment has been made using the method of Hughes and Hannart (2003). The assessment reveals that the Eflow requirements in these basins are as a percentage of mean annual runoff 31-35% for Class A, 21-25% for Class B and 14-15% for Class C. Some small isolated areas within the larger basins exhibit higher requirements of 36-40% for Class A, 26-30% for Class B, 16-20% for Class C. The estimated EFRs decrease with increasing flow variability and increase with the increasing contribution of base flows to total flows (Mazvimavi et al. 2007)
Luvuvhu	Gauging stations located at Luvuvhu at (22.86 S, 30.88 E), (22.43 S, 31.07 E) and (22.85 S, 30.68 E)	Mean daily streamflow shows decreasing trends during the period 1987-2019 at these locations. The decreases are mainly attributed to abstractions for human use since long term annual air temperature and rainfall has not changed over the last 100 years in the Luvuvhu catchment. Although evidence points to degrading water quantities and associated fauna and flora, five prominent challenges to implementing E-flows were found: (i) absence of catchment management agencies/authorities (CMA), water user associations and water boards, (ii) lack of understanding of environmental flow benefits, (iii) limited financial budget, legal position and technical hydrological resources, (iv) lack of institutional and human capacity and (v) conflict of interest. These challenges have existed within the Luvuvhu river catchment since the 1960s (Ramulifho et al. 2019).
Upper Limpopo	Mokolo	An E-flows assessment method called DRIFT-ARID (A modification of the DRIFT method) has been applied to the semi-permanent Mokolo river. DRIFT-ARID is especially designed for E-flows assessments in non-perennial rivers and consists of 11 phases and 29 activities. The method used integrity scores from several disciplines to determine the overall ecosystem integrity of 5 sites under several different scenarios (Seaman et al. 2016 a,b)
Hydrology / Water Resources		

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR FINDINGS
All	Limpopo river basin	The Soil and Water Assessment Tool (SWAT) model was applied to characterize freshwater availability and scarcity in the Limpopo river basin by dividing it into 27 major catchments. Estimates of streamflow (blue water) varied from 0.2 to 570 mm/year between 1984 and 2013 over the basin. The study revealed alternating cycles of one to two years of water surplus periods and three to five years of dry periods. It also revealed that considering the natural water yield 20% of the basin (mostly east) has enough water, while the remaining 80% continues to experience dryness and water stress (Mosase et al. 2019)
5	Luvuvhu sub basin	Provides an update on the water resources of the Luvuvhu sub basin considering uncertainty in parameterizing the Pitman monthly model and in water use data. The flows at the outlet of the basin were between 44.03 Mm^3 and 45.48 Mm^3 per month when incorporating +\-20% uncertainty to the main physical runoff generating parameters. The mean simulated monthly flows were between 38.57 Mm^3 and 54.83 Mm^3 when uncertainty in reservoir capacity (62%) and water use by irrigated crops (50%) was added to the model (Oosthuizen et al. 2018a).
3	Shashe sub basin	An exercise similar to that in the Luvuvhu sub basin (above) revealed that for the Shashe sub-basin incorporating only uncertainty related to the main runoff parameters resulted in mean monthly flows between 11.66 and 14.54 Mm^3. The range of predictive uncertainty changed to between 11.66 and 17.72 Mm^3 after the uncertainty in water use information (small farm and large reservoir capacities and irrigation water use) was added (Oosthuizen et al. 2018b).
2	Mogalakwena sub basin	An exercise similar to that in the Luvuvhu and Shashe sub basins (above) revealed that the simulated mean monthly flows at the outlet of the Mogalakwena sub-basin were between 22.62 and 24.68 Mm^3 per month when incorporating only the uncertainty related to the main physical runoff generating parameters. The range of total predictive uncertainty of the model increased to between 22.15 and 24.99 Mm^3 when water use data were included (Oosthuizen et al. 2018b).
Drought Characteristics		

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR FINDINGS
All	Limpopo basin	A spatial analysis of drought characteristics in the Limpopo basin has been undertaken where drought duration, frequency and severity are investigated and drought Severity-Area-Frequency (SAF) curves have been constructed. The entire Limpopo River Basin was subdivided into four homogeneous regions based on topographic and climate variations in the basin. Monthly and annual SAF curves and maps of probability of drought occurrence have been produced. The results indicated localized severe droughts in higher frequencies compared to moderate to severe low frequency droughts spread over wider areas in the basin. This investigation also revealed that the western part of the basin will face a higher risk of drought when compared to other regions of the Limpopo Basin in terms of medium-term
All	Limpopo basin	A 0.050 × 0.050 resolution PCRaster Global Water Balance (PCRGLOBWB) model has been used to analyze hydrological droughts in the Limpopo River basin in the period 1979–2010 with a view to identifying severe droughts that have occurred in the basin using hydrological and meteorological drought indicators. The indicators considered were able to represent the most severe droughts in the basin and to some extent identify the spatial variability of droughts. Results also show the importance of computing indicators that can be related to hydrological droughts, and how these add value to the identification of hydrological droughts and floods and the temporal evolution of events that would otherwise not have been apparent when considering only meteorological indicators. The study has also characterized drought severity in the basin, indicated by its time of occurrence, duration and intensity
Competing Water Uses		

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR FINDINGS
Letaba, Lower Limpopo and Shingwedzi	Lower Limpopo basin	An analysis is carried out to verify whether the water resources of the Limpopo basin are sufficient for the planned irrigation developments in the Mozambique part of the basin, namely 73 000 ha, in addition to existing irrigation (estimated at 9 400 ha), and natural growth of common use irrigation (4 000 ha). The study finds that total additional water requirements may amount to 1.3 x10^9 m^3/a or more. A river basin simulation model has assessed different irrigation development scenarios, and at two storage capacities of the Massingir dam. The model shows that all planned irrigation is not feasible but a maximum of approx. 58 000 ha can be sustained assuming that Massingir will be operated at increased reservoir capacity. This is about 60% of the envisaged developments. Any additional water use would impact downstream users and create
All	Limpopo river basin	An analysis of hydrological, climatic, ecological, socio-economic and governance systems of the basin indicates that its institutional arrangement is neither simple nor effective. The basin is found to be rapidly approaching closure and if proposed ecological flow requirements for all tributaries were to be met, the basin would be closed. Land use changes, water resources developments in the upper part of the basin coupled with projected rainfall reductions and temperature increases may further decrease downstream river flows. The increase in temperature and decrease in rainfall may especially affect poorer communities who rely on rain fed agriculture. Increased temperatures may increase evapotranspiration from reservoirs resulting in a decrease in water availability. This may result in increased abstraction of groundwater, especially from alluvial aquifers, and consequently an increase in river transmission losses and a further decrease

TABLE 6.2 SUMMARISING HYDROLOGICAL ASPECTS RELATED TO ENVIRONMENTAL FLOWS BY RISK REGION BASED ON PUBLISHED LITERATURE

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR FINDINGS
Climate Change		

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR FINDINGS
All	Limpopo river basin	The effects of climate change on water availability and use (especially for irrigation) is analysed, using a global hydrological model and the Water Simulation Module (WSM) of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). The analysis finds that while water resources of the Limpopo River Basin are already stressed under current (1971-2000) climate conditions, projected water infrastructure and management interventions are expected to improve the situation by 2050 if current climate conditions continue into the future. However, under SRES A1B scenario, water supply availability is expected to worsen considerably by 2050. Given that expansion of irrigated areas has been suggested as a key adaptation strategy for Sub-Saharan Africa, such expansion will need to carefully consider future changes in water availability in African river basins (Zhu and Ringler, 2012).
Marico Crocodile and a part of Upper Limpopo	Crocodile, Marico, Mahalapse, Lotsane	The effect of regional climate on river flow in the upper Limpopo Valley (21–24.5S, 26–30E) is demonstrated. The study finds that the annual cycle of gains from precipitation spikes upward in late summer (Jan–Mar), while losses from evaporation have a broad peak in early summer (Oct–Dec). Different formulations of the surface water balance yield a range of values from −0.21 to −1.69 mm/day, depending on how evaporation is quantified. The study also finds that there is little trend in Limpopo River flow during the period 1959–2014; however, Coupled Model Intercomparison Project Phase 5 (CMIP5) model projections exhibit a
All	Limpopo river basin	Annual and seasonal variations of rainfall and temperature in time and space from 1979 to 2013 is analysed. Annual means of rainfall varied between 160 and 1109 mm, from west to east of the basin during the study period. Annual minimum and maximum temperature ranged from 8◦C in the south to 20◦C in the east of the basin, and 23◦C in the south of the basin to 32◦C in the east. Annual rainfall showed higher CV values (28% to 70% from east to west of the basin) than annual temperature.
		Upward trends for both annual and seasonal rainfall are revealed in most parts of the basin except for the winter season which shows a decreasing trend. Minimum temperature on an annual basis and for the winter and spring seasons has shown an increasing trend while it has shown a decreasing trend for the summer and autumn seasons. Maximum temperature has shown a decreasing trend on an annual, summer, autumn and spring basis but an increasing trend for winter (Mosase and

RISK REGION	MAJOR RIVER AND LOCATION	MAJOR FINDINGS
All	Limpopo river basin	In the last few decades, the Limpopo has experienced a number of extreme rainfall events which have created considerable socio-economic and environmental impacts especially among those dependent on rain-fed agriculture. CHIRPS, 0.05° gridded rainfall data have been used to identify and analyse daily extreme events over the 1981–2016 period. Analysis of the top 20 events have suggested a pattern with rainfall generally decreasing from the eastern to western parts of the basin. The highest rainfall amounts are observed to occur over the regions where there are steep topographical gradients between the mountainous regions of north-eastern South Africa and the Mozambican flood plains. The monthly distribution of the extreme events has shown that most of the events occurred during the late summer months (January–March). On inter-annual time-scales, most of the summers with above average number of events have coincided with La Niña conditions and, to a lesser extent, a positive subtropical South Indian Ocean Dipole (Rapolaki et al. 2019).
Shashe and a part of Middle Limpopo	Shashe and Mzingwane (Umzingwani)	Trends in various parameters of temperature (4 stations), rainfall (10 stations) and discharge (16 stations) from the Shashe and Mzingwane basins have been statistically analysed. It has been determined that rainfall and discharge in the study area have undergone a notable decline since 1980, in terms of the total annual water resources (declines in annual rainfall, annual unit runoff) and the temporal availability of water (declines in number of rainy days, increases in dry spells, increases in days without flow). The main rising risk is identified as an increasing number of dry spells (which is likely to decrease crop yields), and an increasing probability of annual discharge below the long-term average (which could limit water availability). Increasing food shortages are identified as likely consequence of the impact of declining water resource availability on rain-fed and irrigated agriculture. Further, stresses on urban water supplies, especially to Zimbabwe's second-largest city of Bulawayo, which already experiences chronic water shortages, are also predicted (Love et al. 2010).

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8. ANNEXURE

Attached to this report are South African Government notices that describe the management classes and resource quality objectives for some of the tributaries of the Limpopo River. Note that not all tributaries have such information available.

GOVERNMENT NOTICES DEPARTMENT OF WATER AND SANITATION. No. 1617.

30 December 2016 National Water Act, 1998 (Act No.36 Of 1998) Classes of Water Resources and Resource Quality Objectives for the Letaba Catchment

GOVERNMENT NOTICES DEPARTMENT OF WATER AND SANITATION. No. 466

22 April 2016 National Water Act, 1998 (Act No.36 Of 1998) Classes and Resource Quality Objectives of Water Resources for the Olifants Catchment.

GOVERNMENT NOTICES DEPARTMENT OF WATER AND SANITATION. NO. 1388. National Water Act, 1998 (Act No.36 Of 1998) Proposed Classes of Water Resource and Resource Quality Objectives for Mokolo, Matlabas, Crocodile (West) And Marico Catchments.

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