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# Limpopo River Basin Monograph

Sergio Sitoe

Peter Qwist-Hoffman

# Limpopo River Basin Monograph

## (LRBMS-81137945)

## Final Monograph

**Supported by:**

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# CONSULTANCY SERVICES FOR THE PROJECT ON THE LIMPOPO RIVER BASIN MONOGRAPH

*Prepared by:* Aurecon AMEI (Pty) Ltd

***Prepared for:*** **LIMCOM with the support of GIZ**

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**CONSULTANCY SERVICES FOR THE PROJECT ON THE LIMPOPO RIVER BASIN MONOGRAPH**

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Enoch Dlamini: Study Leader (Date)

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Johnny Beumer: Study Manager (Date)

.................................... 18th December 2013

Andrew Tanner: Reviewer (Date)

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**DEUTSCHE GESELLSCHAFT FÜR GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT (GIZ) GmbH**

for

**LIMPOPO RIVER BASIN MONOGRAPH STUDY**

.................................... 18 December 2013.

Sergio Sitoe: Project Manager (LIMCOM) (Date)

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Peter Qwist-Hoffmann: Task Manager (GIZ) (Date)

## CONSULTANCY SERVICES FOR THE PROJECT ON THE LIMPOPO RIVER BASIN MONOGRAPH

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E Dlamini
Aurecon (Pty) Ltd
RSA: Tel: +27 12 427-3111 – Fax: +27 86 764 3505
Enoch.dlamini@aurecongroup.com

## LIST OF REPORTS

| Title | Aurecon Report No. |
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| Inception Report | 6208 |
| Progress Report #1 | 6335 |
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| EWR Training Report | 6642 |
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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADCP | Acoustic Doppler Current Profiler |
| ADMP | Agricultural Drought Management Plan |
| AMD | Acid Mine Drainage |
| ARA | Administração Regional de Águas |
| AV | Aquatic Vegetation |
| BCWIS | Botswana Core Welfare Indicator Survey |
| BOBS | Botswana Bureau of Standards |
| CCs | Catchment Councils |
| CMA/s | Catchment Management Agency/cies |
| DCs | District Councils |
| DGS | Department of Geological Surveys |
| DO | Dissolved Oxygen |
| DWA – Botswana | Department of Water Affairs Botswana |
| DWA – SA | Department of Water Affairs South Africa |
| DWAF | Department of Water Affairs and Forestry |
| EFA | Environmental Flow Assessment |
| EFs | Environmental Flows |
| EHI | Estuarine Health Index |
| EIS | Estuarine Importance Scores |
| EMP | Environment Management Plans |
| EWR | Environmental Water Requirement |
| EWRs | Environmental Water Requirements |
| FRAI | Fish Response Assessment Index |
| GCMs | General Circulation Models |
| GDP | Gross Domestic Product |
| GIS | Geographic Information System |
| GLWD | Global Lakes and Wetlands Database |
| GPA | Global Political Agreement |
| GRI | Gabinete de Rios Internacionais |
| GRIP | Groundwater Resources Information Project |
| HDI | Human Development Index |
| ICM | Integrated Committee of Ministers |
| IDP | Industrial Development policy |
| IEP | Integrated Energy Planning |
| IFSS | Integrated Food Security Strategy |
| IWRM Plan | Integrated Water Resources Management Plan |
| JULBS | Joint Upper Limpopo Basin Study |
| LBPTC | Limpopo Basin Permanent Technical Committee |
| LCMA | Limpopo Catchment Management Agency |
| LEAP | Local Environment Action Plan |
| LIMCOM | Limpopo Basin Commission |
| LIMIS | Limpopo River Basin Management Information System |
| LRB | Limpopo River Basin |

| | |
|---|---|
| LRBMS | Limpopo River Basin Monograph Study |
| MAE | Mean Annual Evaporation |
| MAP | Mean Annual Precipitation |
| MAR | Mean Annual Runoff |
| masl | Meters above sea level |
| MIRAI | Macro-Invertebrate Response Assessment Index |
| MIS | Management Information System |
| MLG | Ministry of Local Government |
| MLGL | Ministry of Local Government and Lands |
| MMEWA | Ministry of Minerals, Energy and Water Affairs |
| MPB | Microphytobenthos |
| MSL | Mean Sea Level |
| MTP | Medium Term Plan |
| NDMO | National Disaster Management Office |
| NDPs | National Development Plans |
| NDRMP | National Disaster Risk Management Plan |
| NEAP | National Environment Action Plan |
| NERSA | National Energy Regulator of South Africa |
| NFEPA | National Freshwater Ecosystem Priority Area |
| NIPF | National Industrial Policy Framework |
| NIPS | National Irrigation Policy and its Implementation Strategy |
| NTU | Nephelometric Turbidity Units |
| NWA | National Water Act |
| NWRS | National Water Resource Strategy |
| OV | Overhanging Vegetation |
| PARP | Poverty Reduction Action Plan (Plano de Acçãopara a Redução da Pobreza) |
| PES | Present Ecological State |
| PID | Participatory Innovation Development |
| POM | Particulate Organic Matter |
| PPP | Purchasing Power Parity |
| RAK | Limpopo River Awareness Kit |
| RSAP III | Regional Strategic Action Plan |
| RWA | Regional Water Authorities |
| RWPS | Regional Water Policy and Strategy |
| S | Substrate |
| SADC | Southern African Development Community |
| SAM | Social Accounting Matrix |
| SAPP | Southern African Power Pool |
| SASS5 | South African Scoring System |
| SCCs | Sub-basin Councils |
| SIC | Standard Industrial Classification |
| TBAs | Transboundary Aquifers |
| TFCAs | Transfrontier Conservation Areas |
| TSC | Technical Steering Committee |
| TWC | Technical Water Council |
| UB | Undercut Banks |

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|---|---|
| USGS | United States Geological Survey |
| WAB | Water Apportionment Board |
| WC | Water Column |
| WIM | Water Impact Model |
| WMA | Water Management Areas |
| WRC | Water Research Commission |
| WRIMS | Water Resource Information Management System |
| WRSM 2005 | Water Resource Simulation Model |
| WSP | Water Services Provider |
| WUA | Water User Association |
| WUC | Water Utilities Corporation |
| WWTWs | Waste Water Treatment Works |
| ZDHS | Zimbabwe Demographic and Health Survey |
| ZINWA Act | Zimbabwe National Water Authority Act |

## GLOSSARY OF TERMS

| | |
|---|---|
| Allocatable Water | Water available to allocate for consumptive use |
| AMD | Acid mine drainage is formed when sulphide minerals in the geological strata, are exposed through mining activities and interact with oxygen and water to form a dilute solution of sulphuric acid and iron that leaches other metals from the material in which it forms. Acid mine drainage in the Witwatersrand typically has a pH value around 3 and is enriched in sulphate, iron and a number of metals, often including uranium. |
| Annexure | Documents produced by others attached to the report. |
| Appendix | Documents produced by the Feasib ility Study attached to the report. |
| Aquifer | Zone below the surface capable of holding groundwater. |
| Anthropogenic | Having to do with people, or caused by humans |
| Biodiversity | The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems |
| Benthic invertebrates | Invertebrate organisms living in or on sediments of aquatic habitats and typically retained by a 500 micron sieve. |
| Catchment | In relation to a watercourse or watercourses or part of a watercourse, this term means the area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points |
| Community | Assemblage of organisms characterised by a distinctive combination of species that occupy a common environment and interact with one another |
| Community composition | All taxa, plants and animals, present in a community |
| Cumulative impact | Impact on the environment which results from the incremental or combined effects of one or more developmental activities in a specified area over a particular time period, which may occur simultaneously, sequentially, or in an interactive manner. |
| Decant (surface) | Spontaneous surface discharge of water from underground mine workings. |
| Difuse Irrigators | Irrigators who are not scheduled under any one of the Irrigation Boards or Water User Associations and who take their water directly from a river, i.e. from the run-of-river flows or from a farm dam in that particular river. |
| Dilution | The reduction in concentration of a substance due to mixing with water |
| Environmental Water | The quantity, quality and seasonal patterns of water needed to maintain aquatic |

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| Requirements | Ecosystems within a particular ecological condition (management category), excluding operational and management considerations. |
| Eutrophic | Ecology lacking oxygen: used to describe a body of water whose oxygen content is depleted by organic nutrients (eutrophication). |
| Feasibility Study | An analysis and evaluation of a proposed project to determine if it is technically sound, socially acceptable, and economically and environmentally sustainable. |
| Fractured rock aquifer | A water-bearing rock mass (aquifer) in which the open spaces that accommodate the water are the result of cracks in the rock. |
| GIS | This abbreviation stands for Geographic Information System. GIS is a combination of computer software and hardware tools used for creating maps and analyzing spatial data. GIS links the map and database information so that questions can be asked and answers given in map or visual form. |
| Groundwater | Water occupying openings below surface |
| Habitat | The natural home of an organism or community of organisms (this also includes the surrounding area) |
| Integrated Water | The objectives and priorities for water resource management, for a given time |
| Water Resource | frame, which have been agreed by the parties as those which will best support the |
| Management (IWRM) Objectives | agreed socio economic development plans for the basin |
| Intertidal | Area of the shore between the highest and lowest tides. |
| Invasive species | A species that does not naturally occur in a specific area and whose introduction does or is likely to cause economic or environmental harm or harm to human health. |
| IWRM Plans | A set of agreed activities with expected outcomes, time frames, responsibilities and resource requirements that underpin the objectives of IWRM. |
| Key Stakeholder | Defined as directly affected parties, those who have a high level of negative or positive influence (in government and civil society domains, and on the direction and success of AMD long-term initiatives) and those whose input is critical to the study (for e.g., representatives of various National, Provincial, and Local Government, NGOs, organised business, mining, industry, labour, agriculture, affected mines, affected water utilities, community leaders, academics, etc.). |
| Level of Assurance | The probability that water will be supplied without any curtailments. The opposite of Level of Assurance is the risk of failure. |
| Reserve (only a South African term) | The quantity and quality of water required to satisfy basic human needs and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource - or more detailed:<br>Consists of two parts – the basic human needs Reserve and the ecological Reserve. The basic human needs Reserve provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene. The ecological Reserve relates to the water |

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|---|---|
| | required to protect the aquatic ecosystems. The Reserve refers to both the quantity and quality of the water in the resource, and will vary depending on the class of the resource. |
| Runoff | Runoff is the water yield from an individual catchment – the sub-basin plus the runoff from all upstream sub-basins. Runoff includes any seepage, environmental flow releases and overflows from the reservoirs in a catchment, if they are present - which is not the case in any of the simulations in this project in which baseline catchment conditions are assumed. |
| Storm water run-off | Storm water run-off from paved areas, including parking lots, streets, residential subdivisions, of buildings, roofs, highways, etc. |
| Sub-tidal | The area of the estuary bottom that is always covered by water and is never exposed at low tides |
| Wastewater | Water containing solid, suspended or dissolved material (including sediment) in such volumes, composition or manner that, if spilled or deposited in the natural environment, will cause, or is reasonably likely to cause, a negative impact |

# EXECUTIVE SUMMARY

## PURPOSE AND PROCESS

### Background to the Study

*The Limpopo River Basin is shared by four SADC Member States, i.e. Botswana, Moçambique, South Africa and Zimbabwe and has a total catchment area of approximately 411 000 km$^2$. The catchment characteristics are very diverse, covering different climatic and topographic zones, as well as land use types, including protected areas. The social and economic developments across the basin are also highly diverse.* ***Figure E1*** *shows the Limpopo River Basin and what parts of the four countries fall within the boundaries of the basin.*

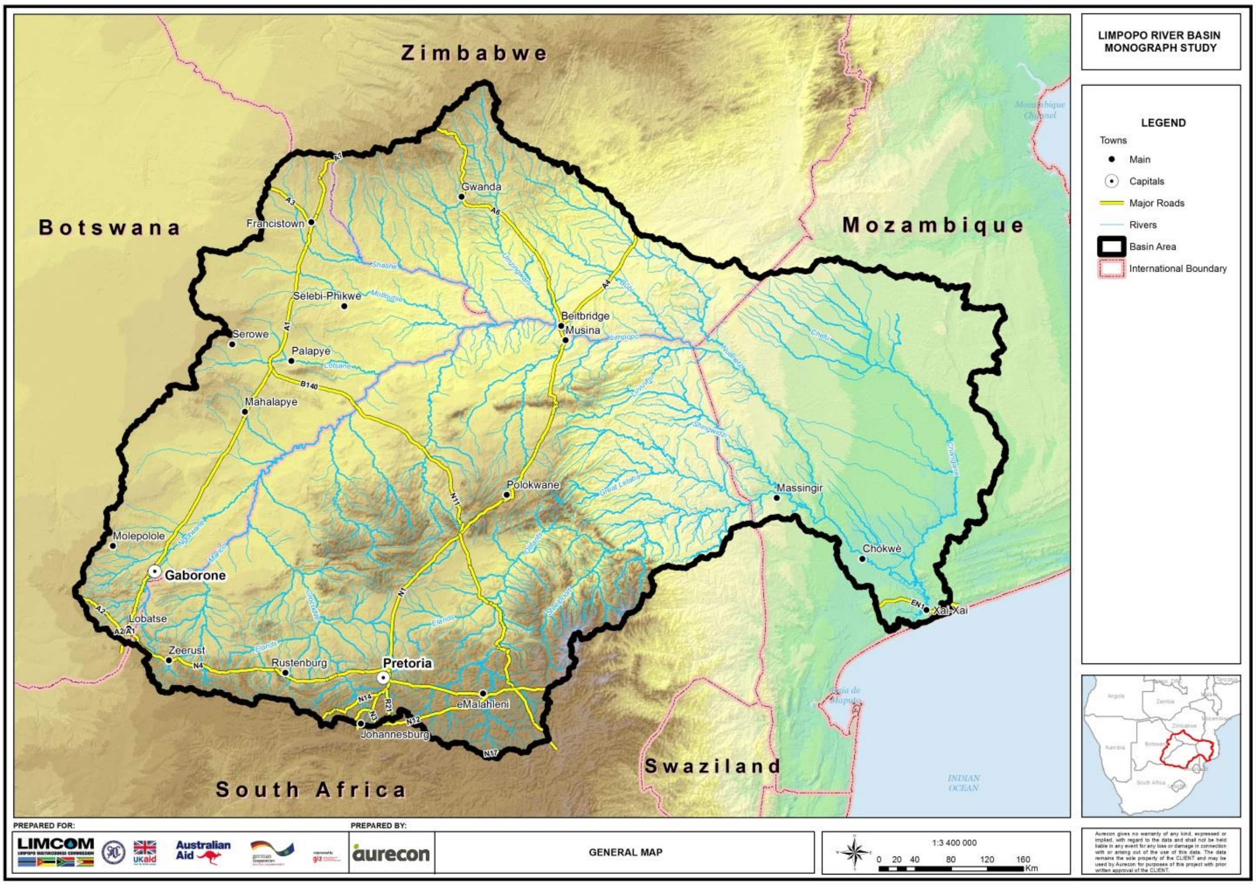



***Figure E1:*** *The Limpopo River Basin and the Country Boundaries*

*The purpose of the Limpopo River Basin Monograph Study (LRBMS) is to compile essential baseline information on the Limpopo River Basin. This is required for the preparation of alternative development scenarios and an Integrated Water Resources Management Strategy and Plan (IWRM Strategy and Plan) for the sustainable management of the Basin.*

*Six themes were agreed for the structure of the monograph and each is described below:*

- *Basin Characteristics*
- *Socio-economy*
- *River Basin Ecosystem*
- *Water Resources*

- *Water Governance, and*
- *LIMIS*

*There are two main elements of the monograph that are the core outputs of the study and they bring together the information from the six themes. The first element is the development of the Limpopo River Basin Information System (LIMIS). This comprises a GIS-based information management system that has been and will continue to be used to capture, analyse and manage all the relevant data for the Limpopo River Basin. The LIMIS is a long-term information management tool that will also be used to monitor the long-term impacts of development and management initiatives on the water resources of the Limpopo River Basin. The second key element is the Water Balance model for the Limpopo River Basin. The Water Balance will indicate where water shortages exist and where interventions are necessary to reconcile water requirements with water availability. The development of the Water Balance for the Limpopo has taken into account all the current water uses (surface and ground water) in the basin under current basin development conditions and management scenarios. It also takes into consideration the water availability, after providing for ecological water requirements and the possible impacts of climate change.*

## *Basin Characteristics*

### *Physical and Climatic Characteristics*

*An overview of the physical and climatic characteristics of the LRB is presented in Chapter 2 and summarised here.*

***Topography:***

*Altitude varies from approximately 2 400 metres above sea level (masl) in the Highveld in South Africa to less than 200 masl for large parts of Moçambique.*

***River Network:***

*The relative scarcity of river channels in the western portion of the study area indicates the arid conditions characteristic of Botswana. 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 Umzingwane River in Zimbabwe. There is only a single tributary in Moçambique, the Changane River which contributes only a small percentage of runoff to the Limpopo River due to the flat nature of the topography in Moçambique. This tributary has significant wetlands associated with it.*

***Estuary:***

*The Limpopo River drains into the sea near Xai-Xai in Moçambique and the estuary that is formed stretches from the coastline approximately 35 km inland.Geology:*

*The geology of northern Sub-Basins in Zimbabwe is dominated by granites – the origin of the Matopos Hills. The geology of the South African portions of the LRB is more variable but granites are also wide-spread, along with sandstones. To the west, in Botswana, unconsolidated and consolidated sands and gravels are predominant. The lithology of the eastern Sub-Basins in Moçambique comprises mainly unconsolidated sands and gravels as well as silt, mud and clay.*

*Soil types in Moçambique, are predominantly Solonetz soils, in Zimbabwe the Luvisol soils and in Botswana soil types are dominated by Arenosols. Soil types in South Africa vary immensely.*

***Climate:***

*Temperature is closely correlated with topography in the LRB. Higher temperatures occur in the low lying Moçambique and along the main stem of the Limpopo River. The highest daily mean temperatures vary from 20ºC in winter and 30ºC in summer.*

*Mean annual rainfall in the Botswana part of the basin is relatively low and varies from 200 mm/a at the point where the Botswana, South Africa and Zimbabwe boundaries join to 400 mm/a further west. In South Africa the MAR increases in a southerly direction from the main stem and varies from 200 mm/a in the vicinity of Beitbridge to >1000 mm/a. In Zimbabwe the rainfall is lower towards the main stem of the Limpopo River but also increases towards the higher lying areas, i.e. towards the north, where it is in the order of 800 mm/a. The northern parts of Moçambique receives approximately 400 mm/a but the MAR increases towards the coast, i.e. Xai-Xai where it tends towards 1000 mm/a.*

*Evaporation is very high between varying from 1800 -2600 mm/a in Moçambique, Zimbabwe and Botswana. In South Africa the evaporation is similar along the main stem of the Limpopo River, but decreases in a southerly direction to approximately 1300 mm/a in the Highveld.*

***Land cover and land use:***

*The dominant land cover is Grassland-cropland mosaic and Savannah. Land uses are rain-fed and irrigated cropland, mining and forestry (only in South Africa). A major portion of the basin is used for national and trans-frontier parks.*

### *Sub-Basin Delineation*

***Figure E2*** *shows the delineation of the Sub-Basins of the LRB. The Sub-Basins were provisionally delimited by application of the Arc-Hydro utility in ESRI's ARCGIS software and then refined by detailed visual inspection of contoured topographic maps. The Sub-Basins are used in the hydrological modelling and water balance components of the Study, as well as for spatial organisation of all information reported under the LRBMS and populated in LIMIS.*

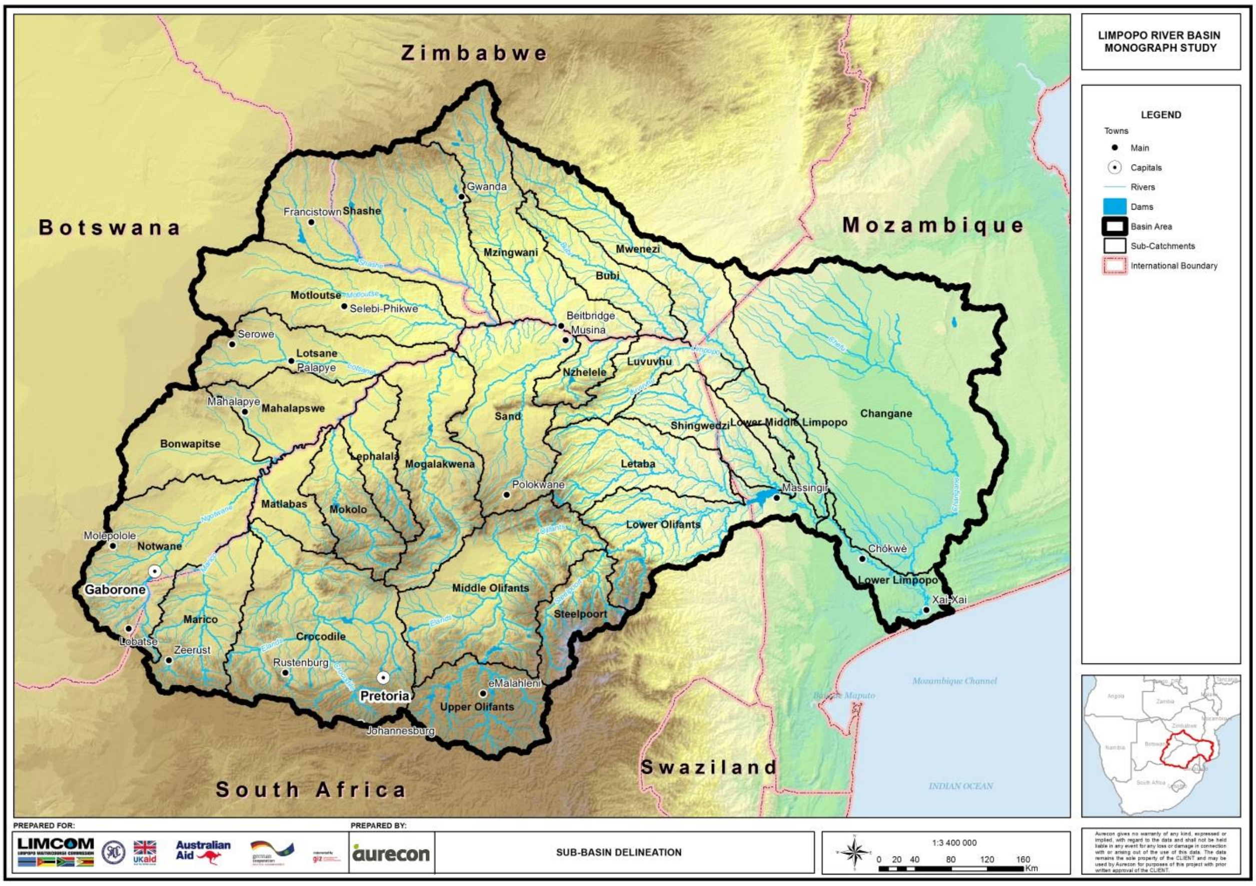



*Figure E2: Delineation of the Sub-basins in the Limpopo River Basin*

### *Infrastructure*

*Major infrastructure that impacts the water resources of the basin are large dams, power stations and water transfer schemes. **Table E1** provides an overview of the infrastructure numbers in the four countries.*

*Table E1: Existing infrastructure in the four countries (including infrastructure planned or under construction)*

| *Type of Infrastructure* | *Botswana* | *Moçambique* | *South Africa* | *Zimbabwe* | *Total* |
|---|---|---|---|---|---|
| *Large Dams** | *10* | *2* | *57* | *28* | *97* |
| *Power Stations (Thermal)* | *1* | | *11* | | *12* |
| *Power Stations (Hydro)* | | | | | *-* |
| *Water Transfer Schemes (Inter-basin)* | | | *5* | *1* | *6* |
| *Water Transfer Schemes (Intra-basin)* | *1* | | *9* | | *10* |

** "Large" in terms of the International Commission on Large Dams (ICOLD) definition*

*The total water storage volume of all the dams is approximately 7528 million m$^3$.*

*Water use by power stations is regarded as a strategic water use for the countries. There are currently 12 thermal power stations in the basin, 11 of them located in South Africa and one on Botswana with a total water use of 226 million $m^3$/a..*

*The Medupi and Kusile thermal power stations in respectively the Mokolo and Upper Olifants Sub-basins are currently under construction and will increase the water requirement by 30 million $m^3$/a. Further thermal power stations are planned for Botswana and South Africa. Hydro power stations are also envisaged at the Massingir Dam in Moçambique and Manyuchi Dam in Zimbabwe.*

*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. A quantity of 60 $m^3$/a is transferred out of the basin from a number of dams in the LRB for water supply to the City of Bulawayo.*

## SOCIO-ECONOMIC PROFILE

*Socio-economic and population information is critical for integrated water resources management. It provides vital data on peoples' livelihoods and dependence on water including their vulnerability to famines, droughts and floods as well as the linkages between water and poverty. The data provides a foundation for the macro socio-economy study of the river basin. Water is a key input to the economy of the Limpopo River Basin. It is used for domestic, industrial, mining, agriculture (livestock and irrigation), forestry and for power generation purposes.*

### Demography

*The Limpopo River Basin comprises a population estimated at about 18 million inhabitants (2012). Gaborone and Pretoria, the capital cities of Botswana and South Africa, respectively are situated in the Limpopo River Basin. Francistown, the second largest city in Botswana, is located in the Limpopo River Basin. Bulawayo, the second largest city in Zimbabwe, is situated just outside the Limpopo Basin but relies on water from the Limpopo River Basin. Two of South Africa's largest metropolitan areas of Tshwane and Johannesburg are also situated in the basin as well as the mining towns of Emalahleni, Rustenburg and the Provincial Capital of the Limpopo Province, Polokwane. In Moçambique the town of Xai-Xai and the village of Chokwe are both situated in the basin. With an increase in urban migration and increase in mining activities, water demand will increase.*

*The population estimates were computed by proportionally distributing the published district population from the census figures over the part of the basin that falls in the Limpopo Basin in that country. Where the censi for the riparian countries were taken at different periods, it necessitated projections to bring the basin population to the same base year (2012).*

*The estimated basin population in 2012 for the Limpopo are shown in **Table E2.***

***Table E2:** Limpopo Population by Country*

| Country | Population |
|---|---|
| Botswana | 1 197 314 |
| Moçambique | 1 109 481 |
| South Africa | 15 078 510 |
| Zimbabwe | 831 747 |
| Basin Total | 18 217 052 |

*The largest population in the Limpopo basin is found in South Africa, largely in the two largest metropolitan areas, Johannesburg and Pretoria as well as the mining areas around Rustenburg and Emalahleni. Zimbabwe is the country with the least population in the basin. In Botswana approximately 60% of the entire population of the country reside in the Limpopo Basin, since the country's population is concentrated in the South and South-Eastern part of the country. Moçambique also has a sizable proportion of its population in the Limpopo basin mainly concentrated along the coastal areas of Xai-Xai and the village of Chockwe.*

*The age distribution of the population of the four basin states is typical of the age population distribution of developing countries. The youth and children (ages below 25) comprise the largest age group (over 80%). With the exception of South Africa, most of the Limpopo population resides in rural areas as shown in **Table E3** below.*

***Table E3 Urban:** Rural Population split*

| Country | Urban Population (%) | Rural Population (%) |
|---|---|---|
| Botswana | 34 | 66 |
| Moçambique | 15 | 85 |
| South Africa | 57 | 43 |
| Zimbabwe | 15 | 85 |

*The population projections given below are based on population growth rates published in the United Nations Secretariat's World Population Prospects projections at a national level. Population projections are presented in **Table E4** from 2012 to 2040 at 5 year intervals.*

***Table E4:** Population growth rates for Limpopo Riparian States used for the Limpopo Basin*

| Intervals | 2010 – 2015 (%) | 2015 – 2020 (%) | 2020 - 2025 (%) | 2025 – 2030 (%) | 2030- 2035 (%) | 2035 – 2040 (%) |
|---|---|---|---|---|---|---|
| Botswana | 1.09 | 0.98 | 0.90 | 0.52 | 0.41 | 0.35 |
| South Africa | 0.51 | 0.43 | 0.44 | 0.35 | 0.27 | 0.20 |
| Moçambique | 2.23 | 2.18 | 2.11 | 2.03 | 1.88 | 1.72 |
| Zimbabwe | 2.15 | 2.09 | 1.39 | 1.12 | 0.93 | 0.82 |

*Source: 2010 United Nations Secretariat's World Population Prospects, U.N. population projections, 2010 to 2040*

*The population as reflected in **Table E5** of the Limpopo Basin is expected to be over 20 million inhabitants by 2040. Socio-economic factors could alter this trend especially if the mining and agricultural and other natural resources of the Limpopo Basin are fully exploited. The population could also increase more through urbanisation especially in South Africa and Botswana.*

***Table E5:** Limpopo Basin Population Projections*

| Intervals | 2012 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| *Botswana* | 1 197 314 | 1 210 365 | 1 222 226 | 1 233 226 | 1 239 639 | 1 244 722 | 1 249 078 |
| *Moçambique* | 1 109 481 | 1 115 139 | 1 119 934 | 1 124 862 | 1 128 799 | 1 131 847 | 1 134 111 |
| *South Africa* | 15 078 510 | 15 414 761 | 15 750 803 | 16 083 144 | 16 409 632 | 16 718 133 | 17 005 685 |
| *Zimbabwe* | 831 747 | 849 630 | 867 387 | 879 443 | 889 293 | 897 564 | 904 924 |
| ***TOTAL*** | **18 217 052** | **18 589 894** | **18 960 350** | **19 320 676** | **19 667 364** | **19 992 266** | **20 293 798** |

## *Human Development Indicators*

*The Human Development Indicator or Index (HDI) is a tool developed by the United Nations to measure and rank countries' levels of social and economic development based on four criteria: Life expectancy at birth, mean years of schooling, expected years of schooling and gross national income per capita. The HDI makes it possible to track changes in development levels over time and to compare development levels in different countries. Water availability and quality has a great influence on human development. In this monograph four human development indicators that can be linked to water have been selected. These indicators have been summarised based on information readily available from reports published in the four member states. The indicators selected are also an indirect measure of other impacts such as malaria and waterborne diseases.*

*Four Human Development Indicators were selected for the monograph. These are summarised below.*

| | | |
|---|---|---|
| ***HIV Prevalence*** | - | *Percentage of people between the ages of 15 and 49 infected with HIV (based on antenatal surveys)* |
| ***Poverty Ratio (P0)*** | - | *Poverty Headcount based on the World Bank poverty threshold of people living on less than $1.25 a day, measured at 2005 international prices, and adjusted for purchasing power parity (PPP)* |
| ***Life Expectancy*** | - | *Indicator of the number of years new born infants will live under prevailing conditions* |
| ***Infant Mortality*** | - | *Number of children who die before the age of 5 years per 1000 live births* |

*The results of these human development indicators are shown in **Table E6** where N = the National Average..*

***Table E6:*** *Human Development Indicators for Limpopo Basin States*

| ***Indicator*** | ***Botswana*** | ***Moçambique*** | ***South Africa*** | ***Zimbabwe*** |
|---|---|---|---|---|
| ***HIV Prevalence*** | *18% (2008)*<br>*N = 23%* | *26% (2010)*<br>*N = 11.5%* | *11% (2008)*<br>*N = 28%* | *21% (2011)*<br>*N = 15%* |
| ***Poverty Ratio*** | *22% (2010)*<br>*N = 20.7%* | *60% (2008)*<br>*N = 54.7%* | *30% (2008)*<br>*N = 26.3%* | *72% (2003)*<br>*N = 72%* |
| ***Life Expectancy (National Figures - 2010)*** | | | | |
| ***Male*** | *54 years* | *49 years* | *53 years* | *49 years* |
| ***Female*** | *52 years* | *51 years* | *43 years* | *49 years* |
| ***Infant Mortality (National Figures - 2010)*** | | | | |
| ***Under 5 years per 1 000 live births*** | *48 children* | *135 children* | *57 children* | *80 children* |

*The results of the human development indicators show that the Limpopo portions of the Member States carry a proportionally larger burden of poverty and HIV Aids prevalence compared to the national averages. There were no figures specific to the Limpopo region regarding life expectancy and infant mortality so national figures are shown. Water can be used to improve the lives of the people in the LRB which has an abundance of natural resources (mining and agriculture). No information was available on vulnerabilities and dependency on water. However, climate change leading to more frequent floods and droughts is seen as a major threat in the Limpopo. The Resilience in the Limpopo Basin (RESILIM) study is gathering and analysing information on climate change and vulnerabilities in the Limpopo. Rural communities remain the most vulnerable because they do not have sufficient coping mechanisms including insurances to cushion them against the threats of floods and droughts.*

***Migration Patterns***

*There are no specific figures on migration specific to the Limpopo Basin. Political and civil war in South Africa (1980s), Moçambique (1970s) and recently in Zimbabwe (2000s) saw a number of people migrating to neighbouring countries and safer parts of the same country. For many years the economic boom I Johannesburg as a result of the "gold rush" and lately the platinum discovery in the Limpopo and North West saw a number of economic migrants moving to those areas in search of employment. Botswana has also seen similar migration after the discovery of diamonds. Droughts have resulted in a number of people from the rural areas of Moçambique and Zimbabwe moving to urban centres in search of food after a series of crop failures.*

***Vulnerability & Dependency on Water***

*No information was available on vulnerabilities and dependency on water. However, climate change leading to frequent floods and droughts is seen as a major threat in the Limpopo. The Resillience in the Limpopo (RESILIM) study is gathering and analysing information on climate change and vulnerabilities in the Limpopo. Rurual communities remain the most vulnerable because they do not have sufficient coping mechanisms including insurances to cushion them against the threats of floods and droughts.*

## *Economic Profile*

*The economic profile in the Limpopo Basin consists of a number of different economic activities. In order to determine what impact water use has for the specific sector, two options are available, i.e. it can be expressed as total macro-economic parameters or also expressed in multipliers of which the impact of the value of water can be determined and possible changes over time can be estimated.*

*The impacts of the following economic activities have been assessed:*

- *Irrigation Agriculture*
- *Commercial Forestry*
- *Mining*
- *Power Generation*
- *Industry*
- *Eco-Tourism*

*The estimates of economic water parameters per water use sector for the entire Limpopo Basin are shown in **Table E7.***

***Table E7:*** *Economic Indicators per Water Use Sector*

| | GDP (US$ Mil) | | | Employment (Numbers) | | | Household Income (US$ Mil) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Direct | Indirect And Induced | Total | Direct | Indirect And Induced | Total | Total | Medium | Low |
| Irrigation | 1 742.8 | 2 120.5 | 3 863.4 | 251 194 | 153 423 | 406 618 | 2 291.7 | 1 197.5 | 1 094.2 |
| Commercial Forestry | 56.8 | 49.1 | 106.0 | 6 866 | 3 921 | 10 787 | 44.7 | 13.5 | 31.2 |
| Mining | 22 440.3 | 20 520.3 | 42 960.5 | 359 806 | 882 573 | 1 242 379 | 18 443.5 | 2 800.4 | 15 643.2 |
| Power Generation | 3 979.6 | 2 542.8 | 6 522.4 | 9 955 | 151 825 | 161 780 | 2 451.8 | 536.8 | 1 915.0 |
| Industry | 4 557.8 | 7 196.2 | 11 754.0 | 25 245 | 85  800 | 111 045 | 6 425.5 | 1 571.7 | 4 853.8 |
| Eco-Tourism | 158.1 | 139.2 | 297.3 | 9 137 | 9 187 | 18 325 | 122.8 | 36.8 | 86.0 |
| **Total** | **32 935.4** | **32 568.1** | **65 503.6** | **662 204** | **1 286 730** | **1 948 934** | **29 780.0** | **6 156.7** | **23 623.4** |

*The table indicates that mining provides the most direct jobs; namely 359 806 with 882 573 indirect and induced number, and a total of 1 242 379. At four household members per employment opportunity, mining sector supports about 5 million individuals. Also emphasising the importance of the mining sector is the U$ 15 643 million annually paid to low income households (42% of the total paid out in salaries and wages) and it generates US$ 43 million of the total US$ 65.5 billion GDP.*

*The irrigation agriculture sector is the second largest employment provider with 251 194 direct and an estimated total of 404 618 employment opportunities.*

*In total water based activities supports about 1.95 million employment opportunities, the total payment to households is US$ 29.8 billion and creates US$ 65 5 billion of GDP.*
*In Botswana irrigation agriculture is the largest provider of employment opportunities.*

*The irrigation agricultural sector is also the largest sector in the Moçambique part of the Limpopo River Basin. Industry is estimated as a smaller while eco-tourism is the smallest.*

*The predominant economic activity in the South African sector of the Limpopo Basin is mining followed by irrigation agriculture and much lower down the scale industry, eco-tourism and power generation.*

*In general mining and irrigation agriculture are the main economic activities in the Zimbabwe section of the Limpopo Basin with game related eco-tourism also important.*

*The efficiency of water use for the total basin varies considerably between economic activities in terms of the value of the water and depends on the indicators selected. This is illustrated in* ***Table E8*** *below.*

***Table E8:*** *Total Limpopo Basin Multipliers*

| Economic sector | GDP (US$ /m$^3$) | | | Employment (Number/million m$^3$) | | | Household Income (US$ /m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Direct | Indirect and Induced | Total | Direct | Indirect and Induced | Total | Total | High and Medium | Low |
| Irrigation | 0.8 | 1.0 | 1.8 | 114.7 | 70.1 | 184.8 | 1.0 | 0.5 | 0.5 |
| Commercial Forestry | 0.7 | 0.6 | 1.3 | 83.1 | 47.4 | 130.5 | 0.5 | 0.2 | 0.4 |
| Mining | 76.2 | 69.7 | 145.9 | 1 222.2 | 3 017.6 | 4 239.7 | 62.6 | 9.5 | 53.1 |
| Power Generation | 17.9 | 11.4 | 29.3 | 45.2 | 682.6 | 727.8 | 11.1 | 2.4 | 8.6 |
| Industry | 182.0 | 287.4 | 469.4 | 1 008.1 | 3 426.3 | 4 434.4 | 273.2 | 79.4 | 193.8 |
| Eco-Tourism | 138.1 | 121.6 | 259.7 | 7 981.3 | 8 025.2 | 16 006.5 | 107.3 | 32.2 | 75.1 |

*The table shows that mining is more efficient in terms of job creation than industry, but in terms of payments to low income households industry is the more effective.*

*Eco – tourism is also a very efficient user of water, but it has limitations in terms of its future growth in the basin.*

*Although irrigation has relative inefficient multipliers its role in providing household and national food security makes it an important role player.*

## *ECO-SYSTEMS AND ENVIRONMENTAL WATER REQUIREMENTS*

*The concept of environmental water requirements (EWRs) or environmental flows (EFs) has taken root in many countries around the world, and has become a baseline for most water resource assessments. The concept grapples with the three important components of a water resource namely quantity, quality and timing and links these with the ecological needs of the ecosystem.*

### *Surface Water Quality*

*Water quality describes the physical, chemical and biological characteristics of water. Water quality in the Limpopo River Basin is highly affected by man-made activities. In this overview of the water quality on the Limpopo River basin, the focus of the data analysis was on the chemical water quality but where appropriate, mention was made of other water quality concerns that have been raised in the mainstem river as well as its sub-basins.*

*Seven water quality variables were selected to describe the fitness for use of the waters in the Limpopo River Basin:*

- *Electrical conductivity (EC) as indicator of the salinity of the water*
- *pH as indicator of the acidity of the water.*
- *Fluorides*
- *Dissolved iron*
- *Sulphate*
- *Nitrates, and*
- *Phosphates*

*To set boundary values, the guidelines and standards applicable for various water uses in the four basin countries were considered. The uses considered were domestic water supply, agricultural water supply (irrigation and livestock watering), and aquatic ecosystems (eutrophication potential).* ***Table E9*** *contains the boundary values which were set and used to classify the fitness for use.*

***Table E9: Boundary values that were set for selected variables to classify the fitness for use of waters in the Limpopo River Basin***

| 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 |

*The water quality status is summarised for each variable:*

- *Salinity (Electrical conductivity) – EC's in Botswana appears to be elevated which is probably an indication of the perennial nature of the rivers (high evaporation and accumulation of salts). In Moçambique salts are elevated but still within a tolerable range. In South Africa salts are elevated in the Crocodile, Lebata, Olifants and upper and middle Limpopo rivers. High salts in the Limpopo River appear to originate from the Crocodile River. In Zimbabwe salts are in a good category.*
- *pH – In general, pH values recorded in the Limpopo River Basin fall within a good category (between 6.5 and 8.5) although there are pockets that are affected by Acid Mine Drainage (AMD).*
- *Fluoride – In general fluoride concentrations fall within a good category (< 0.7 mg/l) although elevated concentrations have been recorded in Notwane and Letlakane Rivers in Botswana.*
- *Iron – Iron concentrations are not routinely recorded in South Africa and Moçambique. Some elevated concentrations have been recorded in the Letlakane River in Botswana.*

- *Sulphate – Sulphate values less than 10 mg/l is generally recorded in rivers not impacted by AMD. However, in rivers affected by AMD, elevated sulphate concentrations occur even though they are still categorised as in a good class. The elevated sulphates in the upper and middle Limpopo River appears to originate in the Crocodile River with some contributions from the Motloutse and Letlakane rivers. The Olifants River in South Africa and Moçambique also shows elevated concentrations and the impacts of AMD.*
- *Nutrients – Nitrate values in Botswana and Moçambique appears to be very high. In South Africa and Zimbabwe, nitrates fall in a good category. Elevated phosphate concentrations occur more often in the basin indicating that eutrophication may be a problem throughout the basin.*

***Figure E3*** *shows the river reaches with water quality concerns.*

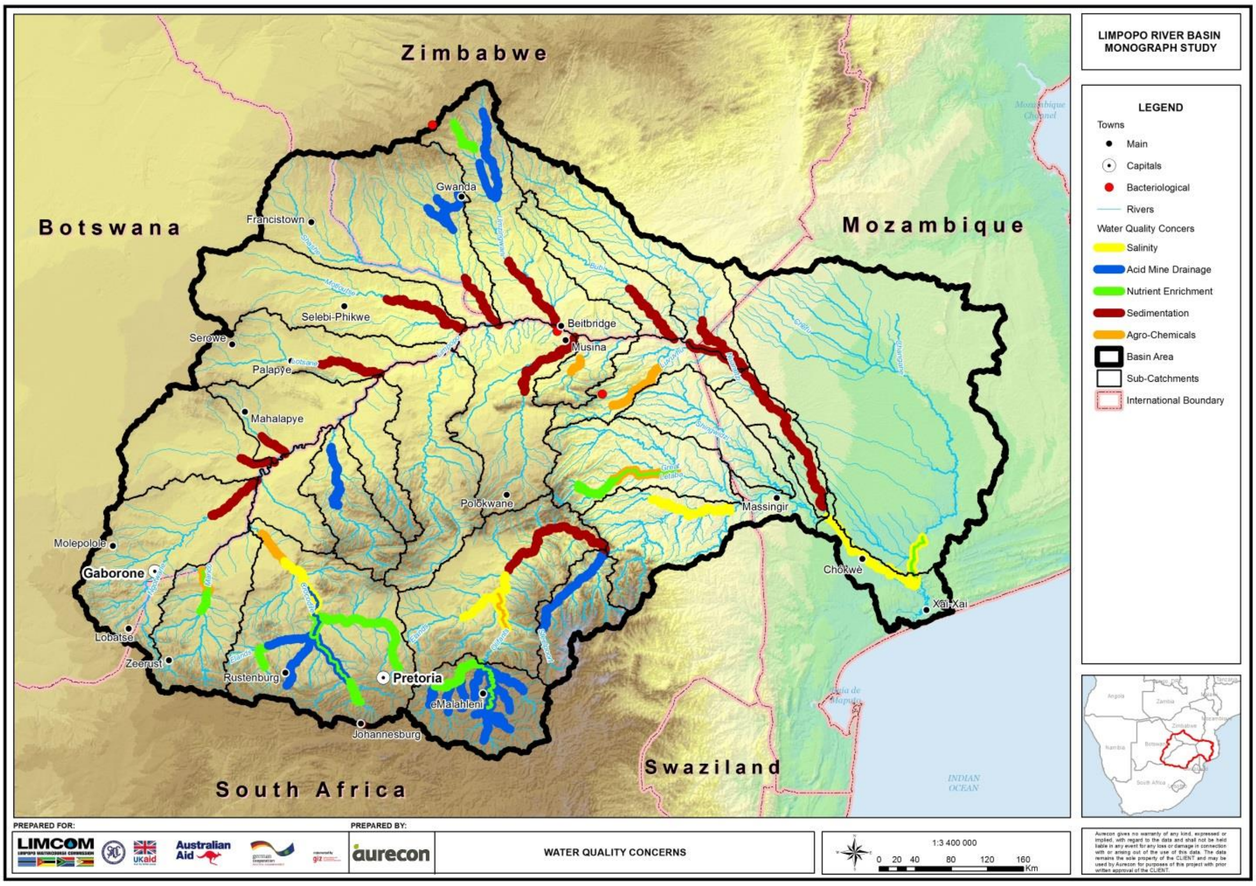



***Figure E3:*** *Map showing the location of key water quality concerns in the Limpopo River Basin*

*Analysis of the general results showed that the average annual storage loss due to sedimentation in all reservoirs throughout South Africa is approximately 0.3%. The average annual loss in the Limpopo Basin (in South Africa) is 0.6%. It is almost twice the average South African value. This scenario adversely affects the long term sustainability of the reservoirs within the Basin.*

### *Conservation Areas & Wetlands*

*The Limpopo River basin contains some of Africa's largest and most renowned conservation areas, such as the Kruger National Park (South Africa) and Great Limpopo Transfrontier Park (Moçambique) as well as the Gonarezhou National Park (Zimbabwe) and Banhine National Park (Moçambique). There are additionally adjacent a great number of smaller reserves, wildlife management areas and privately owned conservation areas and game farms.*

### *Riverine EWRs*

*Large areas of wetlands in the flat low lying areas of Moçambique extend northwards from the Limpopo estuary along the Changane River, to Zinave Natioal Park, and up along the floodplain of the Limpopo river itself.*

*There is a high density of wetlands in the upper catchments of the Olifants, Letaba and Luvuvhu Rivers in South Africa. Unlike the vast coastal plain wetlands of Moçambique, the wetlands of the upper catchments are vast in number but smaller in size.*

*Eight new sites have been selected for the assessment of the EWR based on a standard set of criteria. Sites that had been surveyed in the past as part of other EWR studies (in South Africa) were included in this study and their locations have been considered in the site selection process, informing the selection of new sites for assessment. The eight new sites are shown in **Figure E4.***

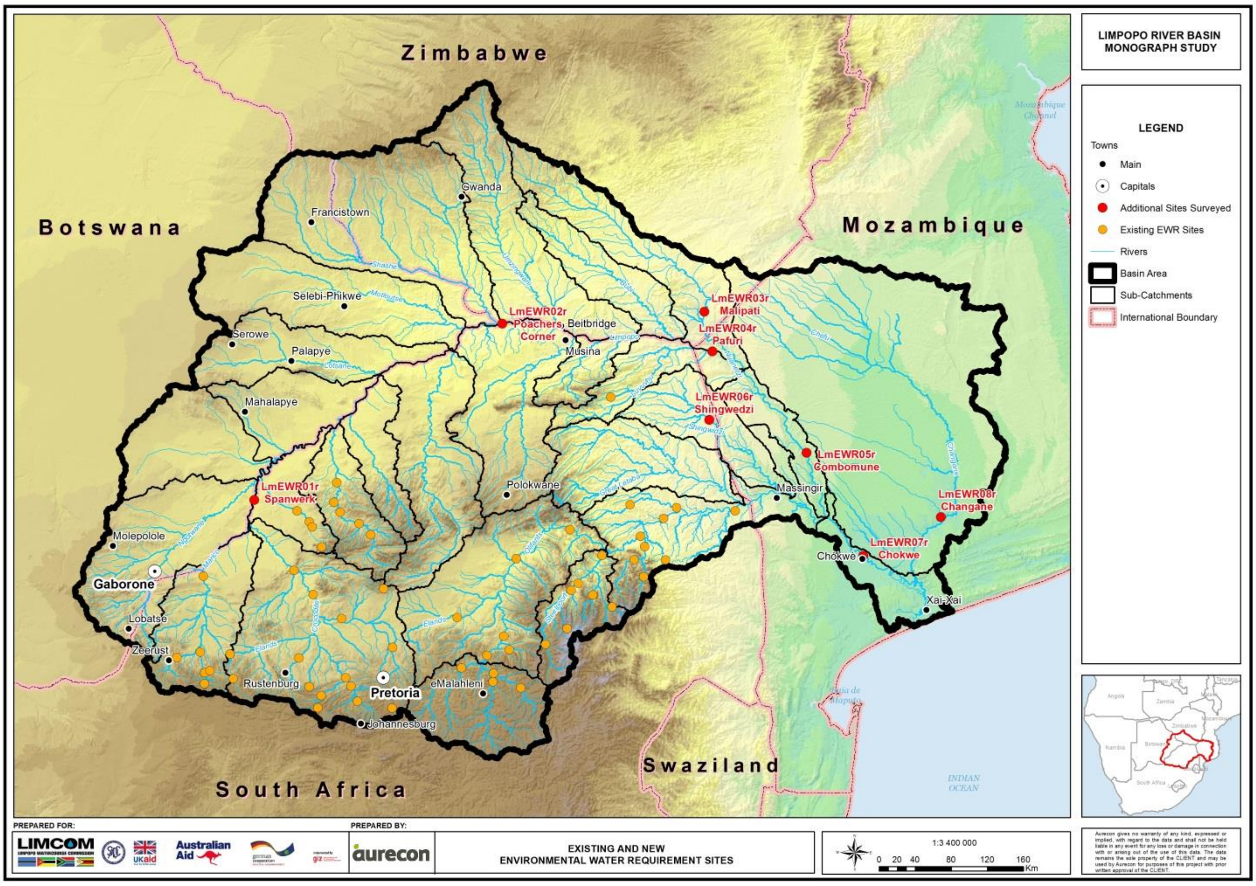



*Figure E4: Selected and Existing EWR sites*

*A PES category (Eco-Status) was determined for each site based on PES assessments of fish, and macro invertebrates. The PES results are reported in **Table E10**.*

*The approach adopted in this study to assess the current ecological state of the fish communities includes the use of the Fish Response Assessment Index (FRAI) (Kleynhans and Louw, 2007).*

*The Macro-Invertebrate Response Assessment Index MIRAI model (Thirion, 2007) determines the ecological condition of the river by integrating the ecological requirements of the invertebrate communities and assemblages and their response to changes in the four main components of the stream system. The South African Scoring System SASS5 method was employed to collect invertebrate information from each of the Limpopo sites where suitable habitat was available.*

***Table E10:** Fish and Invertebrate PES / Eco-Status scores for the eight new sites*

| Site Number | Name of site | Fish based PES | Invertebrates based PES | |
|---|---|---|---|---|
| | | | PES | Condition Class |
| LmEWR01r | Spanwerk | C (67%) | B (80.95%) | Good |
| LmEWR02r | Poachers Corner | C/D (61%) | B (87.25%) | Good |
| LmEWR03r | Malipati | C (66%) | C (74.47%) | Fair |
| LmEWR04r | Pafuri | D (49%) | C (78.83%) | Fair |
| LmEWR05r | Combomune | D (57%) | B (83.92%) | Good |
| LmEWR06r | Shingwedzi | D (52%) | D (57.31%) | Poor |
| LmEWR07r | Chokwe | C (71%) | D (50.87%) | Poor |
| LmEWR08r | Changane | C/D (62%) | E (21.62%) | Seriously modified |

*The above results were used to determine the overall Eco-Status, recommended Eco-status (REC) and EWR for each site. The results are shown in **Table E11**.*

***Table E11:** Recommended EWRs for the 8 surveyed sites*

| EWR site | River | PES | EIS | REC | nMAR ($10^6 m^3$) | EWR % of MAR (REC) |
|---|---|---|---|---|---|---|
| LmEWR1r | Limpopo at Spanwerk | B/C | High | B/C | 591.49 | 27.60 |
| LmEWR2r | Limpopo at Poachers Corner | B/C | Moderate | B/C | 1683 | 30.90 |
| LmEWR3r | Mwanedzi at Malapati | C | Moderate | B/C | 282.73 | 22.00 |
| LmEWR4r | Limpopo at Pafuri | C | Moderate | C | 2792 | 30.90 |

| *EWR site* | *River* | *PES* | *EIS* | *REC* | *nMAR ($10^6m^3$)* | *EWR % of MAR (REC)* |
|---|---|---|---|---|---|---|
| *LmEWR5r* | *Limpopo at Combomune* | *C* | *Moderate* | *C* | *3087* | *26.20* |
| *LmEWR6r* | *Shingwedzi d/s Kanniedood Dam* | *B/C* | *Moderate* | *B* | *81.63* | *28.80* |
| *LmEWR7r* | *Limpopo at Chokwe* | *C* | *Moderate* | *C* | *5572* | *20.60* |
| *LmEWR8r* | *Changane* | *B/C* | | *B/C* | | *21.80* |

***Notes:*** *A table including the data from the many previous studies, mostly located on tributaries of the Limpopo, is to be found in* ***Technical Annexure, Volume*** *B2 PES=Present Ecological State {A-pristine, F-severely degraded}; EIS=Ecological Importance and Sensitivity; REC= Recommended Ecological Category (recommended from an ecological point of view as being reasonably attainable); nMAR=natural Mean Annual Runoff; EWR % of MAR (REC) = the percentage of the nMAR that forms the EWR at the recommended ecological category*

### *Estuarine EWRs*

*Nine sites were selected along the length of the estuary to represent the upper, mid and lower reaches of the estuarine environment. The positions of the sites were ultimately selected on their suitability for application of the chosen assessment methods and informed during the field surveys by in-situ physico-chemical analyses. The in situ physico-chemical processes were also used to determine the upper limit of the estuary, at 35 km from the mouth.*

*The positions of the nine survey sites used in the study are shown in* ***Figure E5****.*


***Figure E5:*** *Survey sites in the Limpopo Estuary*

*The following parameters were measured, procedures followed, samples collected or animals counted at each site:*

- *In situ depth profile measurements of salinity, turbidity, dissolved oxygen, pH and temperature with a multi-parameter probe (see inset photograph).*
- *Riparian, floodplain and estuarine vegetation*
- *Macro-benthic invertebrates*
- *Fish*
- *Water birds*

*Hydrodynamics and mouth morphology were also studied.*

*In its present state the Estuary Health Index (EHI) was scored at 65 and accordingly given a C category status (scoring range 61 - 75) on a scale from A to F reflecting a 'moderately modified' system.*

*The Estuarine Health Index Scores allocated to the Limpopo Estuary are shown in **Table E12** and score categories for determining the PES in **Table E13.***

***Table E12:** Estuarine Health Index Scores for the Limpopo Estuary*

| ***Variable*** | ***Weight*** | ***Score*** | ***Weighted score*** |
|---|---|---|---|
| *Hydrology* | *25* | *58* | *15* |
| *Hydrodynamics and mouth condition* | *25* | *90* | *23* |
| *Water quality* | *25* | *75* | *19* |
| *Physical habitat alteration* | *25* | *80* | *20* |
| ***Habitat Health Score*** | | | ***76*** |
| *Macrophytes* | *25* | *75* | *19* |
| *Invertebrates* | *25* | *80* | *20* |
| *Fish* | *25* | *15* | *4* |
| *Birds* | *25* | *50* | *13* |
| ***Biotic Health Score*** | | | ***55*** |
| ***ESTUARINE HEALTH SCORE*** | | | ***65*** |
| ***Present Ecological Status*** | | | ***C*** |

***Table E13:** EHI Score categories for determining the PES*

| ***EHI Score*** | ***PES*** | ***Description*** |
|---|---|---|
| *91-100* | ***A*** | *Unmodified, natural* |
| *76-90* | *B* | *Largely natural with few modifications* |
| ***61-75*** | ***C*** | ***Moderately modified*** |
| *41-60* | *D* | *Largely modified* |
| *21-40* | *E* | *Highly degraded* |
| *0-20* | *F* | *Extremely degraded* |

*The Estuarine Importance Scores (EIS) allocated to the Limpopo Estuary are listed in **Table E14** below:*

*Table E14: EIS Scores for the Limpopo Estuary*

| Criterion | Score | Weight | Weighted score |
|---|---|---|---|
| Estuary Volume | 100 | 15 | 15 |
| Zonal Rarity Type | 100 | 10 | 10 |
| Habitat Diversity | 100 | 25 | 25 |
| Biodiversity Importance | 90 | 25 | 23 |
| Functional Importance | 100 | 25 | 25 |
| **ESTUARINE IMPORTANCE SCORE** | | | **98** |

*The EIS for the Limpopo Estuary, based on its present state, is 98, i.e., the estuary is **Highly Important.***

*On the basis of this importance score it is recommended that the condition of the estuary should be elevated to a Category B or as per the rule table Present Ecological State + one category.*

*It is estimated that the estuary receives approximately 50% of its natural mean annual run off due to abstraction activities in the catchment. Changes in flow conditions have not influenced mouth state to date as the open mouth is largely tidally driven. Changes in flow could, however, begin to have an effect on mouth status and have definitely had and could increase changes to the physico-chemical conditions of the system.*

## WATER RESOURCES

### Surface Water Sources

#### Analysis approach

*The application of a monthly catchment modelling package - formally known as Water Resource Simulation Model (WRSM2005) - which incorporates the well-known Pitman Model for rainfall-runoff simulation, forms the foundation of the analysis of the surface water resources of the LRB. Monthly modelling input data, comprising rainfall, evaporation and historical water-use information, was compiled for selected gauged sub-basins across the Botswana, Zimbabwe and Moçambique portions of the LRB.*

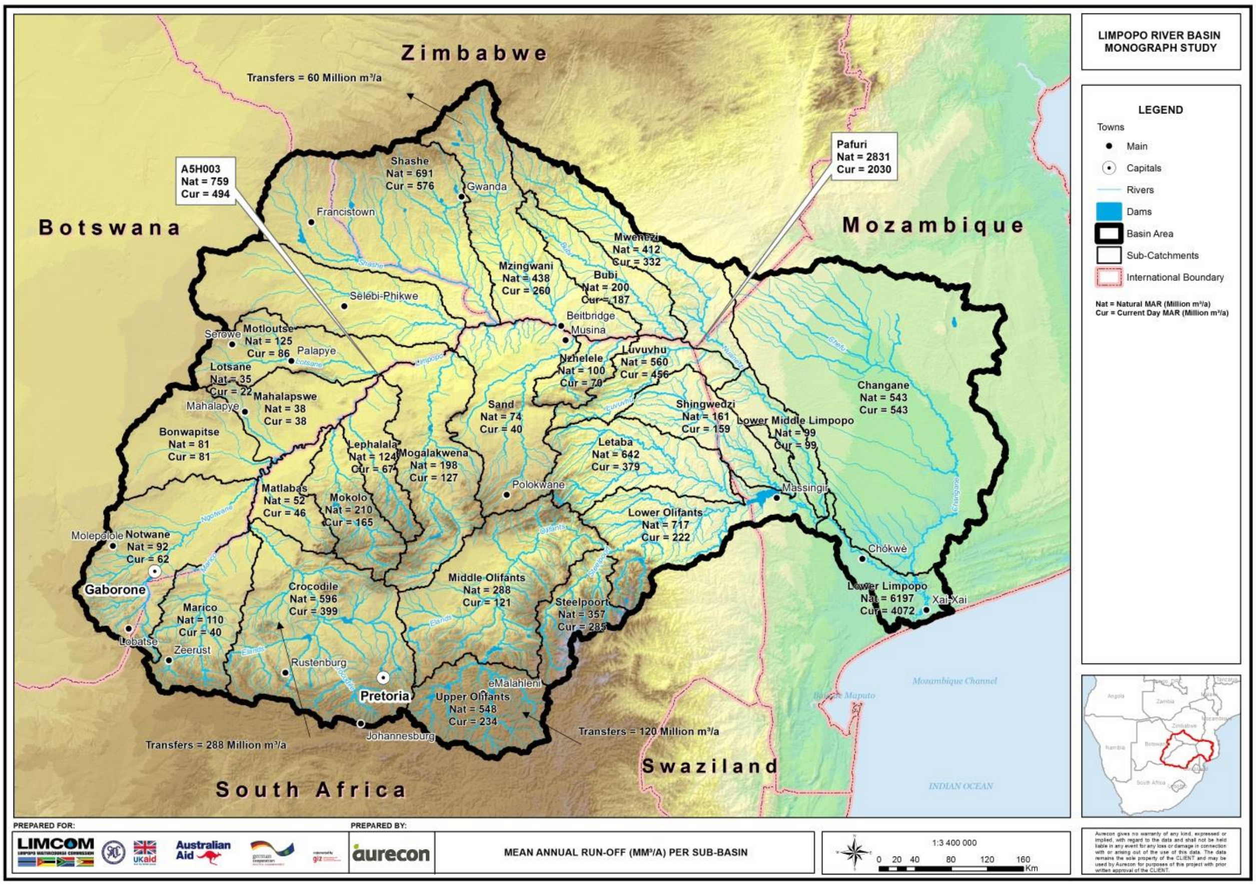
*Missing values in the monthly rainfall records were patched by means of the CLASSR and PATCHR software, while missing monthly streamflow values were patched by means of the PATCHS software.*

*Monthly streamflow data in Botswana, Moçambique, South Africa and Zimbabwe were supplied by these member states. Based on quality of record and location, gauging stations in Botswana, four stations in Moçambique and 20 stations in Zimbabwe were selected for model calibration purposes.*

#### Mean Annual Runoff

*Monthly streamflow sequences were simulated by means of the calibrated Pitman Model configurations per Sub-Basin for the 91-year period, 1920 – 2010. Two sets of streamflows were prepared for current-day and natural catchment conditions, respectively. For the natural scenario, the modelling was done with no human impacts present in the catchment configurations. For the current-day scenario, all existing land-use, water-use and bulk water resource infrastructure were super-imposed on the natural conditions at 2010 levels of demand and land-use, including transfers into and out of the Limpopo Basin.*

*A basin-wide comparison of Mean Annual Runoff (MAR) for current-day versus natural conditions is presented in* ***Figure E6.*** *The nett impacts of consumptive use on the surface water resources vary widely amongst the Sub-Basins and range from less than 1% in the Bonwapitse, Mahalapswe and Changane sub-basins to over 50% in the Upper and Middle Olifants sub-basins and nearly 70% in the Lower Olifants sub-basin. The total cumulative Basin MAR at the mouth of the Limpopo is 4072 million* $m^3/a$ *for current-day condition which is 66% of the 6 197 million* $m^3/a$ *for natural Basin conditions. This indicates that the accumulative nett human impacts on the surface water resources of the Basin currently constitute, on average, somewhat less than 35% of the natural surface water resources.*




**Base date: 2010**

***Figure E6:*** *Comparison of Current Day (2010) MARs versus Natural MARs for Sub-Basins (million* $m^3/a$*)*

***Sub-basin yields***

*The 91-year simulated monthly streamflow sequences were used to determine current-day yields at 1:5 year Recurrence Interval (RI) of failure (80% assurance of supply on an annual basis) for all current-day storages and run-of-river abstraction points in each Sub-Basin, at the Sub-Basin rivers' confluences with the Limpopo main-stem and at a few critical Limpopo main-stem points. The yield modelling was done on a cascading basis, i.e. downstream yields already carry the impacts of upstream 1:5 year RI of failure drafts. The 1:5 year yield was approximated by the annual draft that caused 18 annual failures out of a 91 year sequence. At each yield point a monthly distribution of the annual draft appropriate to the relevant types of water use was employed.*

*The yields were summed per Sub-Basin and the results are presented in **Figure E7.***

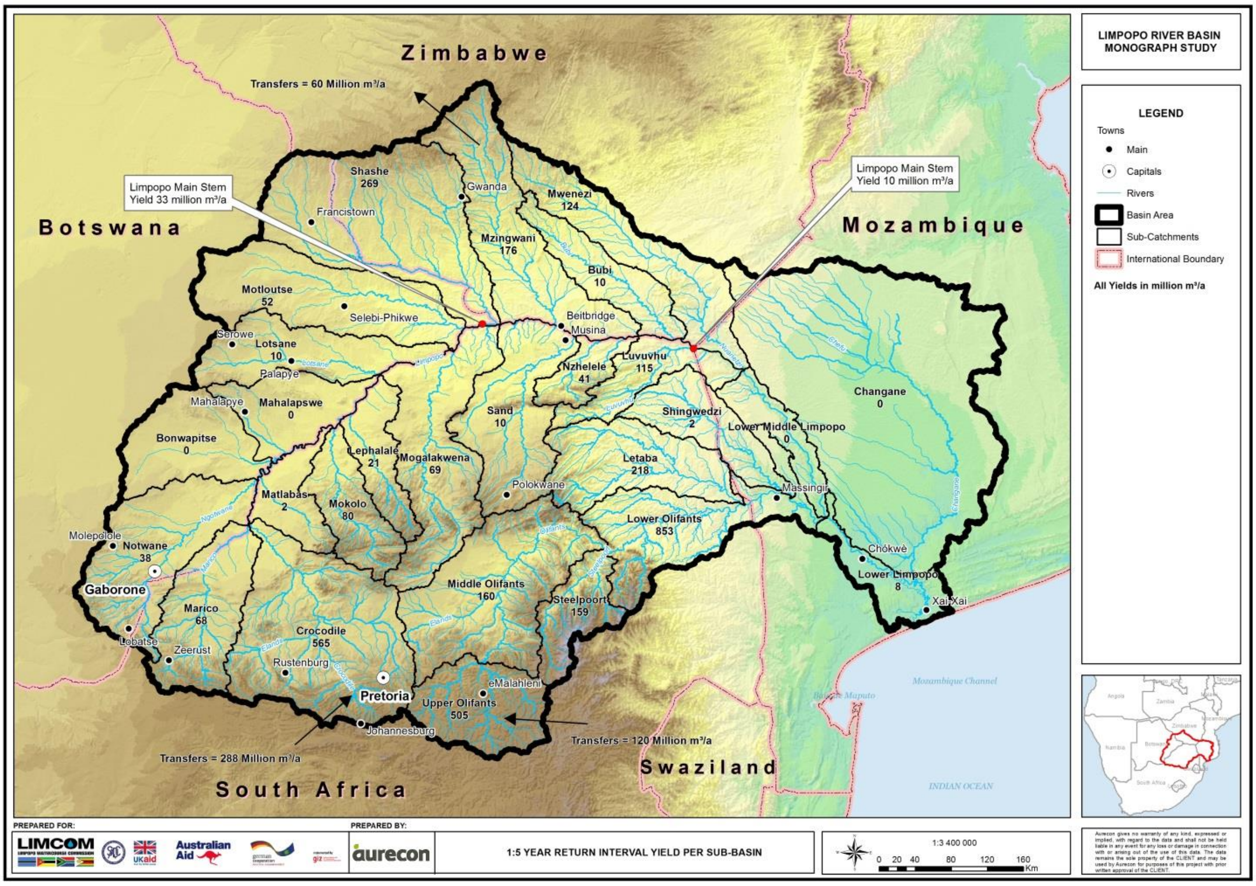



***Figure E7:** Current Day Yields at 1:5 Year RI of Failure (80% Assurance) at Sub-Basin Scale*

## *Floods and Flood Peaks*

*The Limpopo River main-stem is subjected to periodic flooding caused by a range of large-scale weather systems that operate over different parts of the basin.*

*A probabilistic flood analysis for the sub-basins of the Limpopo River basin was done and probable flood peaks for the sub-basins and points on the Limpopo main stem for different rcurrent intervals were determined. These flood peaks are provided in **Table E15.***

*The Botswana sub-basins are absent fom the table due to the sparseness of flood peak data available for Botswana.*

*Results for the South African sub-basins, Upper Olifants, Middel Olifants and Steelpoort are also absent from **Table E15** because their influence on the Limpopo Main-stem flooding is embedded in the Lower Olifants Results.*

*Table E15 : Recurrence Interval Flood Peaks for Sub-basins and Limpopo Main Stem*

| Tributary / Sub-Basin / Main-Stem Gauging Station | Mean Annual Maximum Flood Peak (MAMFP) ($m^3/s$) | Recurrence Interval Flood Peak ($m^3/s$) | | |
|---|---|---|---|---|
| | | 1:20 Year | 1:50 Year | 1:100 Year |
| Shashani | 209 | 774 | 1 172 | 1 507 |
| Tuli | 413 | 1 527 | 2 311 | 2 972 |
| Mzingwane | 729 | 2 697 | 4 082 | 5 248 |
| Bubi | 423 | 1 564 | 2 367 | 3 043 |
| Mwenezi | 693 | 2 563 | 3 879 | 4 987 |
| Marico | 194 | 893 | 1 029 | 1 165 |
| Crocodile | 164 | 752 | 867 | 981 |
| Matlabas | 177 | 671 | 964 | 1 192 |
| Mokolo | 156 | 591 | 848 | 1 049 |
| Lephalale | 167 | 633 | 909 | 1 124 |
| Mogalakwena | 118 | 448 | 644 | 796 |
| Sand | 126 | 479 | 688 | 851 |
| Nzhelele | 440 | 1 773 | 2 723 | 3 550 |
| Luvuvhu | 578 | 2 331 | 3 580 | 4 668 |
| Letaba | 1 136 | 4 579 | 7 033 | 9 169 |
| Shingwedzi | 932 | 3 754 | 5 767 | 7 518 |
| Lower Olifants | 960 | 3 456 | 6 432 | 9 888 |
| Changane | 80 | 272 | 431 | 596 |
| 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 |
| E35 (Chokwe) | 1 952 | 6 637 | 10 521 | 14 542 |
| E38 (Xai-Xai) | 1 799 | 6 117 | 9 697 | 13 403 |

## *Groundwater Resources*

*The scarcity of water has long been a socio-economic threat in Southern Africa. With ever growing demands for this commodity, an investigation of the current state of groundwater resources within the populated Limpopo Basin is deemed necessary. The objective of this study is therefore to describe the groundwater status, potential and role in the Limpopo River basin in the four member states.*

*The basin has been classified into four aquifer types namely fractured, inter-granular, karst and low permeability. Low permeability (low yielding) aquifers are the most predominant aquifer type across the basin (approximately 63% of the area), while fractured (moderate to high yielding) aquifers constitute approximately 19% of the basin. 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%.* ***Figure E8*** *shows the general hydrogeological map of the Limpopo River Basin.*

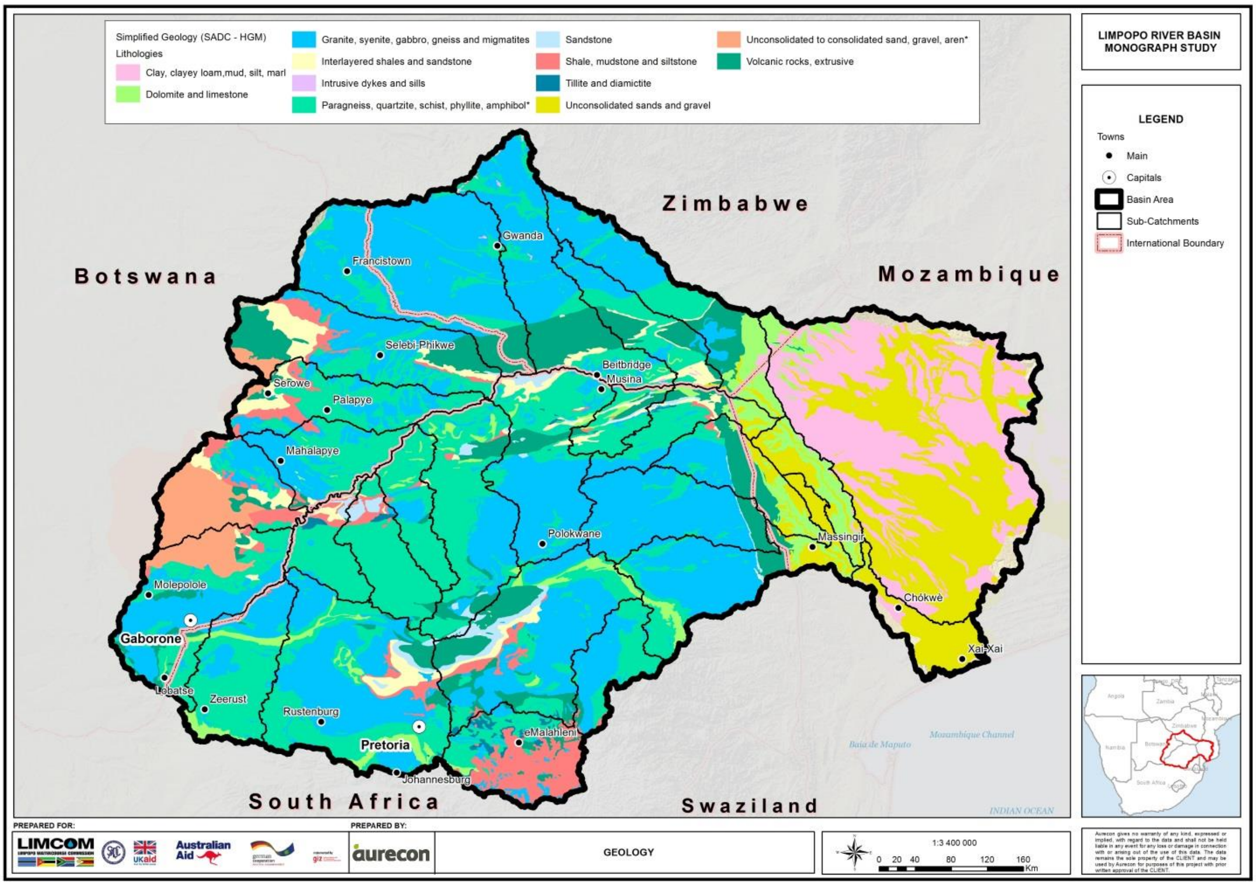



*Figure E8: General Hydrogeological map of the Limpopo River Basin*

*Groundwater is a renewable resource, in that it may be utilised sustainably so long as abstraction is balanced by groundwater recharge. Recharge is defined as the downward flow of water reaching the water table and replenishing a groundwater resource. The volume of recharge on an aquifer is dependent on rainfall. Therefore the volume of precipitation on an area, together with permeability, essentially govern the potential recharge and hence the available groundwater in storage.*

*Groundwater supply potential refers to the volume of groundwater that may be sustainably abstracted from an aquifer. For sustainable groundwater abstraction withdrawal should not exceed the rate of recharge and thus not cause an unacceptable decline in the hydraulic head or deterioration in water quality in the aquifer. An understanding of the supply potential of an aquifer is thus crucial to the successful 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.*

*Apart from local aquifers, both regional and transboundary aquifers occur within the Limpopo river basin. A transboundary aquifer refers to a body of groundwater that intersects political boundaries. The implication of such a body of water is that there are at least two sets of governance over the single resource. Careful management through an international water management institution such as LIMCOM is required in situations such as this to prevent exploitation of the resource by one state which in turn would negatively impact the availability of the resource to other states.*

*According to the SADC hydrogeological map (2010) two Transboundary Aquifers (TBAs) have been identified in the Limpopo river basin, the Tuli Karoo Basin and the Ramotswa dolomite basin. The Tuli Karoo Basin is the most extensive of the two and encompasses portions of South Africa, Zimbabwe and Botswana. The Ramotswa dolomite basin is a karstic aquifer and is shared between South Africa and Botswana. The Limpopo Basin Transboundary Aquifer which is not recognised on the SADC hydrogeological map is shared between South Africa, Moçambique and Zimbabwe. The transboundary aquifers in the Limpopo Basin are shown in* ***Figure E9.***

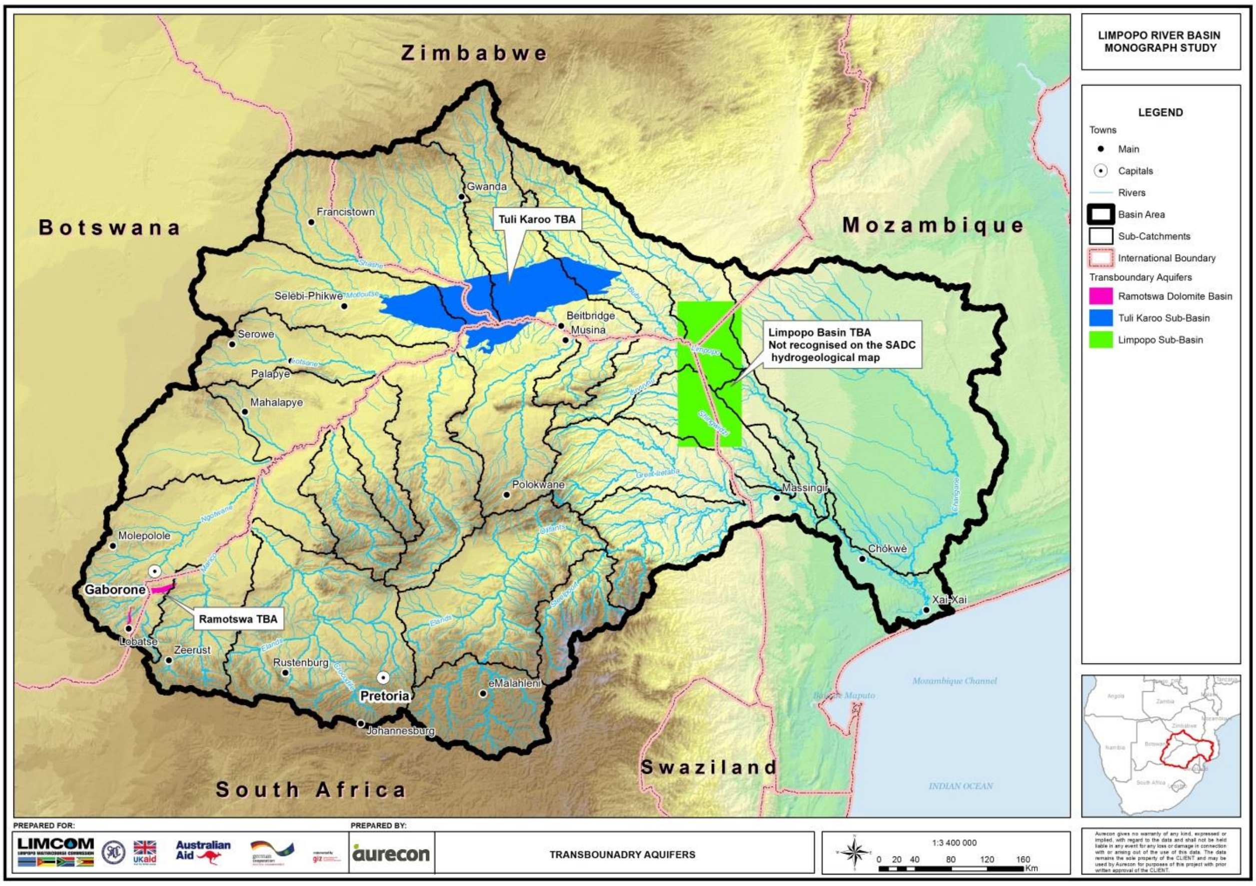



*Figure E9: Transboundary Aquifers in the Limpopo River Basin*

*The Aquifer Productivity is divided in 4 categories based on the expected yield and importance of supply. Aquifers with high productivity are normally used for regional bulk water supply. Aquifers with moderate productivity are normally used for local supply to a village or local user. The "generally low" productivity aquifers are only suitable for local use but can supplement other water supply locally. The low productivity aquifers are only suitable for small local supply and the sustainability cannot be ensured. The aquifer productivity is shown in* ***Table E16*** *and the aquifer productivity is reflected in* ***Figure E10.***

*Table E16: Aquifer Productivity Classification Table, Refer to Figure E9*

| Aquifer Category* | Specific Capacity (ℓ/s/m) | Transmis-sivity ($m^2/d$) | Hydraulic Conductivity | Very approximate expected yield (ℓ/s) | Groundwater productivity |
|---|---|---|---|---|---|
| A1, B1, C1 | >1 | >75 | >3 | >10 | High: Withdrawals of regional importance |
| A2, B2, C2 | 0.1-1 | 5-75 | 0.2-3 | 1-10 | Moderate: Withdrawals for local village supply |
| D1 | 0.001-1 | 0.05-5 | 0.002-0.2 | 0.01-1 | Generally Low: May be utilised for local use |
| D2 | <0.001 | <0.05 | <0.002 | <0.01 | Low productivity supply for local water supply difficult to ensure |

*Notes: A = Unconsolidated and intergranular aquifer*
*B = Fractured aquifer*
*C = Karst aquifer*
*D = Low permeability aquifer*
*The numeric's (i.e A1, A2, B1, etc.) refer to the permeability with a decrease in permeability from 1 to 3*

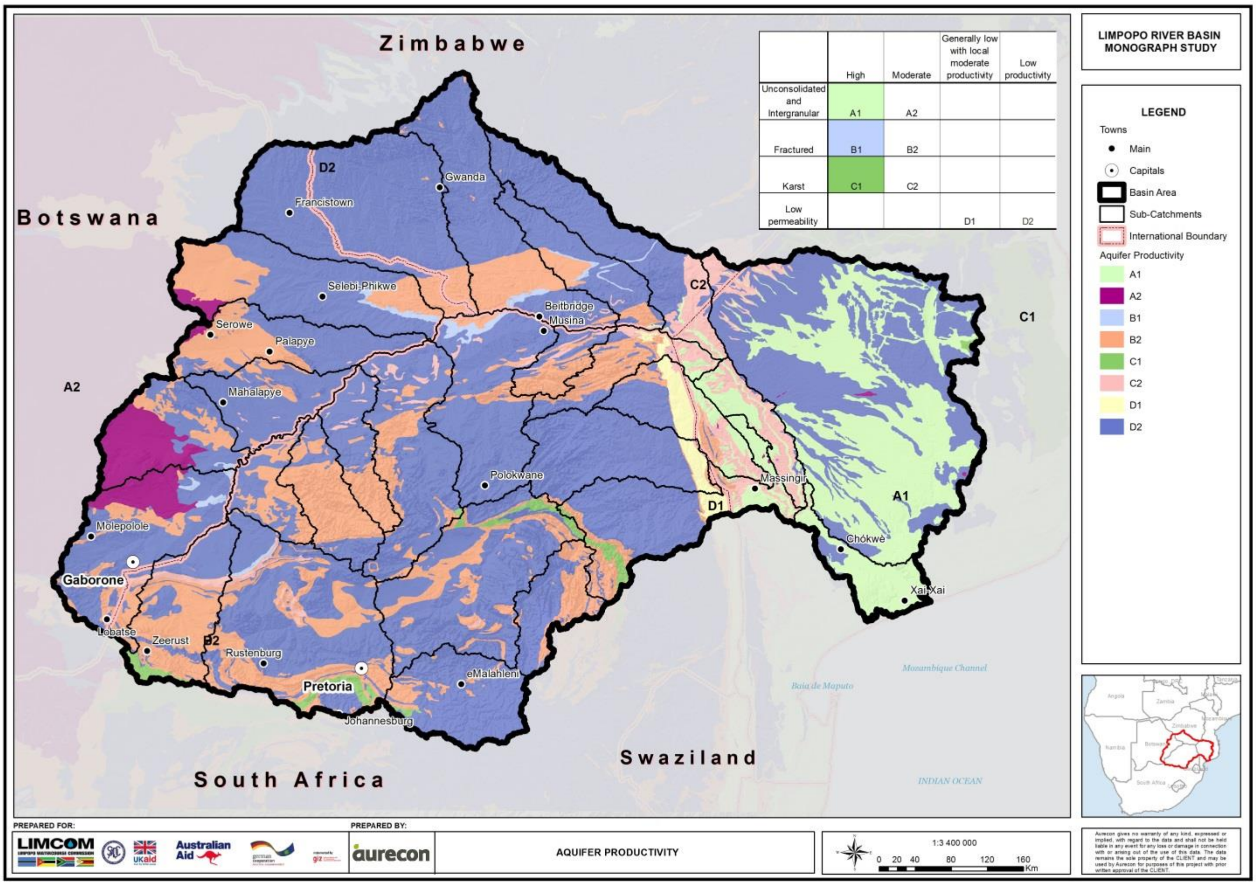



*Figure E10: Aquifer productivity in the Limpopo River Basin*

*Groundwater quality describes the chemical and physical parameters of groundwater water. During investigation of the groundwater resources of South Africa groundwater quality was found to be one of the main factors restricting the development of available groundwater resources. Of the problems associated with water quality, high concentration of total dissolved solids, nitrates and fluoride are considered to be the most common and serious problems on a regional scale.*

*In order to standardise the interpretation of water quality across the basin the World health organisation's (WHO) guidelines for domestic water quality have been adopted and are presented in **Table E17.***

***Table E17:** World Health Organisation (2008) Water Quality Guidelines*

| ***WHO water quality guidelines (WHO, 2008)*** | | |
|---|---|---|
| *Determinant* | *Unit* | *Maximum Limit* |
| *Fluoride* | *mg/ℓ* | *<1.5* |
| *Nitrate (as NO3)* | *mg/ℓ* | *<50* |
| *TDS* | *mg/ℓ* | *<1000* |

***Electrical Conductivity***

*Electrical conductivity (EC) is an indication of salinity and gives an indication of the impact of the geology as well as human influences on the water resource quality. The results indicate that the water quality in terms of EC 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 the geology and perhaps are a result of human impact. The large zone of poor water quality across Moçambique has been attributed to the depositional history of the area. There were very few data points within the Zimbabwe portion of the basin and it is uncertain whether the interpolated EC values in this region are fictitious.*

*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 are present throughout the basin.*

*The presence of nitrates in drinking water is typically associated with pollution from agricultural activities, pit latrines, waste water 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. No nitrate data was received from Zimbabwe or Moçambique.*

## *Water Requirements*

*Water requirements have been determined separately for the following water use sectors; domestic, industry, mining, irrigation, livestock, forestry and power generation.*

*The estimated water requirements in the Limpopo River basin are summarised in **Table E18.***

*Table E18: Estimated water requirements in the Limpopo River Basin*

| Country | Water Requirements (million $m^3$/a) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Domestic | Industrial | Mining | Irrigation | Forestry | Livestock | Thermal Electric Power Generation | Total |
| Botswana | 53 | ~0 | 8 | 7 | - | 20 | 3 | 91 |
| Moçambique | 32 | | | 274 | - | 21 | - | 327 |
| South Africa | 901 | 327 | 285 | 1 974 | 83 | 45 | 223 | 3 838 |
| Zimbabwe | 86* | 1 | 6 | 96 | - | 14 | - | 203 |
| **Total** | **1 072** | **328** | **299** | **2 351** | **83** | **100** | **226** | **4459** |

* Includes the 60 million $m^3$/a water transfer out of the basin to Bulawayo

*The 2010 United Nations Secretariat World Population Prospects were used for projecting domestic water requirements into the future up to 2040. It is expected that the total water requirements for domestic purposes will grow from 1 072 million $m^3$/a in 2012 to 1 198 million $m^3$/a in 2040, i.e. by 126 million $m^3$/a.*

*Increased mining water use requirements predicted for four planned mining projects in the Upper and Middle Olifants, Mokolo and Nzhelele Sub-basins come to a total of 40 million $m^3$/a.*

*The only known future development in irrigation that has already been initiated is 7 000 ha of sugar cane downstream of Massingir Dam in Moçambique requiring 70 million $m^3$/a.*

*Future industrial water requirements will probably follow the growth in developments in the mining and irrigation sectors. No known new industrial projects are due for development in the near future. An industry that was planned at some stage was the Sasol Mafutha Project in the Mokolo Sub-basin in South Africa which would require 37 million $m^3$/a water. The planning however stopped and it is uncertain whether this industrial project will go ahead.*

*Two power stations which are under construction, i.e. Kusile in the Upper Olifants and Medupe in the Mokolo Sub-basins will be completed within the next year and when they come into operation they will increase the water requirements by 30 million $m^3$/a.*

*No substantial changes in water requirements of the forestry and livestock water use sectors are foreseen for the future.*

## Surface Water Balances

*The water balance evaluations in this Study had to be restricted to surface water resources, surface water requirements and environmental water requirements (EWRs) from surface resources, because of a general paucity of data on groundwater utilisation and related yields from existing groundwater infrastructure.*

### General approach

*The surface water balance in each Sub-Basin was calculated by subtracting its total current-day nett average annual human impacts on the surface water resources from the sum of its total annual surface water yields at 1:5 year assurance. The simulated human impacts comprise any or all of the following effects, depending on local circumstances in each Sub-Basin:*

- *current-day abstractions for irrigation, urban, industrial and energy water requirements;*
- *nett reservoir evaporation;*
- *diffuse upstream streamflow reductions due to commercial afforestation and alien plant invasions.*

*Return flows were embedded in the catchment model streamflow outputs.*

*The surface water balances, as well as comparisons of EWRs with current-day streamflows, were examined for the following cases:*

- *i. Per Sub-Basin: Current-day Sub-Basin development levels and water requirements, with no provision made for meeting EWRs*
- *ii. Per Water Balance Region: Current-Day development levels and water requirements, with no provision made for meeting EWRs.*
- *iii. Per EWR site on the Limpopo main-stem: Comparison of EWRs with current-day streamflows. The locations of the EWR sites are presented in **Figure E4.***
- *iv. Per Water Balance Region: Future development levels and water requirements set at 2040 with no provision made for meeting EWRs.*

*The Sub-basins, water balance regions and EWR sites are shown on **Figure E11.***

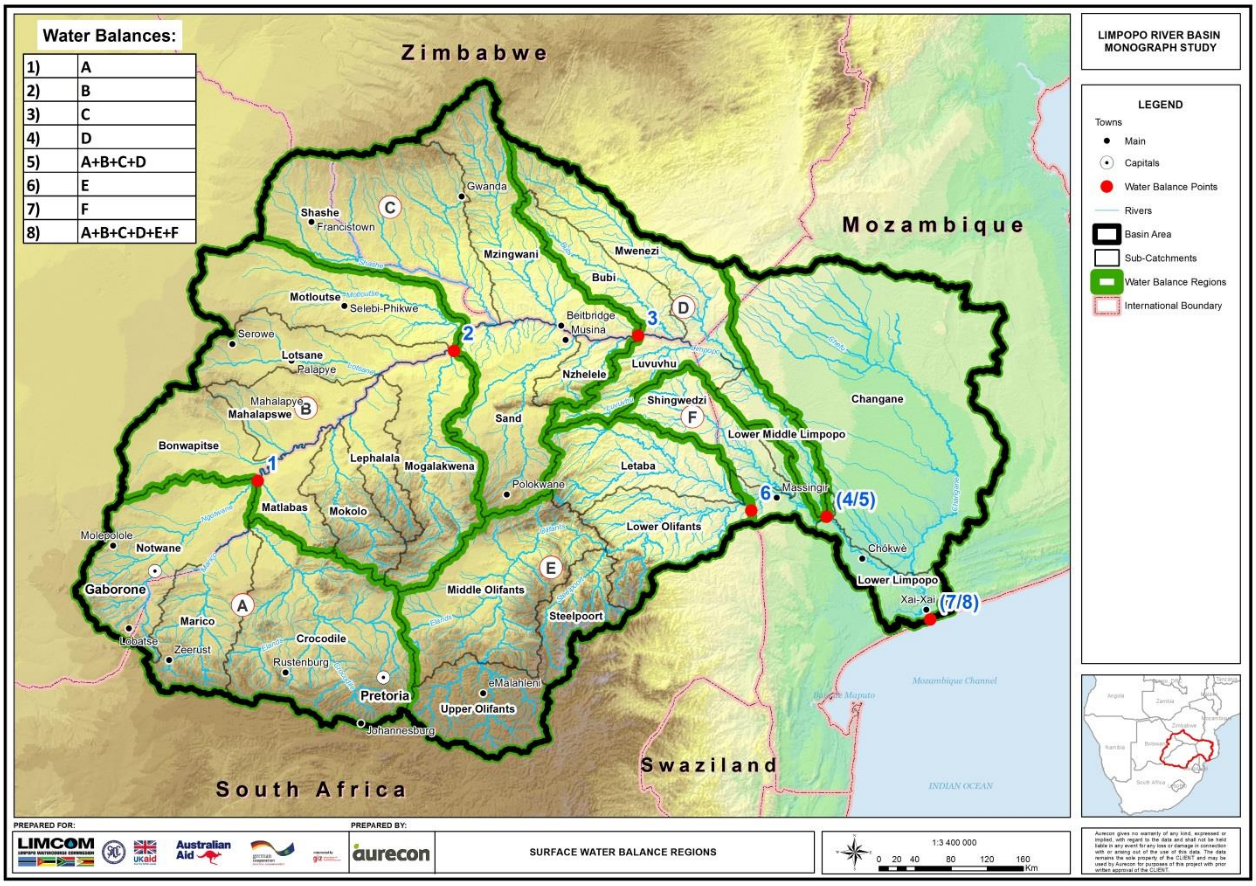



*Figure E11: Surface Water Balance Regions and EWR Sites*

***Table E19** presents the current-day surface water balances for the Water Balance Regions. It is evident from **Table E19** that only Water Balance Region B is currently in notable deficit with regions A and C, in balance, whereas Regions further downstream in the Limpopo Basin display sizeable current-day surpluses. It should be noted that provision of EWRs in these Water Balance Regions would reduce available yields and, hence, increase existing deficits or decrease existing surpluses.*

***Table E19:*** *Surface Water Balances (million $m^3$/a) for Water Balance Regions: Current-Day Conditions*

| Water Balance Region | Total Current-Day Nett Surface Water Impacts | Agriculture: Nett Surface Water Impacts at 1:5 Year Assurance | Urban / Industrial: Nett Surface Water Impacts at 1:50 Year Assurance | Urban / Industrial: Nett Surface Water Impacts at 1:5 Year Assurance | Total Current-Day Nett Surface Water Impacts at 1:5 Year Assurance | Cumulative 1:5 Year Yield# | Current-Day Surface Water Balance |
|---|---|---|---|---|---|---|---|
| **Region A** | 603 | 258 | 345 | 424 | 683 | 681 | -2 |
| **Region B** | 281 | 219 | 62 | 82 | 301 | 257 | -44 |
| **Region C** | 457 | 220 | 237 | 282 | 502 | 496 | -6 |
| **Region D** | 197 | 182 | 16 | 21 | 202 | 249 | 47 |
| **Region A+B+C+D** | 1 538 | 879 | 659 | 808 | 1 688 | 1 683 | -5 |
| **Region E** | 1 128 | 664 | 464 | 577 | 1 241 | 1 337 | 96 |
| **Region F** | 443 | 419 | 24 | 29 | 448 | 568 | 120 |
| **Region A+B+C+ D+E+F** | 3 109 | 1 962 | 1 147 | 1 415 | 3 378 | 3 588 | 210 |

***Notes***: # *Including yields from dams currently under construction or not yet fully operational*
# *Including contributions to yield from urban flows and irrigation flows, where relevant*

***Table E20*** *presents the Sub-Basin water balances for potential 2040 conditions of surface water developments in the respective Sub-Basins that make up the Regions. In the absence of new storage schemes additional to those currently being implemented / more fully utilised, the majority of the Water Balance Regions could be expected be in deficit by 2040. It is emphasised that provision of EWRs in these Water Balance Regions would further increase the deficits*

***Table E20:*** *Surface Water Balances (million $m^3$/a) for Water Balance Regions: 2040 Conditions*

| Water Balance Region | Agriculture: Nett Surface Water Impacts at 1:5 Year Assurance | Urban / Industrial: Nett Surface Water Impacts at 1:50 Year Assurance | Total 2040 Nett Surface Water Impacts at 1:5 Year Assurance | Cumulative 1:5 Year Yield | 2040 Surface Water Balance |
|---|---|---|---|---|---|
| **Region A** | 326 | 583 | 909 | 883 | -26 |
| **Region B** | 197 | 125 | 322 | 257 | -65 |
| **Region C** | 188 | 339 | 527 | 496 | -31 |
| **Region D** | 217 | 24 | 241 | 249 | 8 |
| **Region A+B+C+D** | 927 | 1 072 | 2 000 | 1 885 | -115 |
| **Region E** | 692 | 720 | 1 412 | 1 352 | -60 |
| **Region F** | 451 | 32 | 483 | 568 | 85 |
| **Region A+B+C+ D+E+F** | 2 071 | 1 824 | 3 895 | 3 805 | -90 |

***Notes***: # *Excluding yields from proposed dams that have not progressed to feasibility study stage*
# *Including contributions to yield from urban return flows and irrigation return flows, where relevant*

## Climate Change

*Climate change is projected to have major impacts in the Limpopo River Basin with consequences for the economies of the four co-Basin countries. The semi-arid nature of large portions of the Basin is likely to exacerbate the impacts of climate change because the Basin is already water-constrained.*

*In the last century temperatures have increased by about 1.6°C in the central interior regions of southern Africa. Maximum temperatures in the LRB have increased by a rate of between 1°C and 1.4°C in summer months, with the southern and western regions recording the highest increases.*

*Reported climate change-related projections of mean annual rainfall are depicted in* ***Figure E12.*** *These show that there may be limited, but spatially coherent, decreases in rainfall in the near future in the Basin. In the long term the rainfall is projected to decrease by up to -15%. More frequent high–intensity rainfall events are generally projected, with a consequent increase in local and large-scale flooding.*

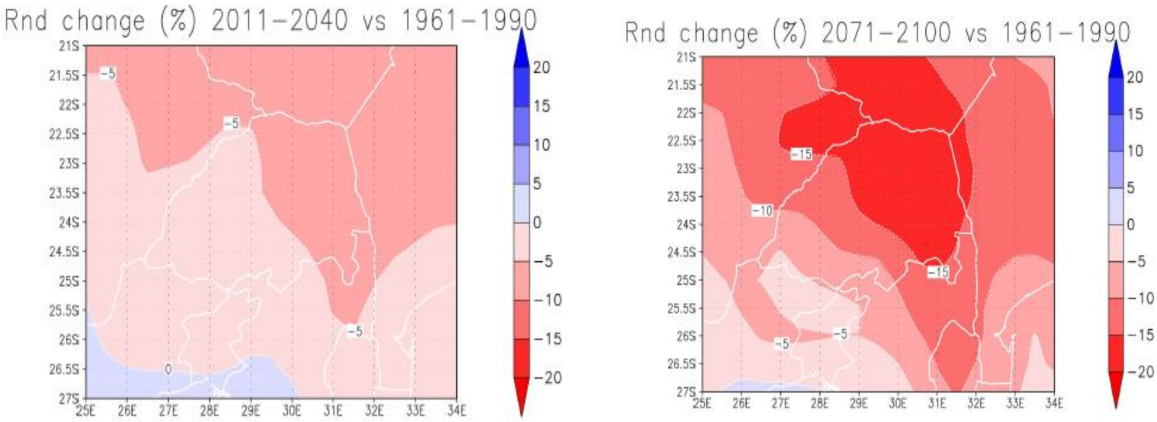



***Figure E12:*** *Climate change related annual rainfall projection variations*

*Vulnerability to climate change is summarised as follows at basin-scale:*

- *As the LRB has a high population of rural poor who are the least resilient of all economic groupings, the projected adverse impacts of climate change would be a major threat to rural livelihoods in this Basin.*
- *The sustainability of all levels of agricultural practices across the LRB, including smallholder farmers, would be deleteriously affected by the projected adverse impacts of climate change. This would have major implications for the socio-economy of the Basin. Firstly, because small-holder farmers have a lower adaptive capacity, they might not have enough resilience to continue to be profitable. Secondly, commercial farmers might be forced to cut back on production, because bulk water availability for irrigation might be reduced.*
- *The high level of utilisation of water resources and even deficits in many Sub-Basins across the LRB would be pushed further into problem territory by the projected adverse impacts of climate change. Such a deleterious trend would threaten the development futures of a number of Zones. For example, development of major energy projects that are located in water-scarce Zones in South Africa and Botswana could potentially be negatively impacted as a result of projected decreases in rainfall.*

## WATER GOVERNANCE

*On **Figure E13**, the boundary of the LRB, the boundaries of the four countries where they overlap with the LRB and the boundaries and names of the provinces within the LRB are shown.*


***Figure E13:** Administrative Map of the Limpopo River Basin*

## *Legal and Policy Framework*

### *International and Regional*

*All four Limpopo Basin States are Members of the African Union (AU), a continental body comprised of 53 member states, which determines macro-level policy trajectories for the African continent, and the Southern African Development Community (SADC).*

*At the regional level, the Revised SADC Protocol on Shared Watercourses is the key instrument for transboundary water management in the SADC. The Revised SADC Protocol (SADC, 2000) is a framework agreement, which contains the generic rules for the management of shared rivers within the SADC region.*

*In 2003 the Limpopo River Basin states concluded an agreement on the establishment of the Limpopo Watercourse Commission (hereafter LIMCOM Agreement), which entered into force in 2011 after the ratification requirements were met.*

*The purpose of the LIMCOM Agreement is to establish the LIMCOM and define the Commission's objectives (Art. 3), functions (Art. 7) and powers (Art. 8) as well the institutional arrangements (Art. 4) and operational rules (Art. 6).*

### *National Legal and Policy Frameworks for Water Management*

*In Botswana, the Water Act (1968) controls the access to and use of water in the country and provides an institutional framework for water allocation and control. A draft Water Bill has been produced as part of the ongoing water sector reform in the country and will, once promulgated as an Act, replace the 1968 Water Act. The Botswana National Water Conservation (WC) Policy (2004) prioritises different water uses. Botswana has also approved a National Policy on Disaster Management in 1996. The National Disaster Risk Management Plan (NDRMP) provides a guideline to plan and implement responses against disasters in the country.*

*In Moçambique the Water Law (1991) stipulates that the water of public domain comprises all inland waters (lakes and reservoirs), surface waters and the riverbeds; ground water; and the hydraulic works, equipment and dependencies. The Environment Law (Law n. ° 20/97) prohibits pollution as well as activities that accelerate erosion, desertification, deforestation or any other form of environmental degradation except as permitted by law. The Master Plan for Disaster Prevention and Mitigation approved in May 2006 and Disaster Management Policy of 1999 are main policy documents for disaster risk reduction in Moçambique.*

*Water Resources Management in South Africa is primarily governed by the National Water Act (1998). The NWA is complemented by the National Water Resource Strategy which provides the framework for the protection, use, development, conservation, management and control of water resources for the country as a whole. In addition, the supply of basic water and sanitation services is regulated in the Water Services Act (108 of 1997). The Disaster Management Act, (2002) provides for an integrated and coordinated policy of disaster risk reduction in which the main emphasis is on disaster risk reduction and aspects of post-disaster recovery.*

*The Water Act (1998) sets the parameters for access to and use of water in Zimbabwe as well as providing for the establishment of catchment and sub-basin councils composed of elected representatives. The Civil Protection Act (1989) is the legal instrument for disaster management in Zimbabwe.*

### *National Development and Sector Policy Framework*

*The long-term development planning in Botswana is guided by the Vision 2016. The Vision emphasises that water resource management and development planning need to be fully integrated in the economic development of the country. Other instruments that guide Botswana's development are the National Policy on Agricultural Development (1991), the revised Botswana National Energy Policy of 2004, the Industrial Development policy (IDP) of 1984, the National Ecotourism Strategy (2005) and the Wildlife Conservation and National Parks Act.*

*The Vision and Strategic Options of Agenda 2025 is an all-encompassing development vision for the country and guides its macro-level strategic planning. Other instruments that guide Moçambique's development are the National Irrigation Policy and its Implementation Strategy (NIPIS) which were formulated in 2002, the Moçambique Energy Policy (1997), the Energy Sector Strategy (2000), the Poverty Reduction Strategy, (PARP II), the Moçambique 'Tourism Policy and Implementation Strategy', the Forestry and Wildlife Policy and Strategy 1997 and the Environmental Act (1997).*

*In South Africa, The National Development Plan (NDP) - Vision for 2030, is a long term national development framework. Imperatives that drive and regulate development in South Africa are also the Water for Growth and Development Framework of 2009, the Integrated Food Security Strategy (IFSS) of 2002, the Agricultural Drought Management Plan (ADMP), the White Paper on Energy Policy (1998), the Integrated Energy Plan (IEP) of 2003, the South African National Industrial Policy Framework (NIPF) of 2007, the Industrial Policy Action Plan, the White Paper on Development and Promotion of Tourism in South Africa formulated in 1996, the Responsible Tourism Guidelines (2001), the Protected Areas Act and its Amendment Act of 2004, the National Environmental Management Act NEMA (1998) and the National Conservation Strategy.*

*The Medium Term Plan (MTP) 2010-2015 is Zimbabwe's National Development Plan which responds to the mandate set out in Article III of the Global Political Agreement (GPA) to support the restoration of economic stability and growth in Zimbabwe. Other imperatives and regulating documents are the Zimbabwe National Agricultural Policy Framework (1995-2020), the Zimbabwe National Energy Policy which was formulated in 2008, the Industrial Development Policy (IDP), 2012-2016, Policy for Wildlife (1992), the National Environmental Policy and the Environmental Management Act, National Environmental Policy and the Policy for Wildlife (1992).*

## *Institutions and Roles*

### *Regional*

*There is a suite of regional institutions that play a role in water related matters.*

*The **SADC Water Division** works together with SADC Member States in supporting, facilitating and coordinating the implementation of regional water related activities.*

*In the Limpopo basin, there has been an increasing realisation by the four basin states, of the importance for joint coordination, management and governance of the basin. A number of bilateral agreements exist and serve to coordinate technical matters between the two states. A Joint Water Commission exists between Moçambique and South Africa, whilst the Joint Permanent Commission for Co-operation facilitates discussion between Botswana and South Africa. South Africa and Zimbabwe are in the process of establishing a Joint Water Commission.*

*The "Agreement on the Limpopo Basin Permanent Technical Committee" was signed by representatives from Botswana, Moçambique, South Africa and Zimbabwe in 1986 and in 2003 representatives from Botswana, Moçambique, South Africa and Zimbabwe signed the Agreement on the establishment of the Limpopo Watercourse Commission. The agreement was ratified by member states in 2011.*

### *National*

*Fundamentally, water resource management within the basin is implemented at national levels through the various institutions and structures in-country.*

*In Botswana, the Ministry of Minerals, Energy and Water Affairs (MMEWA) has overall responsibility for water policy, assisted by the Department of Water Affairs (DWA), Department of Geological Surveys (DGS), Water Utilities Corporation (WUC) and the Ministry of Local Government (MLG) through District Councils (DCs) (Kgomotso, 2005).*

*The Water Apportionment Board in Botswana is a quasi-judicial body charged with the responsibility of administering conditional rights to abstract and use both surface and ground water (Kgomotso, 2005; Earle et al, 2008). The planning, construction, operating, treating, maintaining and distribution of water resources in Botswana's urban centres and other areas mandated by the government is undertaken by the WUC.*

*Moçambique is in the process of transforming the water sector to a model of decentralised management. The National Water Policy aims to decentralise water resources management to autonomous entities at the basin and provincial levels. The National Water Council is the body that defines water policy whilst the National Directorate for Water (DNA), as part of the Department of Public Works and Housing, is responsible for planning, regulatory and monitoring functions regarding water resources as well as for the provision of water supply and sanitation.*

*Five Regional Water Authorities (ARAs) in Moçambique are responsible for the management of water resources and each ARA manages several basins being simultaneously close enough to expedite management and coordination with political authorities (LBPTC, 2010). ARA-SUL is operational within the Limpopo basin and is responsible for a suite of water resource management and related functions including operation and maintenance of dams, monitoring, flood management, and water use licensing. River basin management institutions (UGBs) are intended to be established to manage water resources at a catchment scale. In order to create a more participative environment River basin management committees (RBCs) are being established as consultative bodies to work with the UGBs.*

*The Department of Water Affairs (DWA) in South Africa has nine DWA regional offices. Within the Limpopo basin two regional offices, namely the Mpumalanga Regional Office and the Limpopo Regional Office are present with the former taking responsibility for the Olifants water management area and the latter taking responsibility for the Limpopo water management area. The NWA makes provision for the establishment of Catchment Management Agencies (CMAs) and Water User Associations (WUAs). The CMA will eventually have powers and delegated functions to enable the CMA to issue water use authorisations and to issue compliance monitoring and enforcement directives. Only one CMA has so far been established which concerns the LRB namely the Inkomati CMA insofar that water is transferred from the Komati catchment to the LRB. WUAs are an important element of the framework in that they manage local resources and operate localised infrastructure in this regard. Various WUAs have been established in the LRB.*

*Water services provision is guided by the Water Services Act (Act 108 of 1997) which provides for Water Services Authorities (WSA) that have the responsibility to plan and oversee the provision of water services that are undertaken via a Water Services Provider (WSP).*

*The Department of Water in the Ministry of Water Resources Management and Development in Zimbabwe maintains responsibility and oversight for the water sector. The Zimbabwe National Water Authority (ZINWA), is a parastatal, which acts as an operator and a regulator and is responsible for the following functions at the national level: Water planning and implementation; Management of public dams; Supply of bulk water to the agriculture, industrial and mining sectors; Supply of bulk water to urban centres, and Coordination and supervision of the five catchment councils.*

*Catchment Councils (CCs) are established by the Minister of Water Resources Management and Development, in consultation with the ZINWA.*

### Main Governance Challenges

*A number of challenges have been identified, i.e.:*

- *The alignment between international legal obligations and water management in the framework of national legislation commonly requires further refinement.*
- *Generally there is only a limited degree of alignment between economic development goals between the various water use sectors.*
- *The institutional arrangements, in the various member states, are clearly at differing levels of progress across the Limpopo basin.*
- *Misalignment in planning among member states.*
- *From international levels through to local levels, the monitoring of actions and impacts is not really in place.*
- *Financial challenges are hampering institutional development across the region.*
- *Capacity constraints, both internally (staff) and externally (stakeholders), are significant in all four countries.*

## LIMPOPO INFORMATION MANAGEMENT SYSTEM (LIMIS)

### Need for Information System

*The objective of the LIMIS is to provide the water authorities of the four member countries with a Management Information System (MIS) in order to share and exchange data and information for the comprehensive and effective management of the LRB. Furthermore, the MIS need to adhere to the following objectives:*

- *Develop the databases in such a way that they can contain all the data and information to meet the requirements of the secretariat;*
- *The development of a GIS integrated into the MIS;*
- *Effective data management in terms of populating and maintaining the database.*

### LIMIS Structure

*The MIS is to act as a consolidated "container" of all available relevant information and data as can be seen in* ***Figure E14****, which indicates the various elements of the MIS, as well as the flow of information.*

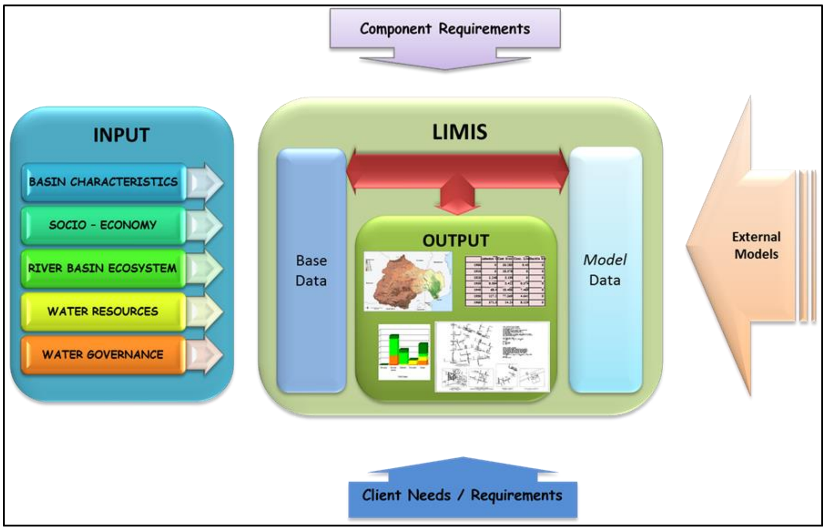



***Figure E14:*** *Layout of LIMIS*

*The detailed design of the LIMIS is based on the following broad components of a MIS, which are briefly described below.*

- *Logon page – user name and details,*
- *Home screen of the MIS – providing background information on the system and related aspects,*
- *Glossary – terminology and abbreviations,*
- *MIS – information and data functionality,*
- *Links –URLs to related sites,*
- *Documentation – relevant documents are made available,*
- *PDF maps – pre-generated maps that can be downloaded.*

*The LIMIS structure consists of five components, indicated by the LIMIS Page layout Shown on **Figure E15**.*

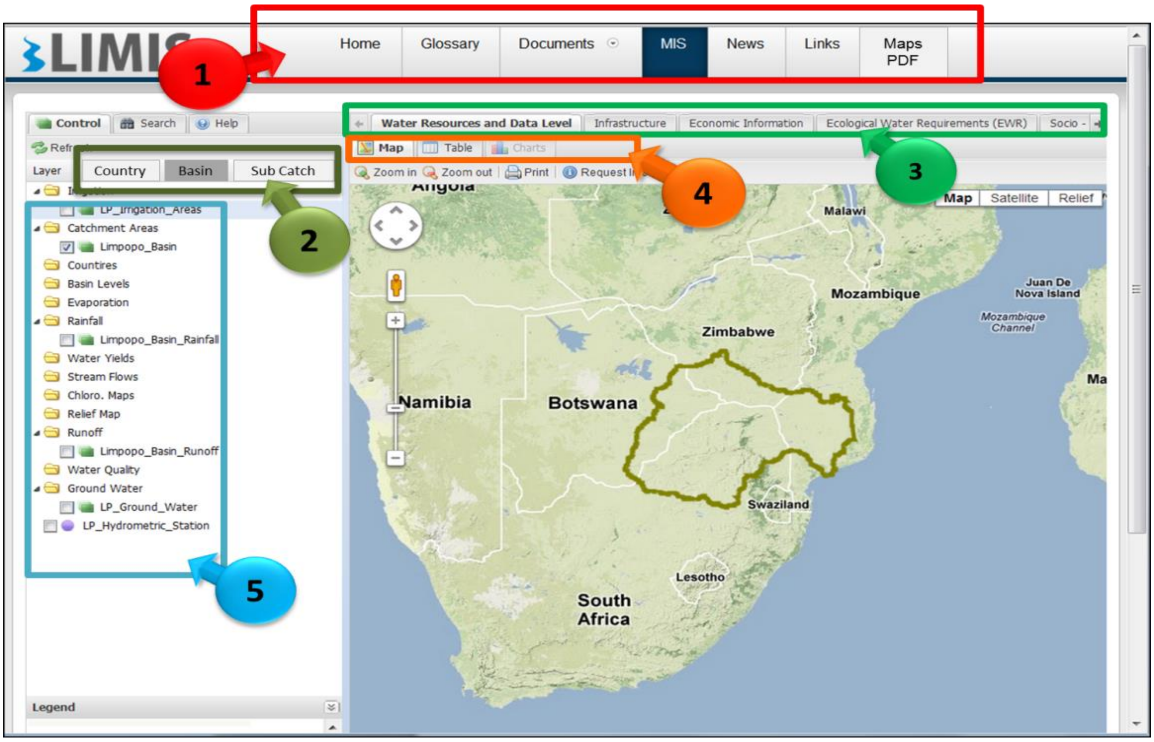



***Figure E15:*** *Selection bars in the LIMIS*

## *Updating of Information*

*As part of the Standards, Procedures and Policies LIMCOM need to define the methodology for updating the data. It would be preferable for the member countries to send their data to a data coordinator in LIMCOM who would update the LIMIS in order to avoid duplication and to exercise version control. This task would be seen as part of the LIMIS administration tasks.*

## *Data Collection*

*The LIMIS database has been designed with the objective of easy data maintenance. Furthermore, the LIMIS does provide the functionality that any other data set can be added and viewed in the LIMIS. This functionality is only available to the administrators of the system.*

*Future data collection needs to be done in terms of the procedure, standards and policy documentation in order to maintain system updating, accuracy, completeness, etc.  As part of the documentation, data maintenance needs to be addressed, which will guide LIMCOM with this responsibility.  A decision has to be taken where the application will be hosted.*

### *LIMIS Administration*

*The administration of the server is currently with Aurecon as the application being run by the service provider.  The administration will become LIMCOM's responsibility once the application is loaded on the server at LIMCOM.  The administration of LIMIS will then become part of the responsibility of the IT department at LIMCOM.*

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- Appendix C : Estuarine Assessment
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**VOLUME C3** Determination of Irrigated Areas and Irrigated Crop Water Requirements in parts of the Limpopo River Basin
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# 1. PURPOSE AND PROCESS

## 1.1 BACKGROUND TO THE STUDY

The Limpopo River Basin (LRB) is shared by four SADC Member States, i.e. Botswana, Moçambique, South Africa and Zimbabwe and has a total catchment area of approximately 411 000 $km^2$. The catchment characteristics are very diverse covering different climatic and topographic zones as well as land use types, including protected areas. The social and economic developments across the basin are also highly diverse. **Figure 1.1** shows the Limpopo River Basin and its main sub-basins.

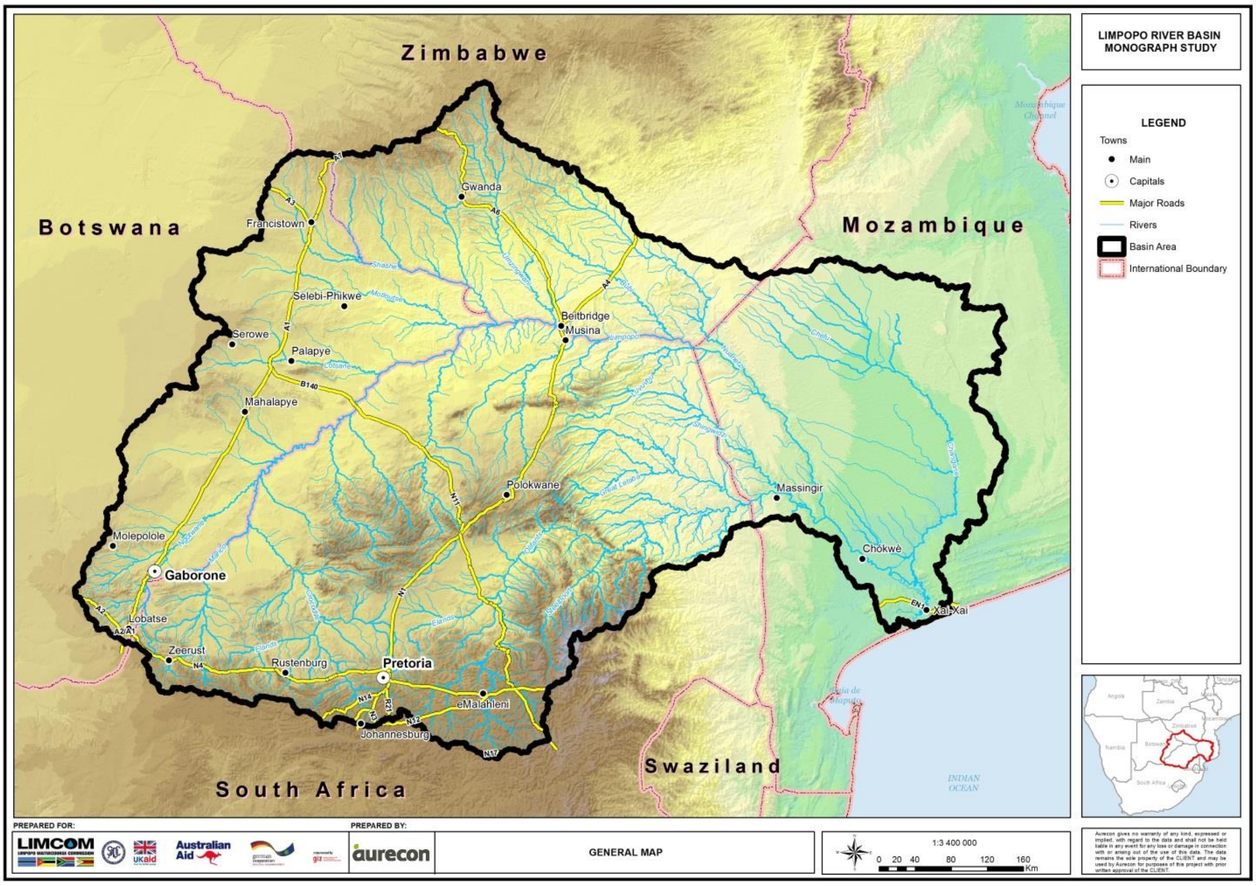



**Figure 1.1: Map of the Limpopo River Basin**

The commitment of the riparian states to managing their water resources in a joint manner dates back to 1986, when the "Limpopo Basin Permanent Technical Committee (LBPTC)" was established. The LBPTC was superseded by the Agreement for the establishment of Limpopo Basin Commission (LIMCOM) which was signed on the 27 November 2003 and entered into force on the 5th September 2011. The establishment of LIMCOM is in line with the requirements of Article 6 of the SADC Revised Protocol on Shared Watercourses. Currently LIMCOM is in the process of establishing its organs (i.e. Functional Committee) as per the Agreement and is preparing the Host Agreement for the establishment of a permanent secretariat to be hosted by Moçambique. The host agreement will be signed between the government of Moçambique and the LIMCOM Member States.

The process of jointly managing the LRB in a sustainable manner began when LBPTC undertook the Scoping Phase of the Joint Limpopo River Basin Study, (JLRBS, January 2010) with the specific objective of confirming the adequacy of all existing studies and data which was considered essential to a basin study and preparing a report which would be used as input in the further phases of the basin study. The Scoping Study also indicates where additional information is required and, with this in mind, devised a work program for the subsequent phase of the Joint Limpopo River Basin Study. The present Terms of Reference for the Limpopo River Basin Monograph Study (LRBMS)follow up on the outputs and recommendations of the Scoping Phase of the JLRBS.

During 2011 the LBPTC developed a framework for an Integrated Water Resource Management (IWRM) Plan, which is the pillar basis for sustainable water resources management of the Limpopo River. The IWRM Plan framework covers five years and is structured around three strategic areas: i) water governance, ii) water management and iii) water resources development. These three strategic areas each cover three strategic objectives namely; a) Disaster Management, b) Water Quality, and c) Water Allocation, which were identified during the JLRBS – Scoping Phase, and subsequently adopted by LBPTC. See **Figure 1.2.**

| | | |
|---|---|---|
| | **Vision** | **Sustainable water security for improved livelihoods in the Limpopo River Basin.** |
| **Limpopo Watercourse Commission**<br><br>**IWRM Plan Overview** | **Mission** | To advice riparian states on the governance, management and development of water resources in the Limpopo River Basin through integrated water resources management to improve social equity, promote economic efficiency and ensure sustainable development |
| | **IWRM Programme Goal** | Develop the capacities (individual, organisational and institutional) in the riparian states for the sustainable management and development of the Limpopo River Basin |

| **Strategic Objectives** | **Strategic Areas** | | |
|---|---|---|---|
| | **Water Governance** | **Water Management** | **Water Resources Development** |
| **Disaster Management** | Objective 1.1<br>Disaster Preparedness*<br>LIMCOM strengthen coordination amongst Member States to reduce the adverse effects of droughts and floods | Objective 1.2<br>Early Warning<br>LIMCOM facilitates the establishment of an early warning system for floods and droughts in the Limpopo River basin | Objective 1.3<br>Water Infrastructure<br>LIMCOM coordinates the management and development of water infrastructure in the Limpopo River Basin for reducing impacts of floods and droughts |
| **Water Quality** | Objective 2.1<br>Standards<br>LIMCOM promotes the adoption of common water quality standards for abating transboundary water pollution | Objective 2.2<br>Monitoring and Reporting System<br>LIMCOM facilitates the development of a Transboundary Water Quality Monitoring and Reporting System in the Limpopo River Basin | Objective 2.3<br>Best Practices<br>LIMCOM facilitates the implementation of pilots, and the assessment and dissemination of best practices on the abatement of transboundary water pollution caused by different sectors |
| **Water Allocation** | Objective 3.1<br>Benefit Sharing<br>LIMCOM promotes the equitable and reasonable utilisation of water resources in the Limpopo River Basin | Objective 3.2<br>Monitoring<br>LIMCOM facilitates the dissemination of data and information on water resources and water usage in the Limpopo River Basin | Objective 3.3<br>Water Availability and Efficient Use<br>LIMCOM promotes methods to increase water availability and the efficient use of water resources in the Limpopo River Basin |

**Figure 1.2: The IWRM Plan Framework**

The Limpopo River Basin Monograph will serve as the baseline for the Limpopo River Basin IWRM Plan, and form a foundation to monitor progress and evaluate impacts of the implementation of the Plan. Subsequent to the completion of the monograph, a series of other steps are envisaged and include preparing:

- Basin Development Scenarios;
- Limpopo long term IWRM Strategy and Plan.

The chronology of the activities leading to the Limpopo IWRM Strategy and Plan is depicted in **Figure 1.3.**

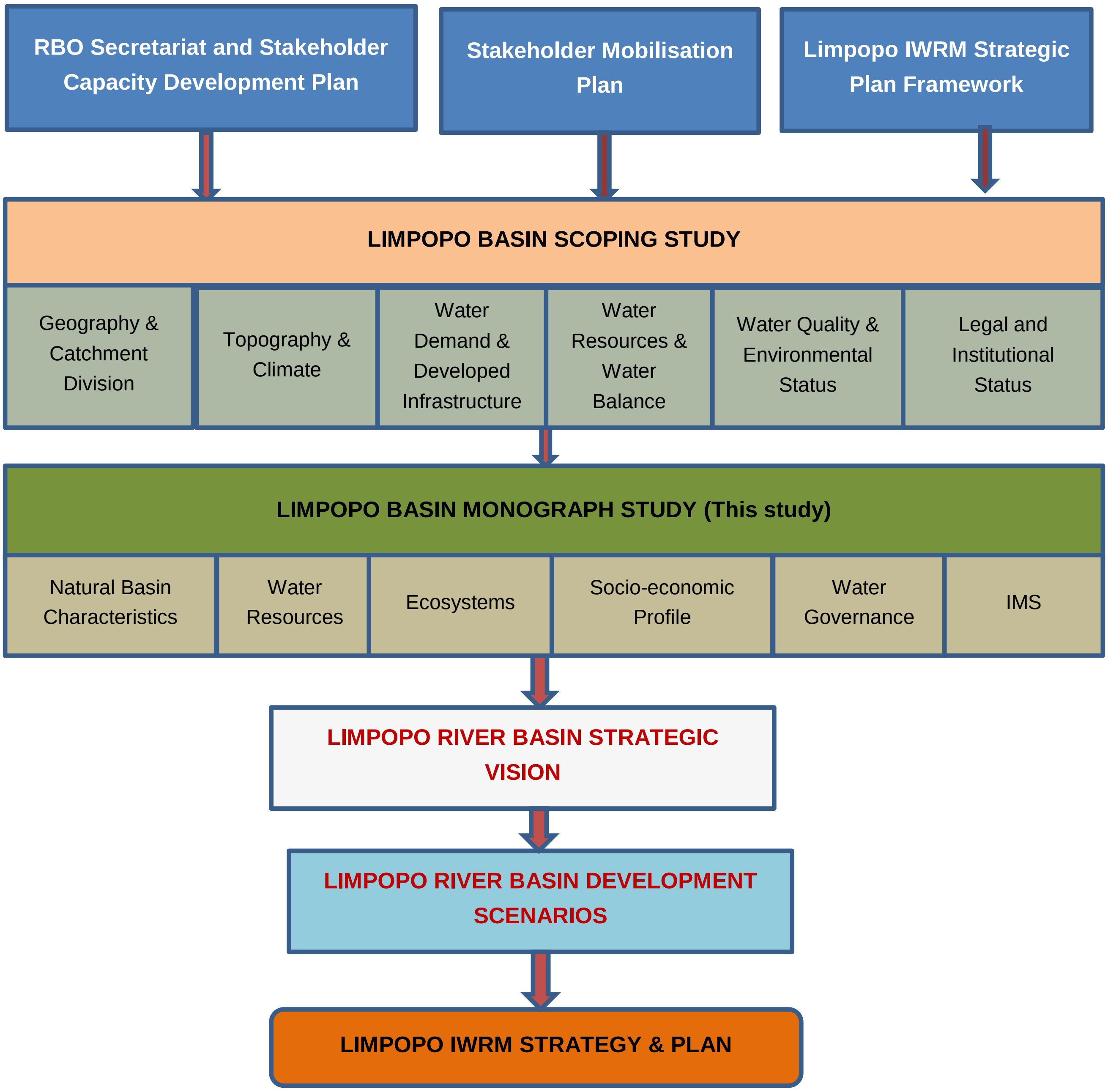



**Figure 1.3: Illustration of the chronological activities related to the Joint Limpopo River Basin Study**

Other related activities that are being undertaken by LIMCOM within the same time frame as the Monograph include:

- Setting-up a monitoring and evaluation system for the implementation of the IWRM Plan;
- Development of the LIMCOM stakeholder participation strategy, that will define how stakeholder participation should be undertaken to support the LIMCOM process, and in particular how stakeholder participation should be approached to achieve the three strategic objectives;
- Producing a Video documentary on different aspects of the Limpopo River Basin.

The consultant for the Limpopo Monograph has worked with the LIMCOM Secretariat to ensure that necessary information from the Monograph study is made available to these other activities and vice versa. The Monograph is a reflection of the current basin status, and does not deal with future development scenarios other than future development plans that have already been developed or are in the process of implementation. The understanding is that further future development scenarios will be analysed in the next phase of the Joint Limpopo River BasinStudy.

## 1.2 PURPOSE OF THE LIMPOPO RIVER BASIN MONOGRAPH

The purpose of the Limpopo River Basin Monograph Study (LRBMS) is to compile essential baseline information on the Limpopo River Basin. This is required for the preparation of alternative development scenarios and an Integrated Water Resources Management Strategy and Plan (IWRM Strategy and Plan) for the sustainable management of the Basin.

Six themes were agreed for the structure of the monograph and each is described below:

- Basin Characteristics
- Socio-economy
- River Basin Ecosystem
- Water Resources
- Water Governance, and
- LIMIS

Specific objectives are addressed through the components of the study as shown in **Table 1.1**.

**Table 1.1:** Specific objectives for various components of the study

| Comp No | Study Component | Objective |
|---|---|---|
| 1 | Limpopo River Basin Characteristics | To define the basic physical and social characteristics of the Limpopo River Basin. |
| 2 | Limpopo River Information Management System | To develop a Web based GIS information management system for use by decision-makers and stakeholders as a decision-support tool for water resources management. |
| 3 | Surface water resources assessment | To compute natural river runoff and estimate flood and monitoring flow characteristics (e.g. such as rating curves and safe yields), and assess the possible effects of climate change on the future surface water resources. |
| 4 | Groundwater resources assessment | To assess water demand and groundwater availability that can potentially be supplied by groundwater, and estimate the possible effects of climate change on the future groundwater resources. |

| Comp No | Study Component | Objective |
|---|---|---|
| 5 | Land use and socio-economy | To estimate the present and historic trends in land use and provision of the basic information on demographic variables, settlement patterns and socio-economic as well as economic developments in the different parts of the basin. |
| 6 | Water demand and infrastructure inventory | To estimate the present water demand for different sectors and different parts of the river basin, including an inventory of water resources development-related infrastructure. |
| 7 | Environmental studies and water quality | To estimate the environmental flow requirements for the tributaries main stem and estuary of the Limpopo River basin including a description of the present and historic trends in water quality. |
| 8 | Water balance analysis | To assess the present safe yields and water balance for the Limpopo River basin. |
| 9 | Legal and institutional review | To review the policy, legal and institutional framework for water resources management in the Limpopo Basin. |
| 10 | Training | To conduct targeted training on selected subjects related to the Monograph to enhance stakeholder participation and understanding of the monograph output. |

## 1.3 PROCESS FOLLOWED IN DEVELOPING THE MONOGRAPH

The development of the Limpopo River Basin Monograph (LRBM) is a complex multi-disciplinary and multi-national project which requires a systematic and integrated approach. The “Capacity WORKS” model developed by the German Government which provides a strategic management approach was followed in the detailed planning and execution of the Monograph.

The Limpopo River Basin Monograph comprises many inter-linked activities and a study flow diagram shown in **Figure 1.4** was produced to guide the planning process and shows how the various interlinked processes are integrated together to produce the key outputs of the study. The study flow diagram only shows the important links since there are too many other formal and informal links between the activities to be shown.

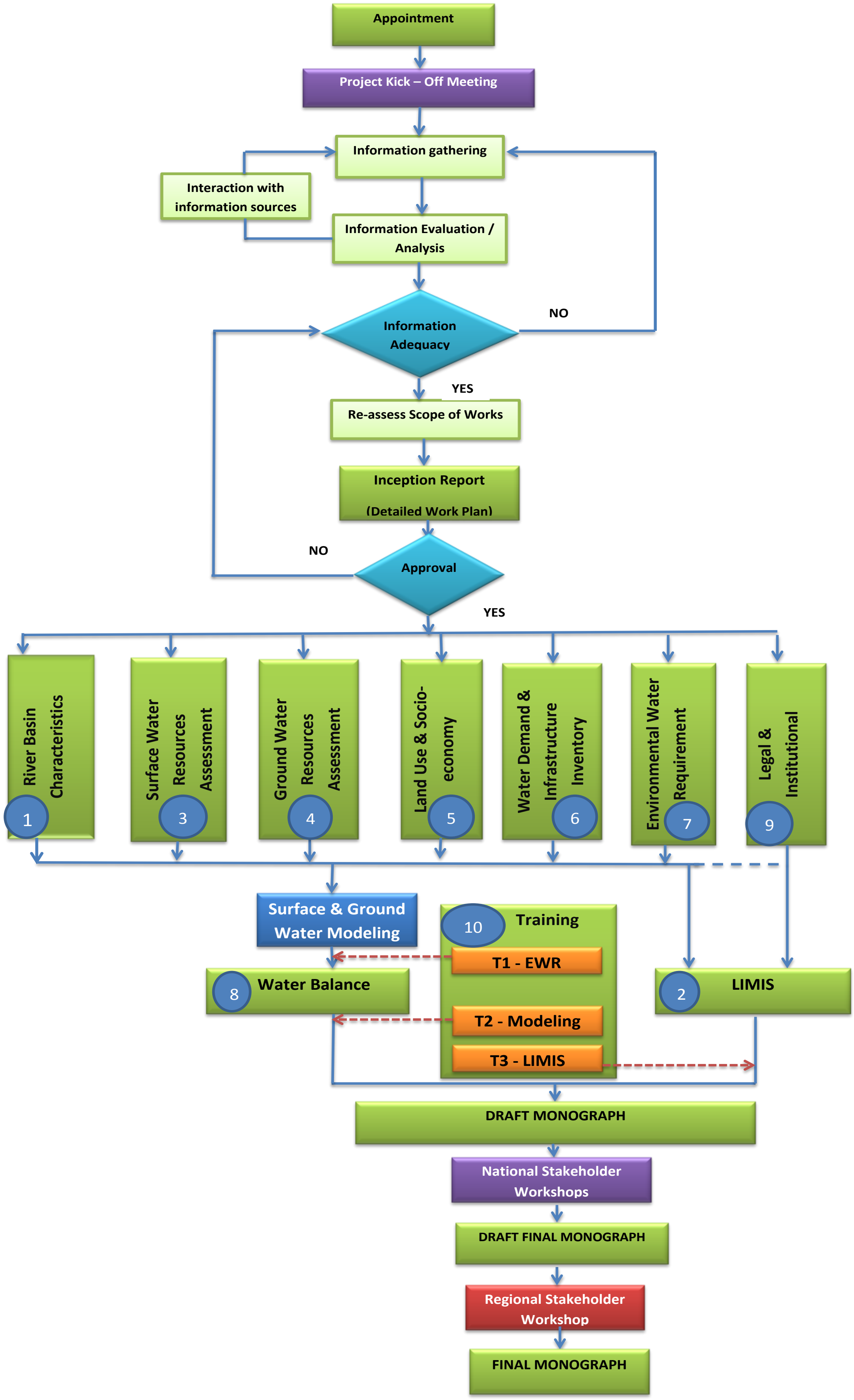



**Figure 1.4:** Study Flow Diagram

The components of the Monograph feed into two main elements of the monograph that are the core outputs of the study. The first element is the development of the Limpopo River Basin Information System (LIMIS). This comprises the development of a GIS-based information management system that has been and will continue to be used to capture, analyse and manage all the relevant data from the Limpopo River Basin. The information management system is a long-term information management tool that will also be used to monitor the long-term impacts on the water resources of the Limpopo River Basin. The second key element is the Water Balance model for the Limpopo River Basin. The Water Balance will indicate where water shortages exist and where interventions are necessary to reconcile water requirements with water availability. The development of the Water Balance for the Limpopo takes into account all the current water uses (surface and ground water) in the basin under current basin development conditions and management scenarios. It consider ecological water requirements and possible impacts of climate change. A water resource modelling approach was used to assess the Water Balance of the Limpopo River Basin as schematically shown in **Figure 1.5.**

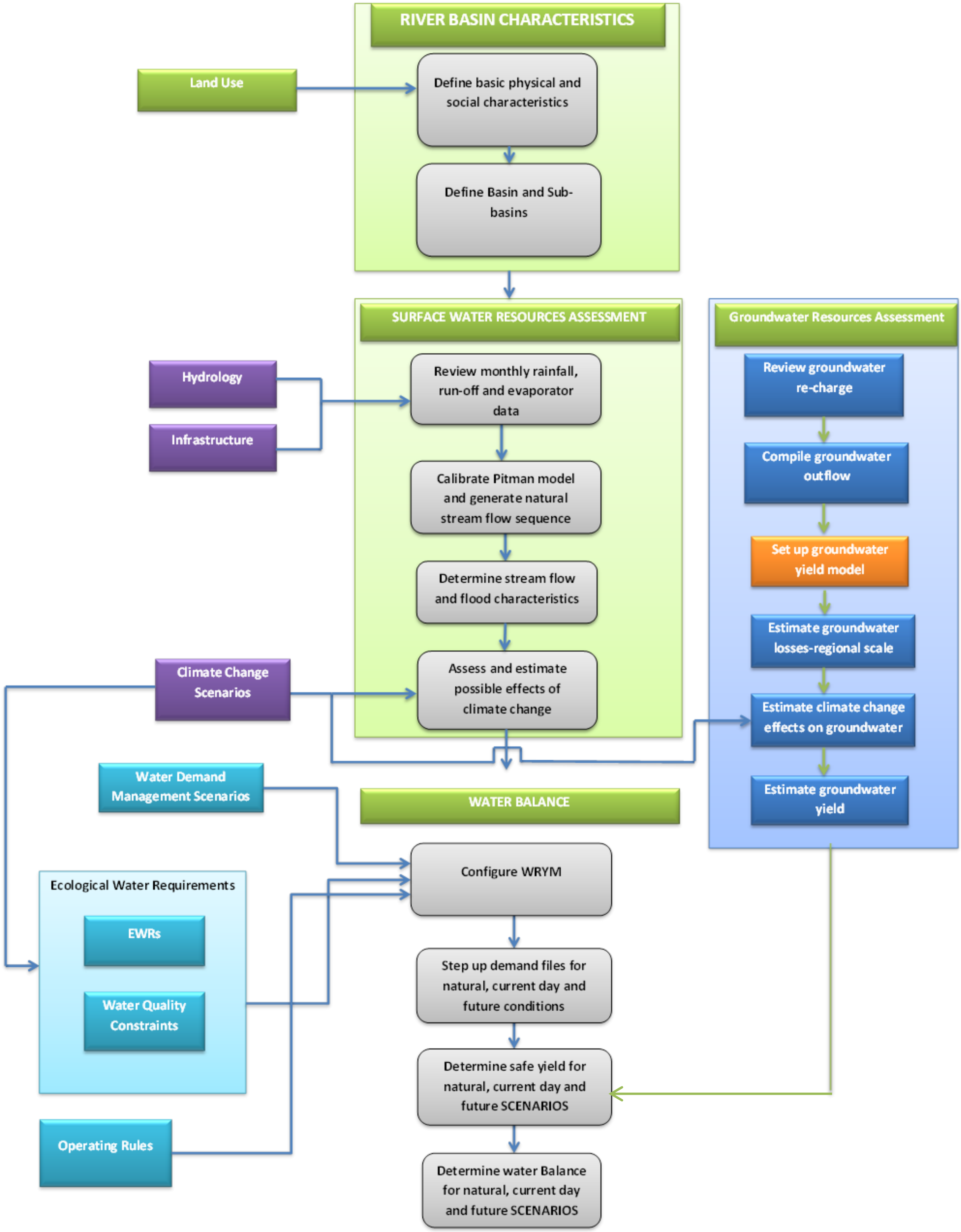



**Figure 1.5:** Approach for the Water Balance Assessment of the Limpopo River Basin

### 1.3.1 Structure of the Limpopo River Basin Monograph

Difficulties were foreseen in trying to package the Monograph according to the various components of the study. These difficulties arise from the fact that these components are interlinked. Consideration was given to aligning the structure of the Limpopo Monograph with the SADC Regional Strategic Action Plan on Integrated Water Resources Management Phase III (RSAP III). However, direct alignment with the RSAP III was \not possible as vital Monograph information would be lost. However, the RSAP III structure is suitable for the development of an IWRM Strategy and Plan. A decision was made to structure the Monograph according to six themes and describe the various Monograph components under the following themes:

- Natural Basin Characteristics
- Socio-economy
- River Basin Ecosystem
- Water Resources
- Water Governance, and
- LIMIS

The schematic view of the structure of the Limpopo River Basin Monograph is shown in **Figure 1.6** and the chapters of the Monograph are organised in accordance with these themes.

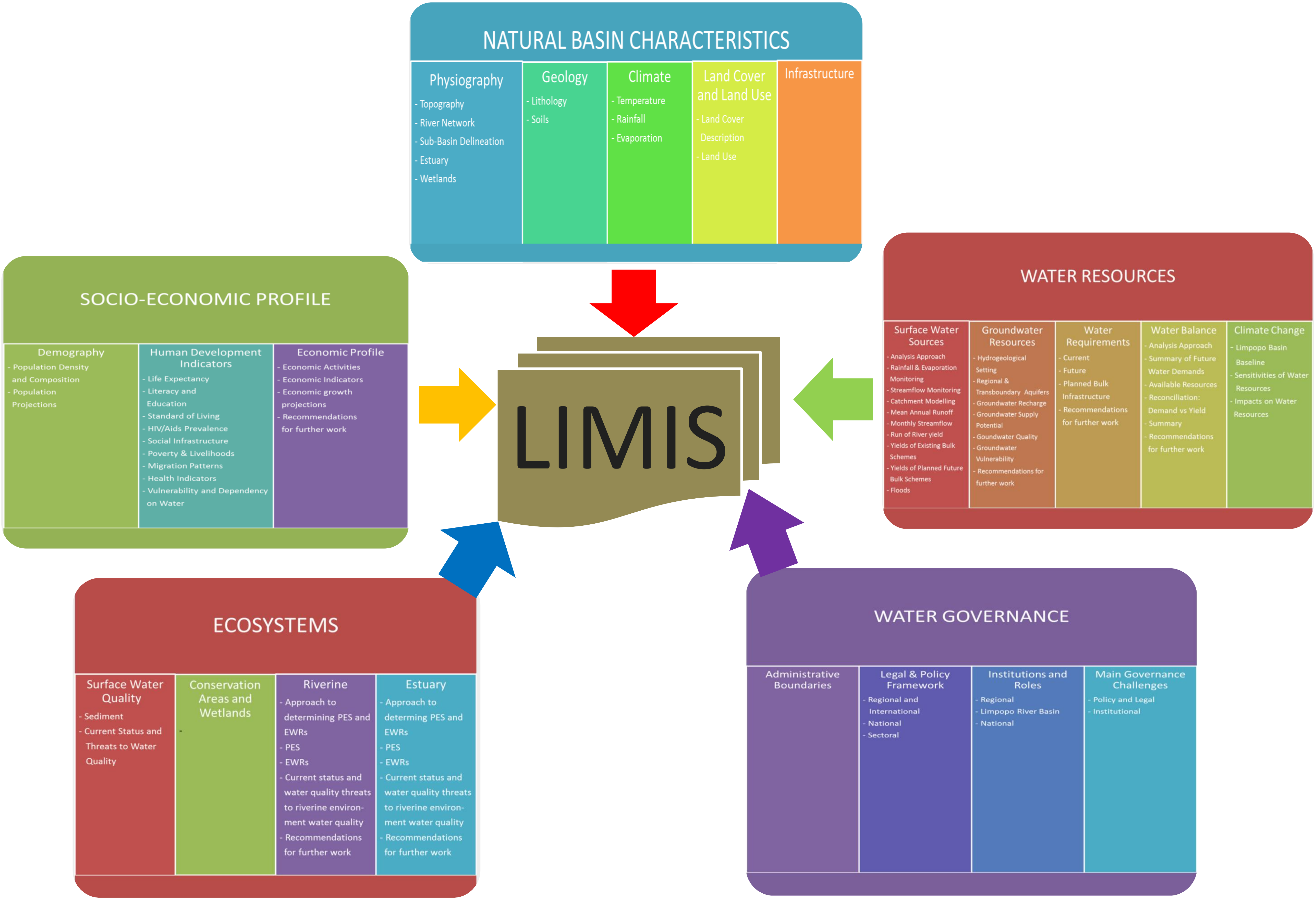



**Figure 1.6:** Structure of the Limpopo River Basin Monograph

### 1.3.2 Challenges

Challenges encountered in the development of the Limpopo River Basin Monograph include the following:

- The duration of the study and available budget only allowed one ecological field survey (in dry season), for both the riverine and estuary. This limited the methodologies that can be used to accurately assess the ecological water requirements for the basin. Only a few new ecological survey sites were added in Botswana, Mozambique and Zimbabwe compared to the numerous sites in existence in South Africa.
- The ecological water requirements for the estuary require a range of flow scenarios to accurately determine. As a result, the impact of the ecological water requirement on the yield of the system could not be confidently determined.
- The interaction between the riverine and estuary EWRs need to be studied. It could well be that the timing of prescribed riverine EWRs will not necessarily compliment the estuary EWR. The study's objective should be to find EWR provisions that will both optimally satisfy the rivers and estuary.
- Disparities in the quantity (density) of information between the Member States (e.g. rainfall, temperature and water level stations) which limits the analytical methods that can be used. Accurate flood peak information to assess floods was also limited because most of the stage – discharge curves were exceeded during most flood events.
- Numerous data essential for proper calibration of the water resources models was either missing or anomalous from most of the Member States. This reduces the accuracy of the water resources assessments. This information includes; borehole level, groundwater quality and use, dam level information, interbasin transfer data and information on the numerous farm and stock watering dams.
- Budget limitations also limited the validation and comprehensive inputs from stakeholders because the Draft Monograph document could not be printed and distributed to all stakeholders prior to the national stakeholder workshops. Therefore, a majority of the stakeholders who participated did not have access to the documents.

# 2. BASIN CHARACTERISTICS

## 2.1 INTRODUCTION

### 2.1.1 Physical and Climatic Characteristics

An overview of the physical and climatic characteristics of the LRB which covers an area of 411 000 km$^2$ is presented in this Chapter.

## 2.2 PHYSIOGRAPHY

### 2.2.1 Topography

The topography of the LRB is presented in **Figure 2.1.** Altitude varies from approximately 2 400 metres above sea level (masl) in the Highveld in South Africa to less than 200 masl for large parts of Moçambique.

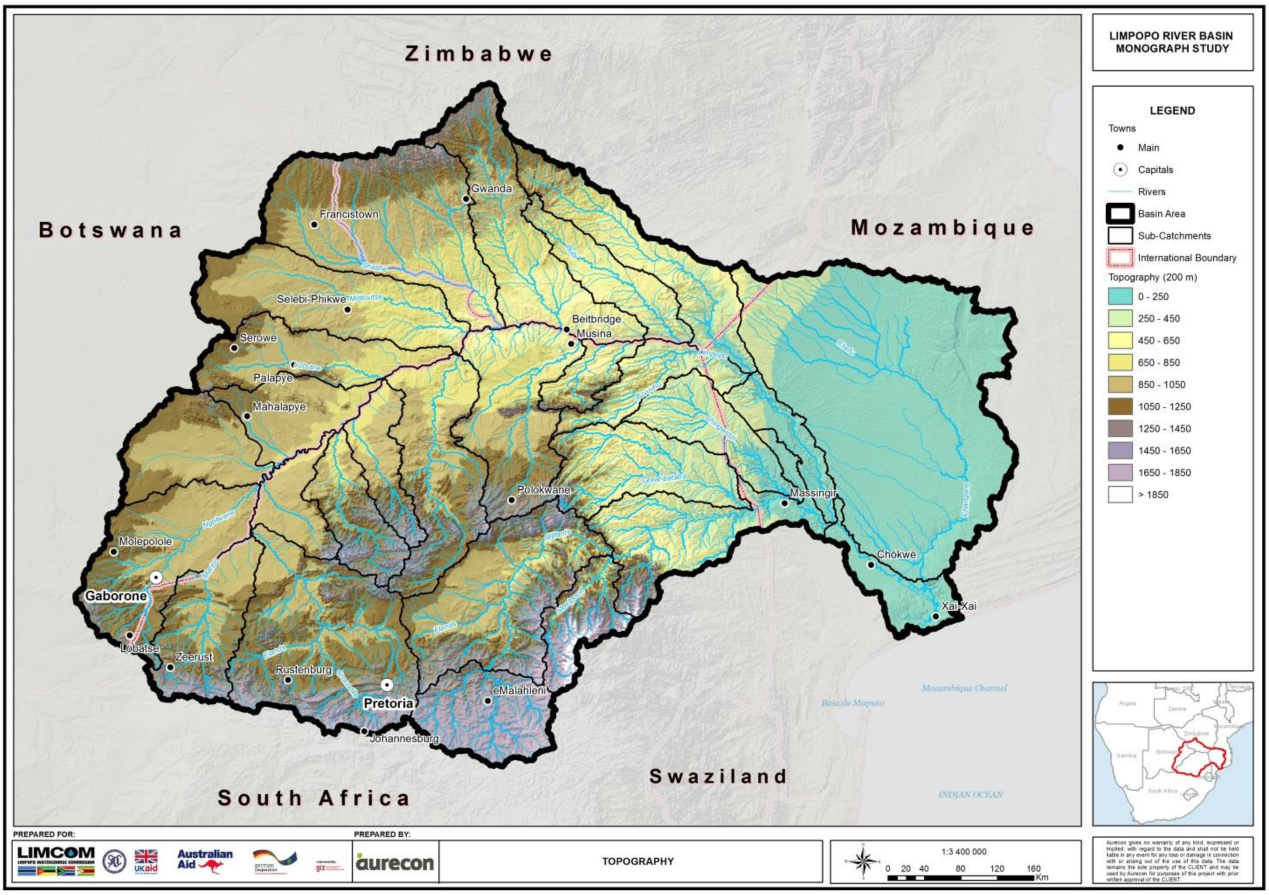



**Figure 2.1:** Topography of the Limpopo River Basin

### 2.2.2 River Network

The river network in the study area is depicted in **Figure 2.2.** The relative scarcity of river channels in the western portion of the study area indicates the arid conditions characteristic of Botswana. 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 Umzingwane River in Zimbabwe. There is only a single tributary in Moçambique, the Changane River which contributes only a small percentage of runoff to the Limpopo River. This tributary has significant wetlands associated with it.

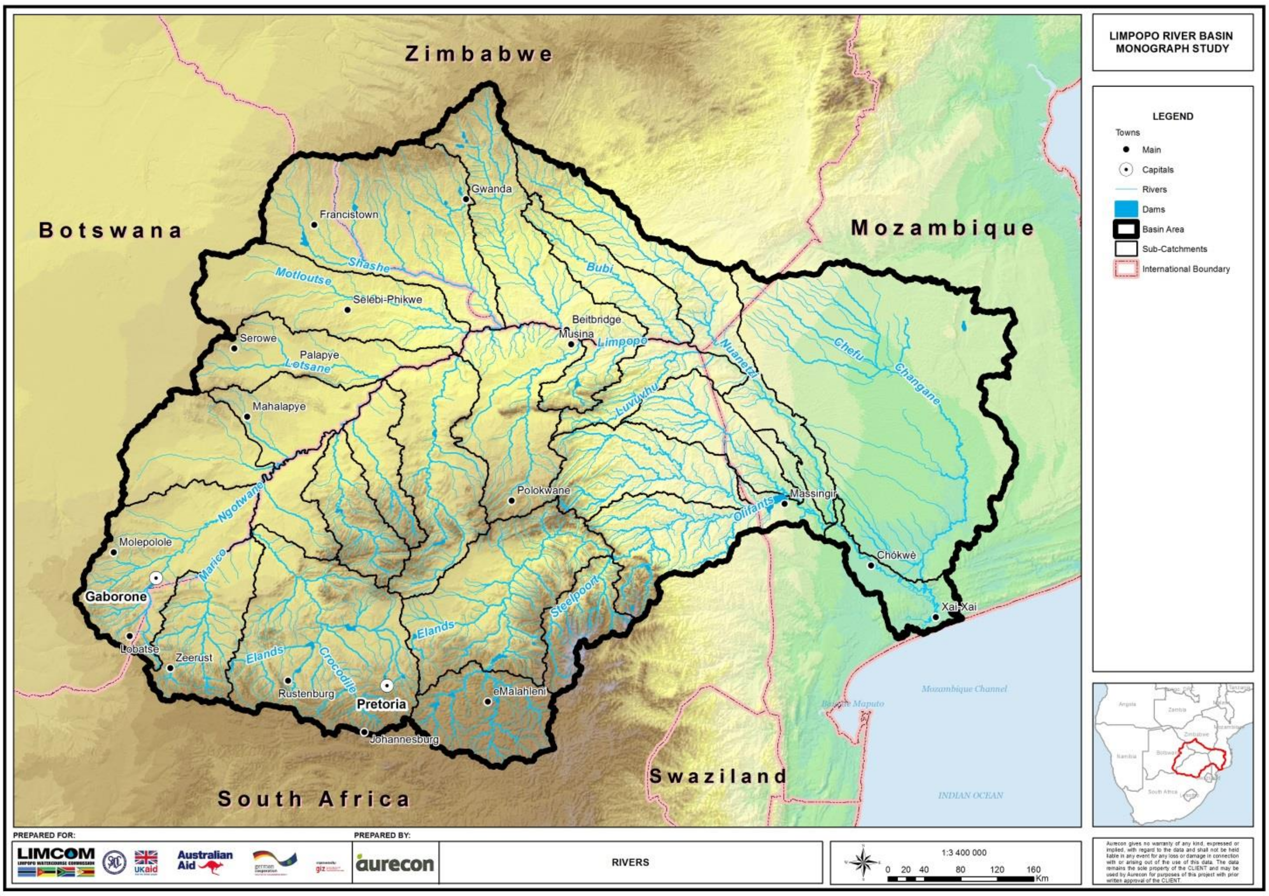



**Figure 2.2:** River Network in the Limpopo River Basin

### 2.2.3 Sub-Basin Delineation

**Figure 2.3** shows the delineation of the Sub-Basins of the LRB. The Sub-Basins were provisionally delimited by application of the Arc-Hydro utility in ESRI's ARCGIS Reference software and then refined by detailed visual inspection of contoured topographic maps. A number of the Sub-Basins in the Scoping Study were found to be erroneous. The Sub-Basins proposed are used in the hydrological modelling and water balance components of the Study, as well as for spatial organisation of all information reported under the LRBMS and populated in LIMIS.

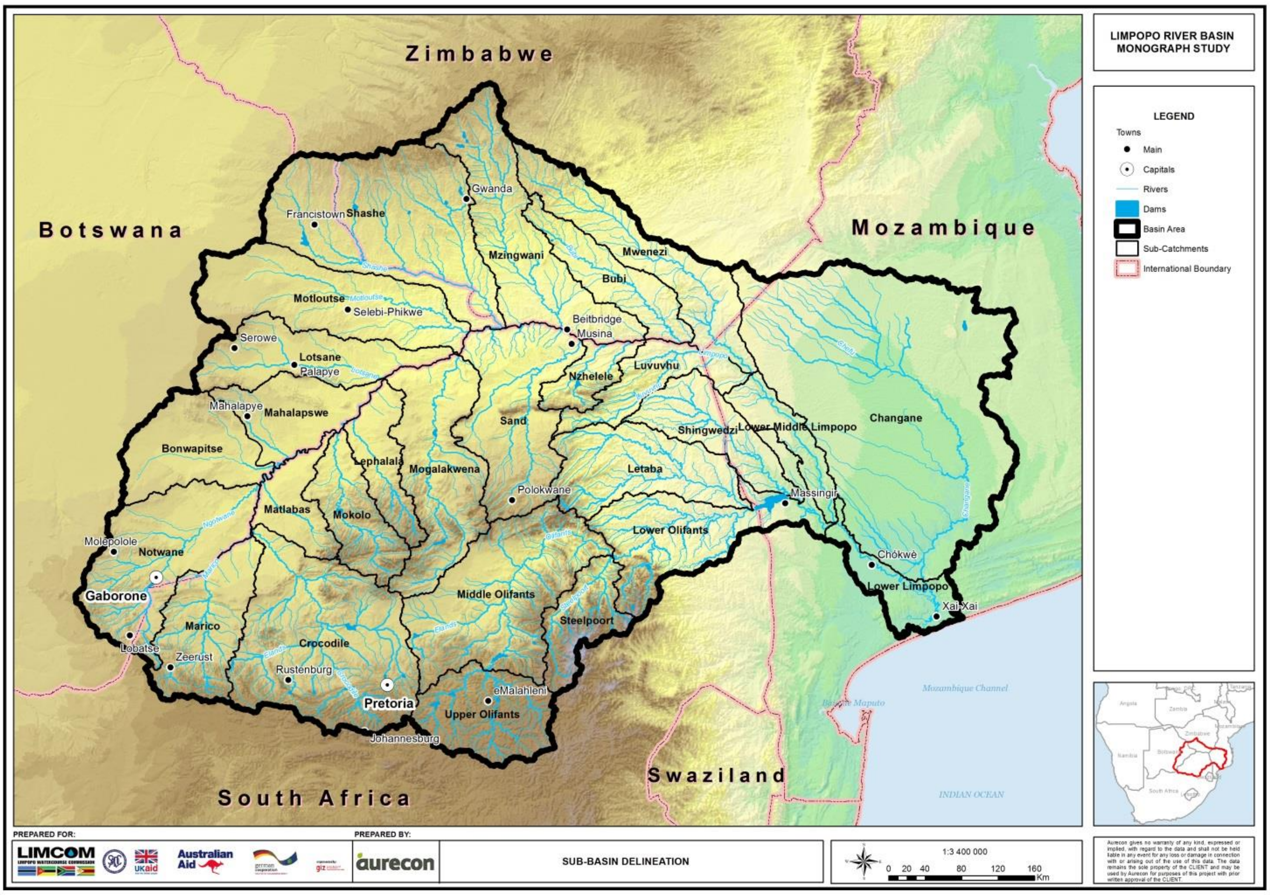



**Figure 2.3:** Delineation of the Sub-basins in the Limpopo River Basin

### 2.2.4 Estuary

The Limpopo River drains into the sea near Xai-Xai in Moçambique and the estuary that is formed stretches from the coastline approximately 35 km inland. A comprehensive description of the estuary is provided in **Chapter 4.5**.

### 2.2.5 Wetlands

The locations of wetlands in the LRB are presented in **Figure 2.4.** These are predominantly located in the Lower Limpopo and Changane River Sub-Basins in Moçambique and in high lying areas in South Africa.

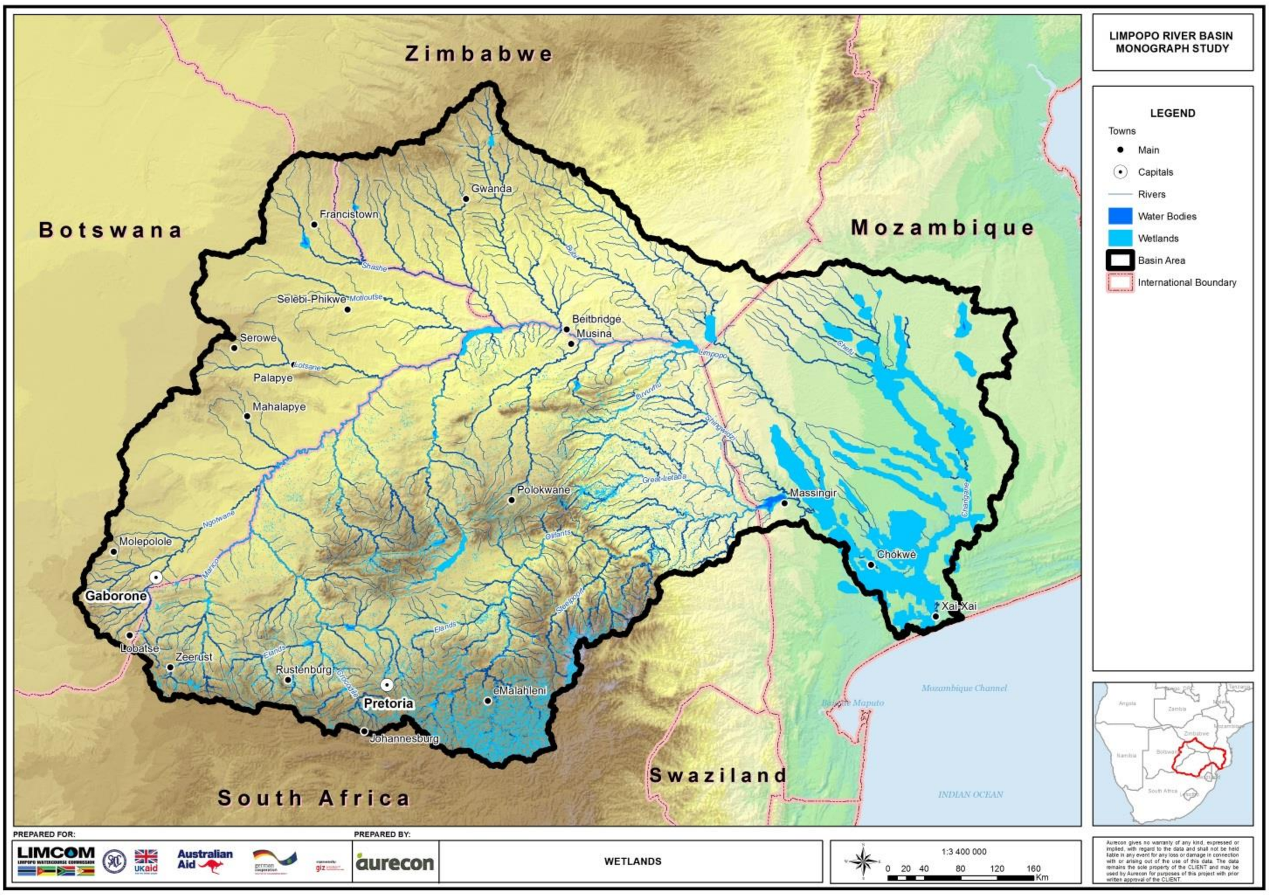



**Figure 2.4:** Location of Wetlands in the Limpopo River Basin

## 2.3 GEOLOGY

### 2.3.1 Lithology

**Figure 2.5** presents a simplified overview of the geology of the LRB. The geology of northern Sub-Basins in Zimbabwe is dominated by granites – the origin of the Matopos Hills. The geology of the South African portions of the LRB is more variable but granites are also wide-spread, along with sandstones. To the west, in Botswana, unconsolidated and consolidated sands and gravels are predominant. The lithology of the eastern Sub-Basins in Moçambique comprises mainly unconsolidated sands and gravels as well as silt, mud and clay derived from Tertiary, Cretaceous and the Volcanic Upper Karoo formation.

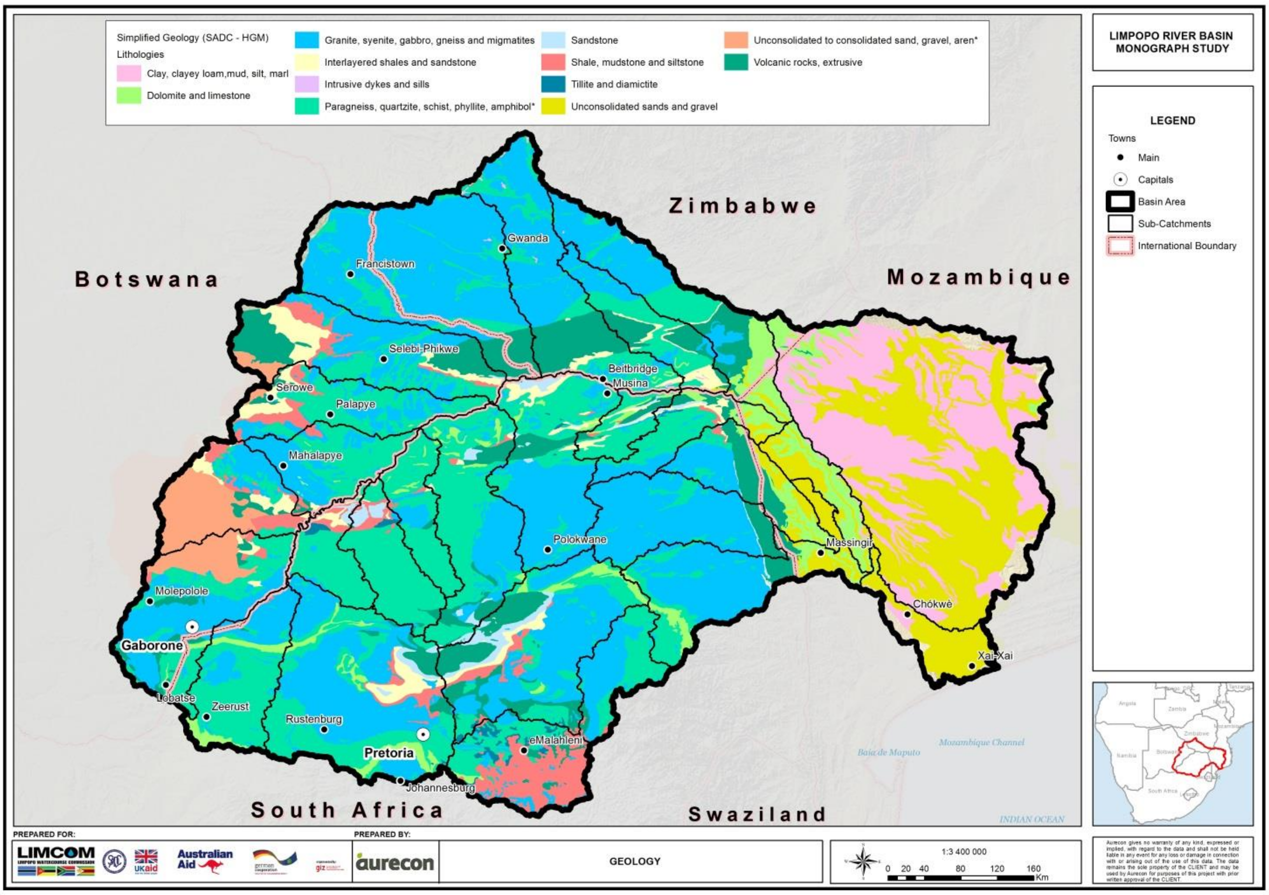



**Figure 2.5:** Overview of the Geology of the Limpopo River Basin

The simplified geology of the Limpopo Basin was obtained from the South African Development Community. Hydrogeological Map and Atlas and is based on Geological map of the Southern African Development Community (SADC) Countries, 1 : 2 500 000 scale. Published by the Council for Geoscience, South Africa, 2009 ( Hartzer. F.J).

### 2.3.2 Soils

The major soil types in the LRB are depicted in **Figure 2.6.** The Moçambique 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. The Zimbabwe Sub-Basins mainly have the Luvisols soil type, which is characterised 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 are dominated by Arenosols, which are sandy-textured soils that lack any significant soil profile development. In the South African Sub-Basins the soil types are immensely varied.

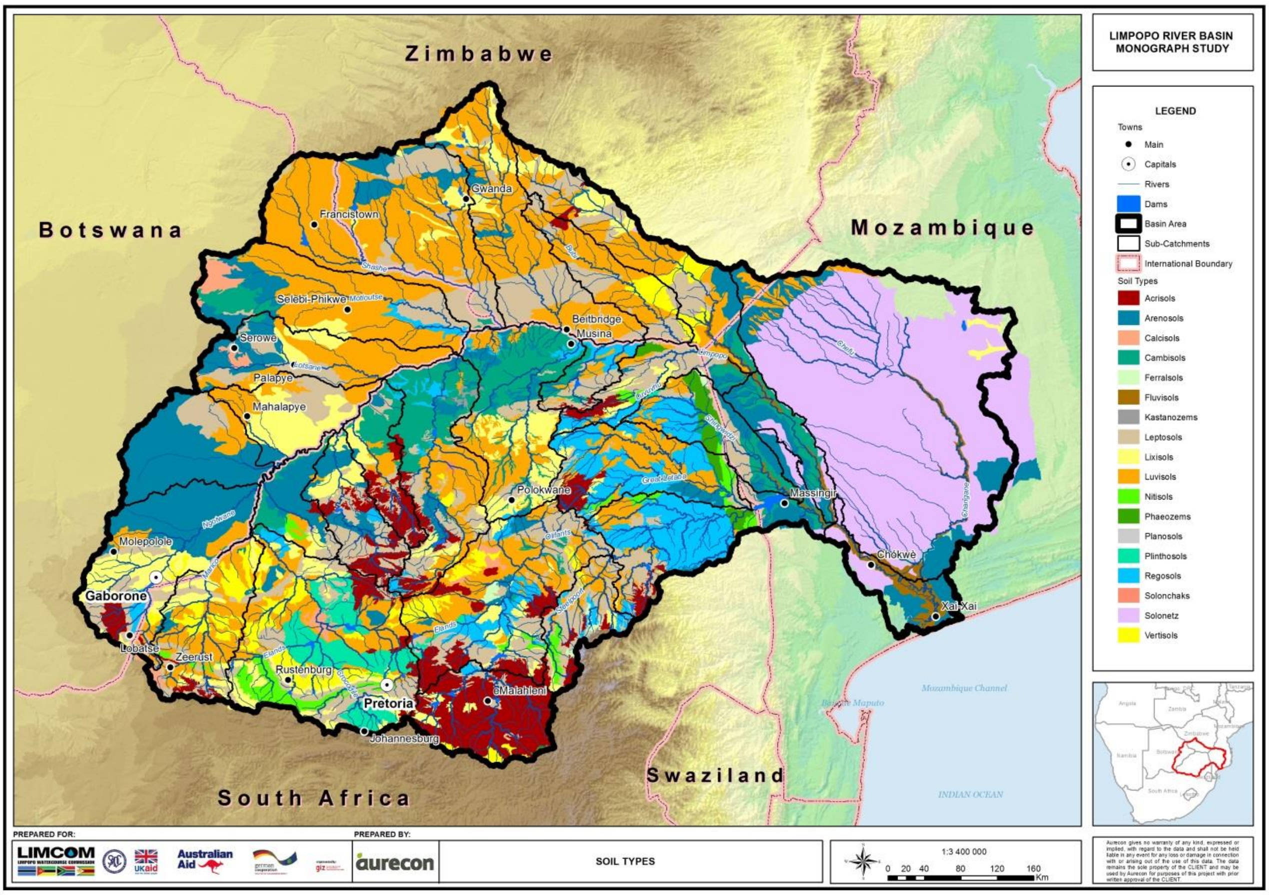



**Figure 2.6:** Major Soil Types in the Limpopo River Basin

## 2.4 CLIMATE

### 2.4.1 Temperature

**Figure 2.7** shows the daily mean temperature in January and **Figure 2.8** the daily mean temperature for July. Temperature is closely correlated with topography in the LRB. In summer the high altitude Matopo's in Zimbabwe and the Highveld of South Africa are between 5 and 10°C cooler (temperatures typically of 20° C) than the central LRB (temperatures typically 25 to 30° C) in summer. Interestingly the low altitude eastern portion of the LRB in Moçambique has higher summer temperatures (about 30 degrees C) than the arid parts of Botswana (around 25 degrees C).

This pattern is similar for the winter daily average temperatures although absolute temperatures are much lower (ranging from 6 to 20 degrees C).

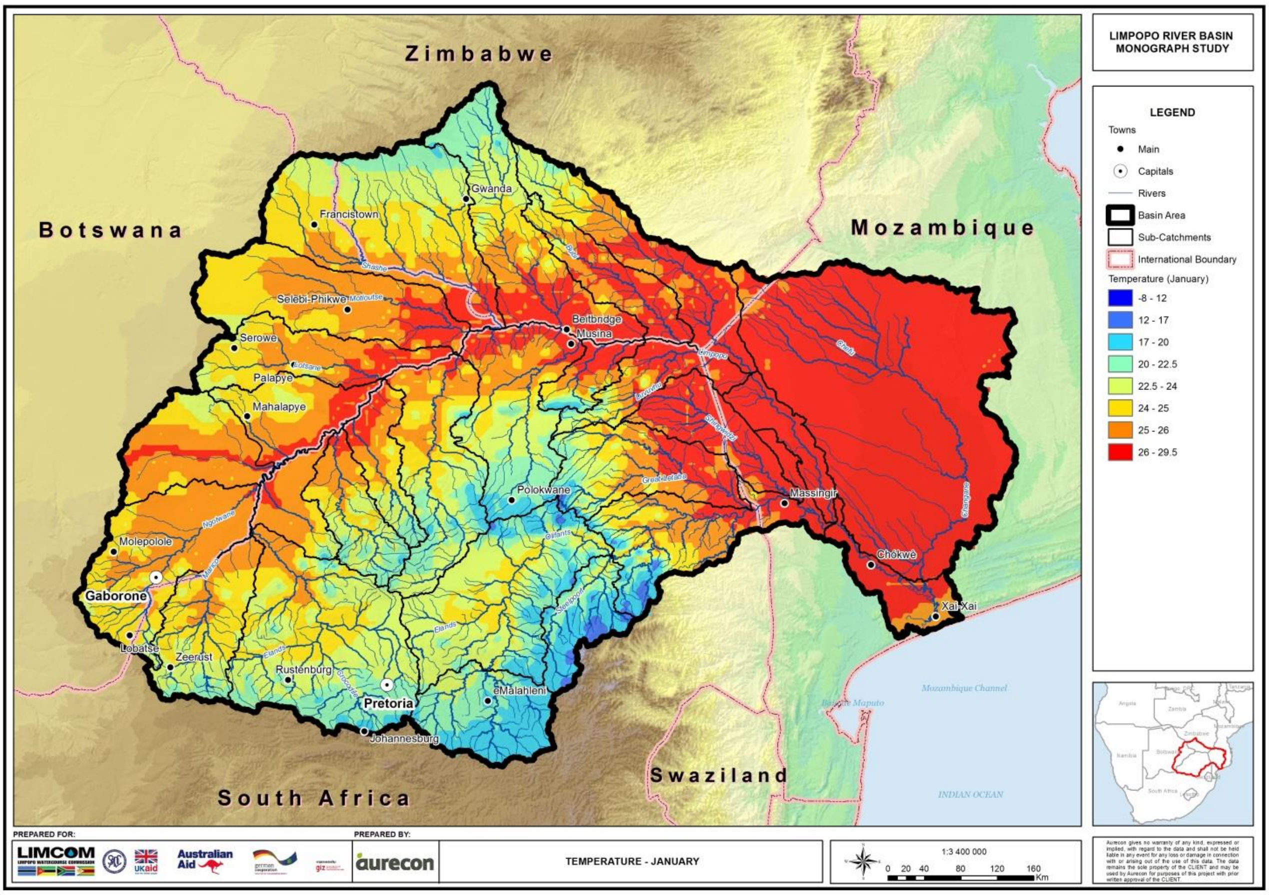



**Figure 2.7:** Daily mean temperature in January

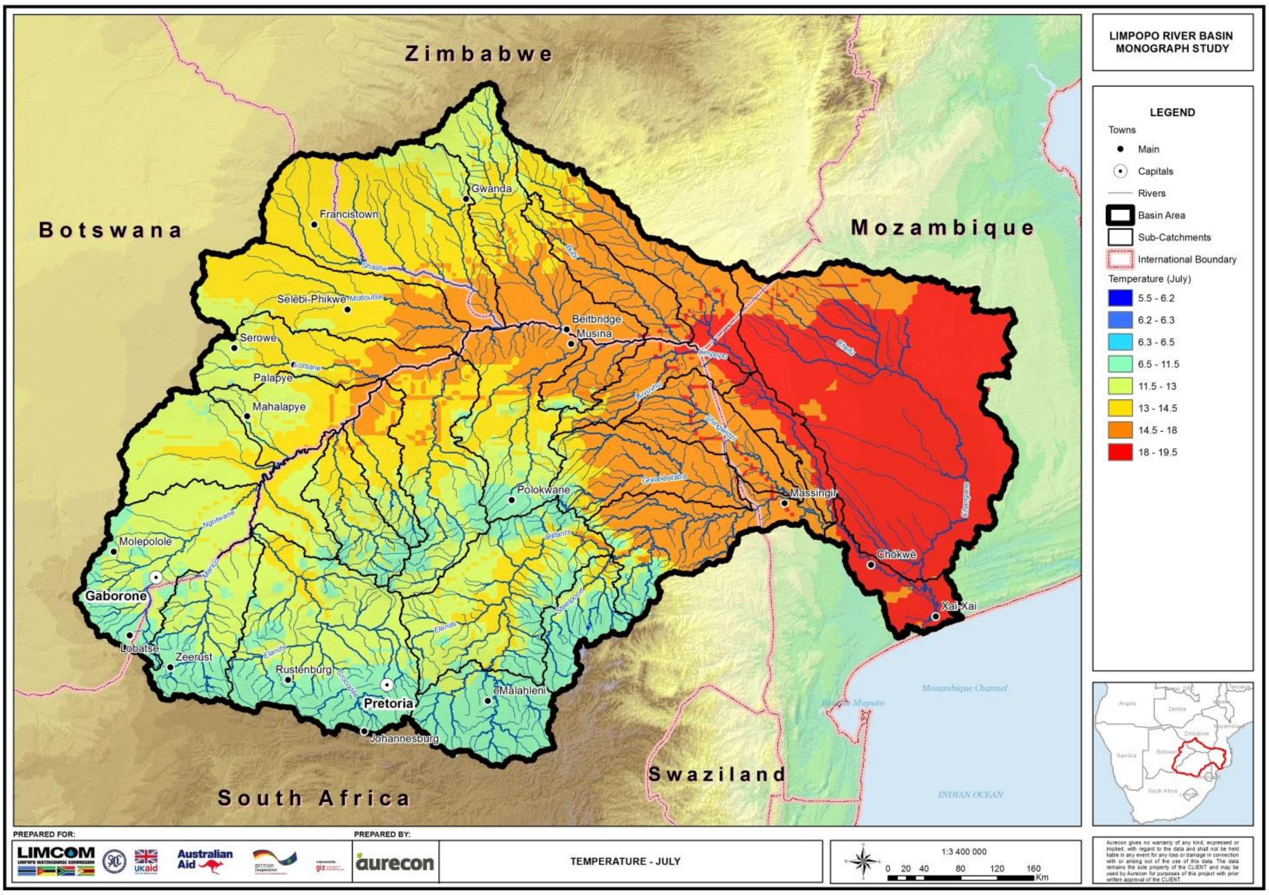



**Figure 2.8:** Daily mean temperature in July

### 2.4.2 Rainfall

The distribution of Mean Annual Precipitation (MAP) across the LRB is presented in **Figure 2.9.** The catchments to the west, especially in Botswana, experience low rainfall (around 400 mm per year). Generally, MAP increases in an easterly direction, except for the vicinity of the Limpopo River main-stem where low MAP becomes more severe in an easterly direction. The Beit Bridge area has the lowest MAP (between 250 to 350 mm/year). To the east of Beit Bridge the MAP then generally increases in an easterly direction, reaching more than 800 mm/year near the coast. MAP generally increases to the north and south of the Limpopo River. In the Zimbabwe portions, MAP ranges from about 800 mm/year in the Matopos to 300-400 mm/year near the Limpopo River main-stem. Similar conditions exist in South Africa with the rainfall gradient ranging from 800 mm/year in the Magaliesberg to the south to 300-400 mm/year near the Limpopo River main-stem. A large portion of the LRB in South Africa has a MAP of between 500-800 mm/year. This results in this portion of the LRB contributing the majority of the main-stem flows.

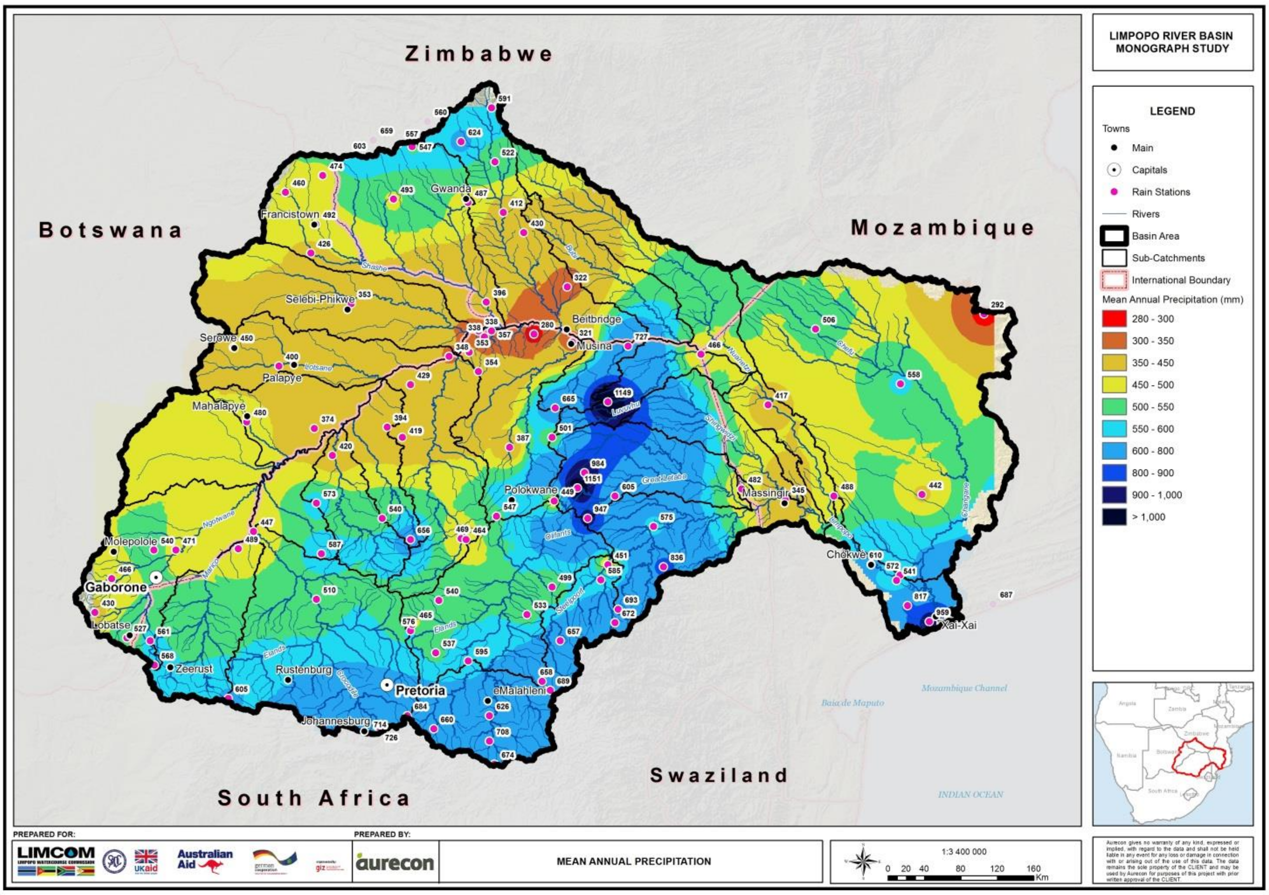



**Figure 2.9:** Distribution of Mean Annual Precipitation (MAP) across the Limpopo River Basin

### 2.4.3 Evaporation

The distribution of Mean Annual Evaporation (MAE) based on measured S-pan evaporation is shown in **Figure 2.10.** Of particular interest is the low spatial variability of evaporation when compared with rainfall. Generally, MAE in the south of the LRB is in the order of 1500 mm/year, about 2200 mm/year in the vicinity of the Limpopo River and approximately 2000 mm/year to the north of the LRB. Of note is the high evaporation in the west of Botswana (2200-2400 mm/year). Although the average temperature is lower than that in Moçambique the evaporation is higher reflecting the drier conditions in Botswana.

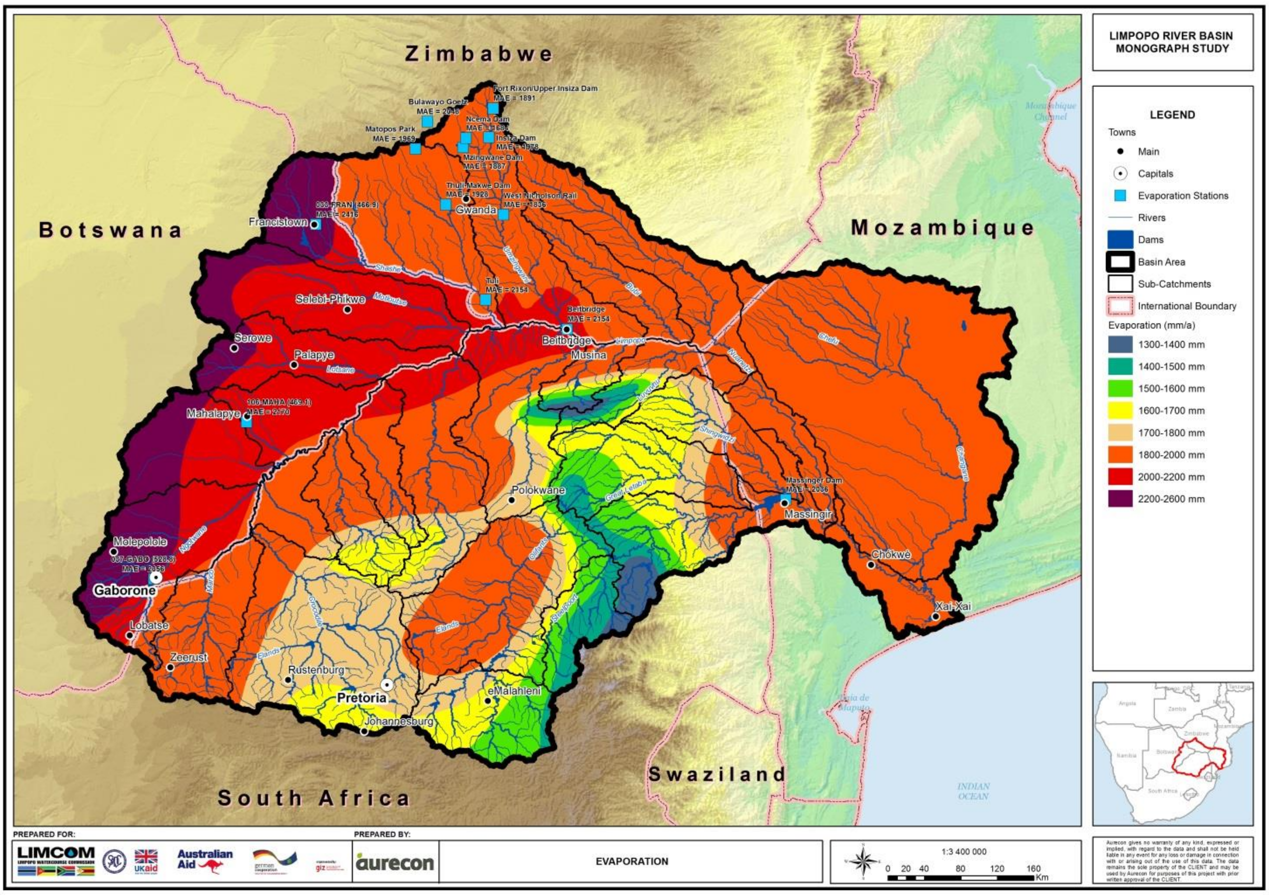



**Figure 2.10:** Mean Annual Evaporation

## 2.5 LAND COVER AND LAND USE

### 2.5.1 Land-Cover Description

A high-level overview of the distribution of land-cover in the LRB is presented in **Figure 2.11.** Grassland-Cropland mosaics and Savannah are by far the dominant land-cover categories.

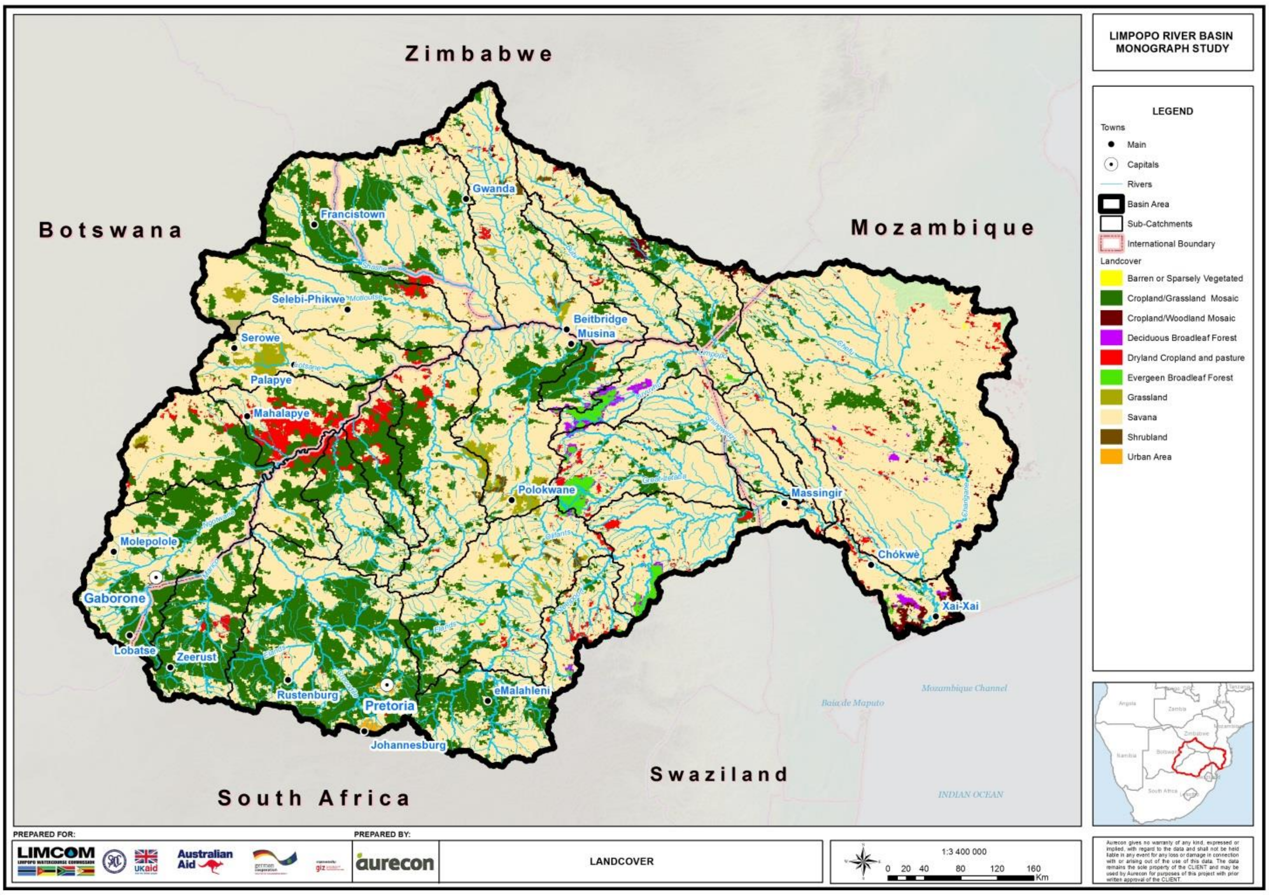



**Figure 2.11:** High-level overview of the distribution of land-cover in the Limpopo River Basin

### 2.5.2 Land Use

A high-level overview of the distribution of land-use in the LRB is presented in **Figure 2.12** including large bulk water supply dams, as well as the location of smaller farm dams. Dry land agriculture and irrigated cropland are identified, although this latter category should be treated as an interim classification until better data is obtained (especially in Zimbabwe). The National Parks/conservation areas are also displayed.

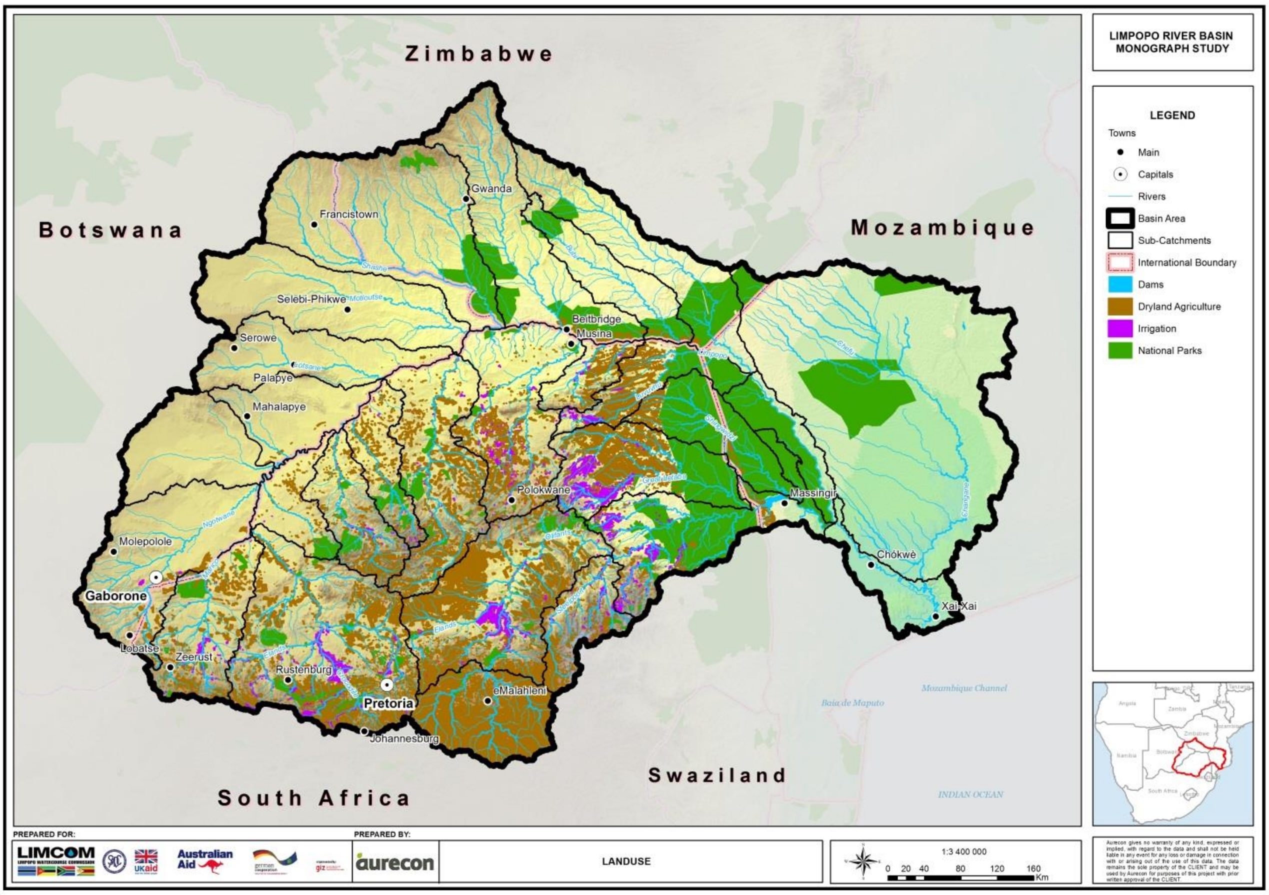



**Figure 2.12:** High-level overview of the distribution of land-use in the Limpopo River Basin

## 2.6 INFRASTRUCTURE

The major water infrastructures in the Limpopo basin are the dams, power stations and transfer schemes. Each of these types of infrastructure is described below.

### *Dams*

Dams vary in size from small farm dams, of which there are literally hundreds, to large dams as registered on the register of the International Committee for Large Dams (ICOLD). The dams presented in this monograph are limited to the dams that are considered to be “large” in terms of the ICOLD definition. These large dams include dams with a height of more than 15m, or if the height is between 10m and 15m, dams which meet one of the following criteria:

- Dam wall length of more than 500m;
- Storage capacity of more than 3 million $m^3$;
- Flood discharge of more than 2 000 $m^3$/a,
- Unusual conditions in dam type or foundation.

The 97 LRB dams meeting these criteria are listed in Appendix A. The information was retrieved from the dam database of Food Aid Organisation (FAO)/Aquastat, which was compiled in 2006. Supplementary information was obtained from the water departments/ministries in each of the four countries.

The 97 large dams are too many to show on a map. **Figure 2.13** therefore depicts only the large dams with a storage capacity of more than 30 million $m^3$.

**Figure 2.14** shows the dams in the Limpopo River Basin as listed in **Appendix A** into different size groups and it can be seen that the biggest numbers of dams have a cross storage capacity of below 100 million $m^3$.

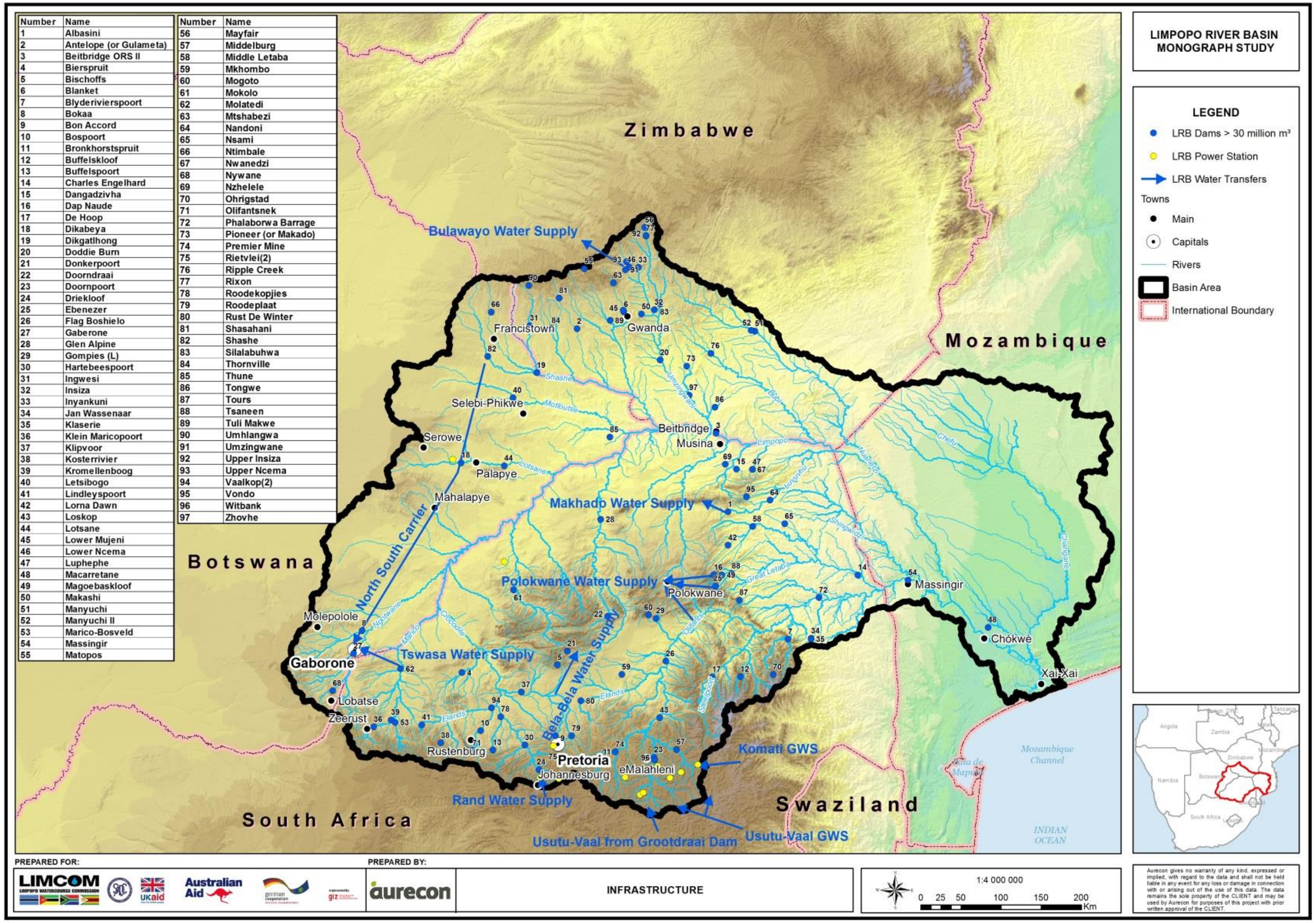



**Figure 2.13:** Water Related Bulk Infrastructure in the Limpopo Basin

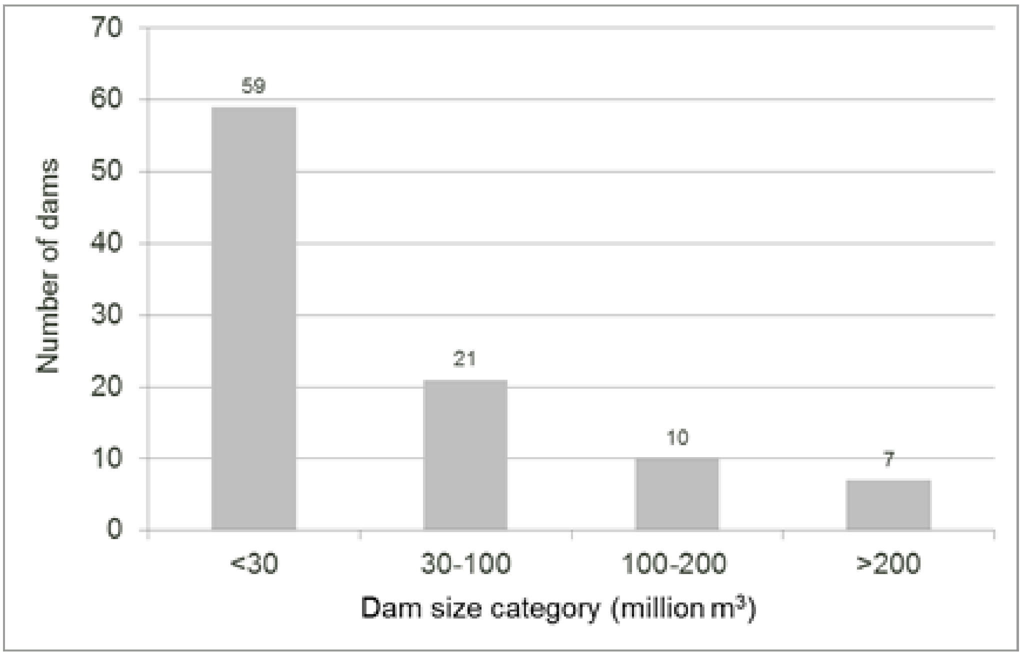



**Figure 2.14:** Dam size groups and numbers in the LRB

***Power stations***

There are currently 12 thermal power stations in the basin, 11 of them located in South Africa, with a total water use of 223 million $m^3$/a, and the Morupele power station in Botswana. Two stations in South Africa are under construction.

All thermal power plants, including the two under construction and are listed in **Table 2.1.**

It is noticeable that the majority of the South African power plants are grouped in the very South of the Limpopo basin close to the major coal fields near Johannesburg and Pretoria. One is in the Mokolo sub-basin and a second in this sub-basin is under construction.

Data are based on recent information (mainly 2011, 2012) from various sources such as BPPC and ESKOM.

**Table 2.1:** Thermal Power Stations

<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 #</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: # - Under construction*

Thermal power stations that are being planned for the future are listed in **Table 2.2**.

**Table 2.2:** Thermal power stations envisaged for the future

| Name of Power Station | Country | Sub-basin | Power Generation Capacity (MW) | Water Requirements million m³/a |
|---|---|---|---|---|
| Morupele B | Botswana | Lotsane | 600 | 18 |
| Mmamabula | Botswana | Mahalapswe | 1 200 | ± 40 |
| Exaro Private | South Africa | Mokolo | | 3 |
| Medupe II | South Africa | Mokolo | 4 764 | 15 |

There are currently no substantial hydro-power stations, only a small one at Lydenburg in South Africa.

Two hydro-power stations are, however, being planned as listed in **Table 2.3.**

**Table 2.3:** Planned Hydro-Power Stations

| Name of dam where hydro-power will be generated | Country | Sub-basin | Power Generation Capacity (MW) | Water Requirements million m³/a |
|---|---|---|---|---|
| Massingir Dam | Moçambique | Lower Olifants | 28 | 2 488 |
| Manyuchi Dam | Zimbabwe | Mwenezi | 5 | Unknown |

### *Transfer Schemes*

Water transfer schemes have been developed in the Limpopo River basin to augment locations with water deficits. Transfers are either classified as intra-basin transfers which constitute water transfers within the Limpopo basin or inter-basin transfers which constitute water transfers from one river basin to another. The latter only occur in South Africa.

**Table 2.4:** Water Transfer schemes in the Limpopo basin

| Name | Purpose of Water Transfer Scheme | Rivers/Tributaries involved | | Countries involved | Transfer volume (million $m^3$/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 Rustenburg via Rand Water. | 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 Resources Development Project (ORWRDP) | Water supply to Mogalakwena (including mines at Mokopane) | Olifants River (Flag Boshielo Dam) | Sterk River | South Africa | 40 (Design stage) |
| Gravelotte Supply | Water Supply to Gravelotte mine | Groot Letaba River System (Tzaneen Dam) | Olifants River | South Africa | 2 |
| Thabina Dam Water Transfer | Water supply to villages in the north of Olifants Catchment | Groot Letaba River System (Thabina Dam) | 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 Bela | Apies/Pienaars River System | Mogalakwena River System | South Africa | 3 |

| | | | | | |
|---|---|---|---|---|---|
| Tshwasa Water Scheme | 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:<br>• Upper Ncema<br>• Lower Ncema<br>• Mzingwane<br>• Inyakani<br>• Insiza<br>• Mtshabezi | Bulawayo in Zambezi catchment | Zimbabwe | Unknown at this stage. Info will be obtained. |
| North-South Carrier | Supply to Gaborone and other towns | Lower Shashe | Ngotwane | Botswana | 45 |

It is noticable that much more water is transferred into the Limpopo basin than out of it. The Vaal River System and indirectly the Orange-Senqu basin is the largest supplier of water to the Limpopo Basin, followed by the Komati and Usuthu basins.

# 3. SOCIO ECONOMIC PROFILE

***(Refer Technical Annexure Volume A1: Socio-Economic Profile)***

## 3.1 INTRODUCTION

Socio-economic and population information is critical for integrated water resources management. It provides vital data on peoples' livelihoods and dependence on water including their vulnerability to famines, droughts and floods as well as the linkages between water and poverty. The data provides a foundation for the macro socio-economy study of the river basin. Water is a key input to the economy of the Limpopo River Basin. It is used for domestic, industrial, mining, agriculture (livestock and irrigation), forestry and for power generation. This section of the report first provides demographic data for the Limpopo River Basin and includes human development indicators for each riparian country and sub basin. It then describes the economic profile, the sectoral water use and economic benefits of that use by country.

## 3.2 DEMOGRAPHY

### 3.2.1 Population Density and Composition

The Limpopo River Basin comprises a population estimated at 18 million inhabitants (2012). Gaborone and Pretoria, the capital cities of Botswana and South Africa, respectively, are situated in the Limpopo River Basin. Francistown, the second largest city in Botswana is also located in the Limpopo River Basin. Bulawayo, the second largest city in Zimbabwe, is situated just outside the Limpopo River basin but relies on water from the Mzingwane tributary of the Limpopo Basin. Two of South Africa's largest metropolitan areas of Tshwane and the northern half of Johannesburg as well as the mining towns of Emalahleni, Rustenburg and the Provincial Capital of the Limpopo Province, Polokwane are in the basin. In Moçambique the town of Xai-Xai and the village of Chokwe are both situated in the basin. With an increase in urban migration and an increase in mining activities, water demands will increase.

### 3.2.2 Methodology used to estimate Basin and Sub-basin Population

The latest population census data for the four Member States was obtained from the National Census Offices of each of the countries. The recent population censuses were as follows:

- Botswana and, South Africa – 2011,
- Moçambique – 2007
- Zimbabwe - 2012 (preliminary results).

The census district maps and associated population were also obtained from the census offices. To compute the Limpopo basin and sub-basin populations for the four countries the census district maps and populations for the various countries were overlaid in GIS together with the Limpopo basin and sub-basin maps. The GIS tool was used to convert the district population into the sub-basin population by using the areas of the census district that fall within the Limpopo sub-basins. For Botswana and South Africa the enumeration area populations were used to obtain a more accurate population estimate. Unfortunately enumeration area population figures were not readily available for Zimbabwe and Moçambique. For Moçambique administrative district population were used to obtain a more accurate population estimate. The population data for Moçambique was brought to the same base year of 2011 using the population growth rate as published by

Population Division of the Department of Economic and Social Affairs of the United Nations. The 2012 preliminary population for Zimbabwe was used for 2011.

The estimated basin and sub-basin population in 2011 for the Limpopo are shown in **Table 3.1.**

**Table 3.1:** Limpopo Population by Country and by Sub-Basin

| Sub-basin | Area $km^2$ | Population | | | | Total Population |
|---|---|---|---|---|---|---|
| | | Botswana | Moçambique | South Africa | Zimbabwe | |
| Bonwapitse | 12 030 | 140 746 | 0 | 0 | 0 | **140 746** |
| Bubi | 8 619 | 0 | 0 | 0 | 90 513 | **90 513** |
| Changane | 65 571 | 0 | 434 427 | 0 | 14 047 | **448 474** |
| Crocodile | 29 699 | 0 | 0 | 6 528 426 | 0 | **6 528 426** |
| Lephalale | 6 777 | 0 | 0 | 102 623 | 0 | **102 623** |
| Letaba | 13 822 | 0 | 96 | 898 099 | 0 | **898 195** |
| Levuvhu | 3 927 | 0 | 3 084 | 336 184 | 0 | **56 579** |
| Lotsane | 12 810 | 56 579 | 0 | 0 | 0 | **617 624** |
| Lower Limpopo | 5 618 | 0 | 617 624 | 0 | 0 | **16 548** |
| Lower Mid-Limpopo | 7 934 | 0 | 16 548 | 0 | 0 | **553 208** |
| Lower Olifants | 15 206 | 0 | 18 708 | 534 500 | 0 | **339 268** |
| Mahalapswe | 8 700 | 61 076 | 0 | 0 | 0 | **61 076** |
| Marico | 13 267 | 13 863 | 0 | 298 090 | 0 | **311 953** |
| Matlabas | 5 670 | 0 | 0 | 49 174 | 0 | **49 174** |
| Middle Olifants | 23 134 | 0 | 0 | 2 246 469 | 0 | **2 246 469** |
| Mogalakwena | 19 196 | 0 | 0 | 556 673 | 0 | **556 673** |
| Mokolo | 8 338 | 6 | 0 | 88 849 | 0 | **88 849** |
| Motloutse | 19 706 | 140 764 | 0 | 0 | 0 | **140 764** |
| Mwenezi | 14 889 | 0 | 3 391 | 0 | 242 510 | **245 901** |
| Mzingwani | 20 801 | 0 | 0 | 0 | 235 515 | **235 515** |
| Notwane | 18 264 | 601 826 | 0 | 36 689 | 0 | **638 515** |
| Nzhelele | 4 238 | 0 | 0 | 146 583 | 0 | **146 583** |
| Sand | 15 715 | 0 | 0 | 857 936 | 0 | **857 936** |
| Shashe | 29 464 | 182 460 | 0 | 0 | 249 162 | **431 622** |
| Shingwedzi | 9 279 | 0 | 15 603 | 465 801 | 0 | **481 404** |
| Steelpoort | 6 877 | 0 | 0 | 311 362 | 0 | **311 362** |
| Upper Olifants | 11 591 | 0 | 0 | 1 621 052 | 0 | **1 621 052** |
| **Basin Total** | **411 142** | **1 197 314** | **1 109 481** | **15 078 510** | **831 747** | **18 217 052** |
| **Total Population/ Country (million)** | | **2.03** | **23.5** | **51.7** | **12.9** | **90.13** |
| **Percentage in Limpopo Basin** | | **60%** | **8%** | **29%** | **7%** | |

**Figure 3.1** shows the Limpopo population for the four countries at sub-basin level.

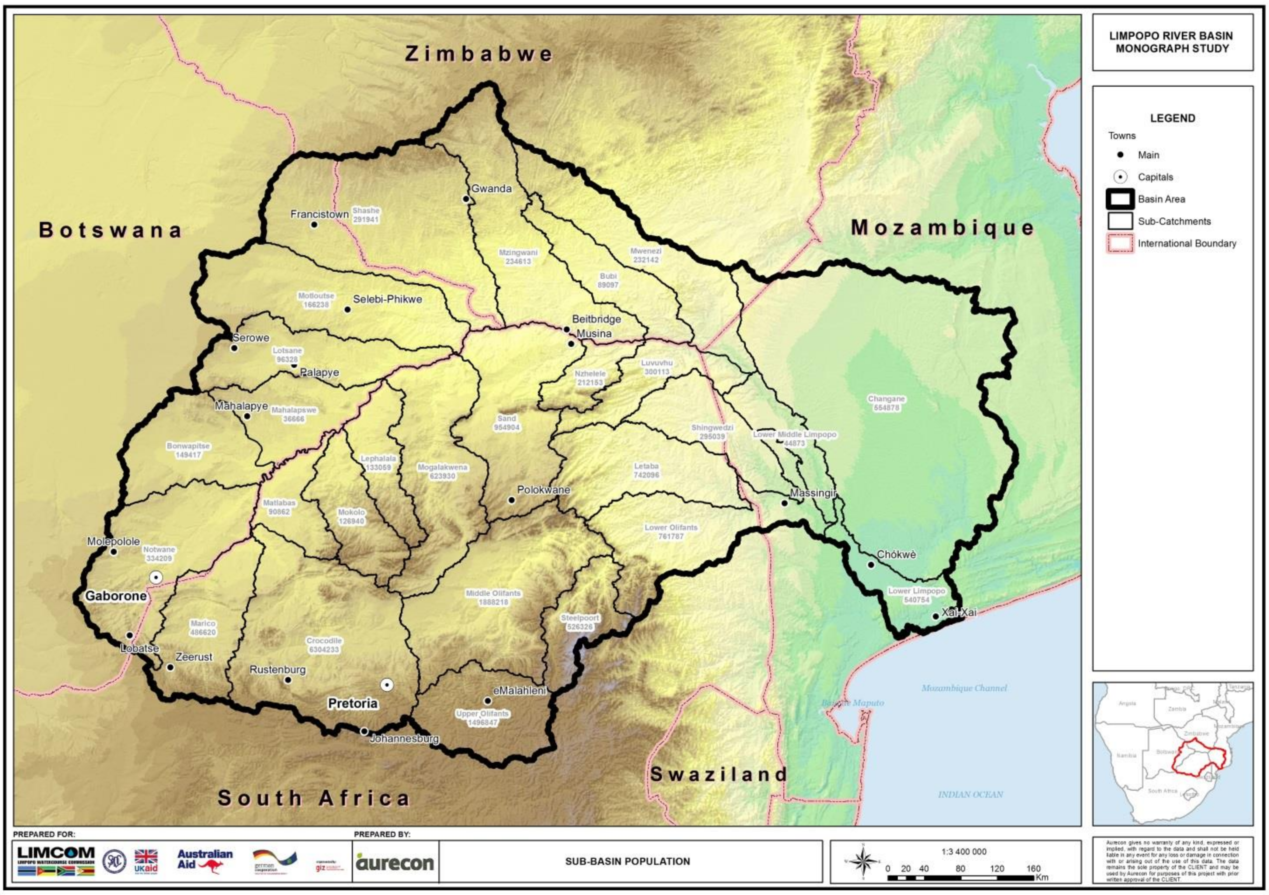



**Figure 3.1:** Population in the Limpopo River Sub-basins.

The accuracy of the population estimate for Moçambique is limited as the population census of 2007 had to be projected to bring it to the 2011 base year. Another factor affecting the accuracy of the population figures is the lack of enumeration level census data in Zimbabwe and Moçambique. Even in Botswana and South Africa where enumeration areas were available, there were no census data associated with these. GIS techniques were used to resolve these at census district level.

The largest population in the Limpopo basin is found in South Africa largely in the two largest metropolitan areas, Johannesburg and Pretoria, and the mining areas around Rustenburg and Emalahleni. Zimbabwe is the country with the least population in the basin. In Botswana approximately 60% of the entire population of the country reside in the Limpopo Basin since the country's population is situated in the South and South Eastern border of the country.

Moçambique also has a sizable proportion of its population in the Limpopo basin mainly concentrated along the coastal areas of Xai-Xai and the village of Chockwe.

### 3.2.3 Population Projections

The population projections in **Table 3.2** are based on population growth rates published inthe United Nations Secretariat's World Population Prospects projections at a national level. It is not possible to accurately project the population growth rates in the Limpopo River Basin parts of the countries. It is possible that using the

United Nations Secretariat's World Population Prospects national population growth rates at basin level could present inaccurate projections. Also, the assumptions used by the United Nations Secretariat's World Population Prospects may not entirely apply to the Limpopo Basin. However, for a lack of any other credible method the national population growth rates derived by the United Nations Secretariat's World Population Prospects were used in this Monograph. The methodology used by the World Bank to determine the national population growth rates can be sourced from the United Nations Secretariat's World Population Prospects Website and will not be repeated here.

There are always challenges in projecting population figures well into the future because the population drivers that influence population growth such as migration patterns, immigration, lifestyles, health, and other socio-economic factors change over time. Population projections are presented from 2010 to 2040 at 5 year intervals and are given in **Table 3.2**.

**Table 3.2:** Population growth rates for Limpopo Riparian States used for the Limpopo Basin

| Intervals | 2010 – 2015 (%) | 2015 – 2020 (%) | 2020 - 2025 (%) | 2025 – 2030 (%) | 2030-2035 (%) | 2035 – 2040 (%) |
|---|---|---|---|---|---|---|
| Botswana | 1.09 | 0.98 | 0.90 | 0.52 | 0.41 | 0.35 |
| South Africa | 0.51 | 0.43 | 0.44 | 0.35 | 0.27 | 0.20 |
| Moçambique | 2.23 | 2.18 | 2.11 | 2.03 | 1.88 | 1.72 |
| Zimbabwe | 2.15 | 2.09 | 1.39 | 1.12 | 0.93 | 0.82 |

Source: 2010 United Nations Secretariat's World Population Prospects, U.N. population projections, 2010 to 2040

The population growth rates in **Table 3.2** were used to project populations for the Limpopo Basin in each of the riparian states as shown in **Table 3.3**.

**Table 3.3:** Limpopo Basin Populations Projections

| Intervals | 2012 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| Botswana | 1 197 314 | 1 210 365 | 1 222 226 | 1 233 226 | 1 239 639 | 1 244 722 | 1 249 078 |
| Moçambique | 1 109 481 | 1 115 139 | 1 119 934 | 1 124 862 | 1 128 799 | 1 131 847 | 1 134 111 |
| South Africa | 15 078 510 | 15 414 761 | 15 750 803 | 16 083 144 | 16 409 632 | 16 718 133 | 17 005 685 |
| Zimbabwe | 831 747 | 849 630 | 867 387 | 879 443 | 889 293 | 897 564 | 904 924 |
| **TOTAL** | **18 217 052** | **18 589 894** | **18 960 350** | **19 320 676** | **19 667 364** | **19 992 266** | **20 293 798** |

The population as reflected in **Table 3.3** of the Limpopo Basin is expected to increase by 11.4% to over 20 million inhabitants by 2040. Socio-economic factors could alter this trend especially if the mineral, water agricultural and other natural resources of the Limpopo Basin are fully exploited. The population could also increase more through urbanisation especially in South Africa and Botswana. All these factors could place strain on the water resources of the basin.

## 3.3 HUMAN DEVELOPMENT INDICATORS

The Human Development Indicators or Index (HDI) is a tool developed by the United Nations to measure and rank countries' levels of social and economic development based on four criteria: Life expectancy at birth, mean years of schooling, expected years of schooling and gross national income per capita. The HDI makes it possible to track changes in development levels over time and to compare development levels in different countries. Water availability and quality has a great influence on human development. In this monograph four human development indicators that can be linked to water have been summarised. These indicators have been selected based on information readily available from reports published in the four member states. The indicators selected are also an indirect measure of other impacts such as malaria and waterborne diseases.

Four Human Development Indicators were selected for the monograph:

| | | |
|---|---|---|
| **HIV Prevalence** | - | Percentage of people between the ages of 15 and 49 infected with HIV (based on antenatal surveys) |
| **Poverty Ratio (P0)** | - | Poverty Headcount based on the World Bank poverty threshold of people living on less than $1.25 a day, measured at 2005 international prices, and adjusted for purchasing power parity (PPP) |
| **Life Expectancy** | - | Indicator of the number of years new born infants will live under prevailing conditions |
| **Infant Mortality** | - | Number of children who die before the age of 5 years per 1000 live births |

### 3.3.1 HIV/AIDS Prevalence

The Prevalence of HIV indicator generally refers to the percentage of people ages 15 to 49, who are infected with HIV. HIV prevalence statistics are generally published at national and district / provincial level. From the district / provincial statistics it is possible to infer on the HIV prevalence trends in the Limpopo Basin for each of the countries.

### 3.3.2 Poverty Ratio

There are various measures of poverty that are used by different countries and for different purposed. Amongst the most commonly used indices are:

- Headcount Index ($P_0$) - measures the proportion of the population that is poor. It is the most popular index because it is easily understood. Its weakness is that it does not indicate how poor the poor are.
- Poverty Gap Index ($P_1$) - measures the extent to which individuals fall below the poverty line (poverty gaps) as a proportion of the poverty line.
- The Gini Index - measures income inequality.
- Human Poverty Index - represents the extent of poverty in a country. It uses indicators of the most basic dimensions of deprivation: a short life, lack of basic education and lack of access to public and private resources.

Each country has its own national poverty line or poverty threshold. The World Bank poverty threshold is $1.25 a day which is the proportion of the population living on less than $1.25 a day, measured at 2005 international prices, and adjusted for purchasing power parity (PPP). LIMCOM and the riparian states have to agree on the poverty index to use for the Limpopo River Basin to ensure compatibility of the data. In this Monograph the simple headcount Index at $1.25 a day will be used because it is the most commonly available data on poverty on the three riparian states.

### 3.3.3 Life Expectancy

The life expectancy at birth indicator measures the number of years a new born infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life (World Bank, 2008). It is also a measure of overall quality of life in a country and summarises the mortality at all ages. It can also be thought of as indicating the potential return on investment in human capital and is necessary for the calculation of various actuarial measures. Life expectancy data was only available at National level.

### 3.3.4 Infant Mortality in the Basin

The Child Mortality indicator is the probability per 1 000 that a new-born baby will die before reaching age five, if subject to current age-specific mortality rates (World Bank 2008). There is no information on child mortality specific to the Limpopo River Basin. Child mortality statistics were only available at National level.

The figures in the Limpopo basin and the National averages for the Human Development Indicators are shown in **Table 3.4, where N = the National Average.**

**Table 3.4:** Human Development Indicators for the Limpopo Basin States

| Indicator | Botswana | Moçambique | South Africa | Zimbabwe |
|---|---|---|---|---|
| **HIV Prevalence** | 18% (2008)<br>N = 23% | 26% (2010)<br>N = 11.5% | 11% (2008)<br>N = 28% | 21% (2011)<br>N = 15% |
| **Poverty Ratio ($P_0$)** | 22% (2010)<br>N = 20.7% | 60% (2008)<br>N = 54.7% | 30% (2008)<br>N = 26.3% | 72% (2003)<br>N = 72% |
| **Life Expectancy (National Figures - 2010)** | | | | |
| **Male** | 54 years | 49 years | 53 years | 49 years |
| **Female** | 52 years | 51 years | 43 years | 49 years |
| **Infant Mortality (National Figures - 2010)** | | | | |
| **Under 5 years per 1 000 live births** | 48 children | 135 children | 57 children | 80 children |

The results of the human development indicators show that the Limpopo portions of the Member States carry a proportionally large burden of poverty, and HIV Aids prevalence that the national averages. In general HIV prevalence is on the decline in the Member States as a result of increase in HIV education and treatment, although in Moçambique and Zimbabwe the percentages are well above the National Averages.

A weakness in the Human Development Indicators is that the surveys are conducted at different times by the member states, making it difficult to have figures for a common base year.

## 3.4 MIGRATION PATTERNS

Migration can be defined as a change in a person's permanent or usual place of residence. Along with fertility and mortality, migration is one of the components of population change. There a various definitions of migration. Information on previous and usual province of residence refers to migration between 1996 and 2011 for all riparian countries. Lifetime migration on the other hand deals with movements based on where the person was born and where they currently reside. Migration can either be within a country or across the countries border. There are no specific figures on migration specific to the Limpopo Basin.

There are various causes of migration and include; political instability or civil war, economic factors (unemployment) and natural disasters (famine, floods, droughts, etc.). Political and civil war in in South Africa (1980's), Moçambique (1970's) and recently in Zimbabwe (2000's) saw a number of people migrating to neighbouring countries and safer parts of the same country. For many years the economic boom in Johannesburg as a result of the "gold rush" and more recently the platinum mining in the Limpopo and North West Provinces of South Africa saw a number of economic migrant moving to those areas in search of employment. Botswana has also seen similar migration after the discovery of diamonds. Droughts have resulted in a number of people from the rural areas of Moçambique and Zimbabwe moving to urban centres in search of food after a series of crop failures.

## 3.5 VULNERABILITY AND DEPENDENCY ON WATER

Water can be used to improve the lives of the people in the Limpopo River basin which has an abundance of natural resources (mining and agriculture). No information was available on vulnerabilities and dependency on water. However, climate change leading to frequent floods and droughts is seen as a major threat in the Limpopo. The Resilience in the Limpopo (RESILIM) study is gathering and analysing information on climate change and vulnerabilities in the basin. Rural communities remain the most vulnerable because they do not have sufficient coping mechanisms including insurances to cushion them against the treats of floods and droughts.

## 3.6 MACRO-ECONOMIC PROFILE

***(Refer Technical Annexure Volume A2: Economic Baseline & Macro-Economic Multipliers)***

### 3.6.1 Introduction

The economic profile in the Limpopo Basin consists of a number of different economic activities. It is expressed as total macro-economic parameters and also expressed as multipliers, from which the value of water can be determined and possible changes over time can be estimated.

### 3.6.2 Economic Overview

The Limpopo River Basin serves four countries, and the basin and its catchments face a number of water resource challenges. Greatest of these challenges is sharing scarce water resources between various competing needs. Already, a large part of the catchment is threatened by water scarcity. Water is imported where there is already an over-allocation of water, and yet there are new needs for water that must still be met.

The management of the Limpopo River system is increasingly pressured to take a holistic or integrated approach to the problem. It is clear that a return to pre-development environmental conditions, 'the river's natural state', is not a management option. There is, therefore, a need to balance the development in the Limpopo River system with ensuring that the ecological system, within the basin continues to function in an agreed condition. In order to do that it is imperative that the value of the water, where it is withdrawn from the system for use as a factor of production, is determined, so that the benefits can be optimised.

### 3.6.3 Methodology

#### 3.6.3.1 *Macro-Economic Models*

The economic baseline provides the impacts of water usage when the full water allocation is available in the respective sub-basins for variables such as Gross Domestic Product (GDP), employment, and income received by low income households. The GDP measures economic growth created by water and employment and payments to low income households is an indication of the impact on the socio-economic conditions in the basin in terms of alleviating poverty.

GDP is worldwide used an economic growth indicator, GDP consists of the following elements:

- Surplus Value,
- Salaries and Wages, and
- Indirect Tax, excluding income tax.

GDP is therefore included to present the contribution of the water dependent activities in a region or sub – basin to the overall economy.

As salaries and wages are components of GDP, it is necessary to present them separately to indicate the socio – economic contribution of the water based activities and specifically their contribution to low income households. It is presented in three categories namely payments to high income households, medium and low income households.

Employment creation is a very important element of the socio economic situation in any region and is therefore calculated and presented.

GDP and employment are presented in terms of direct, indirect and induced impacts:

- Direct Impacts: refer to impacts occurring directly in the irrigation or other water dependent activity.
- Indirect Impacts: refer to those effects occurring in the different economic sectors that link backward to a specific sector due to the supply of intermediate inputs used in the production process.
- Induced Impacts: refer to the chain reaction triggered by the salaries and profits (less retained earnings) that are ploughed back into the economy in the form of private consumption expenditure.

To accomplish this, an econometric model was constructed with the multipliers synthesised from representative Social Accounting Matrix (SAM) for the Limpopo Basin, as basis. The Water Impact Model (WIM) was used for the primary sectors such as irrigation agriculture and commercial forestry. The SAM and its multipliers were also applied to the secondary and tertiary sectors. A production economic modelling approach was used for the industries.

A broad schematic representation of the different sectors of the economy is shown below.

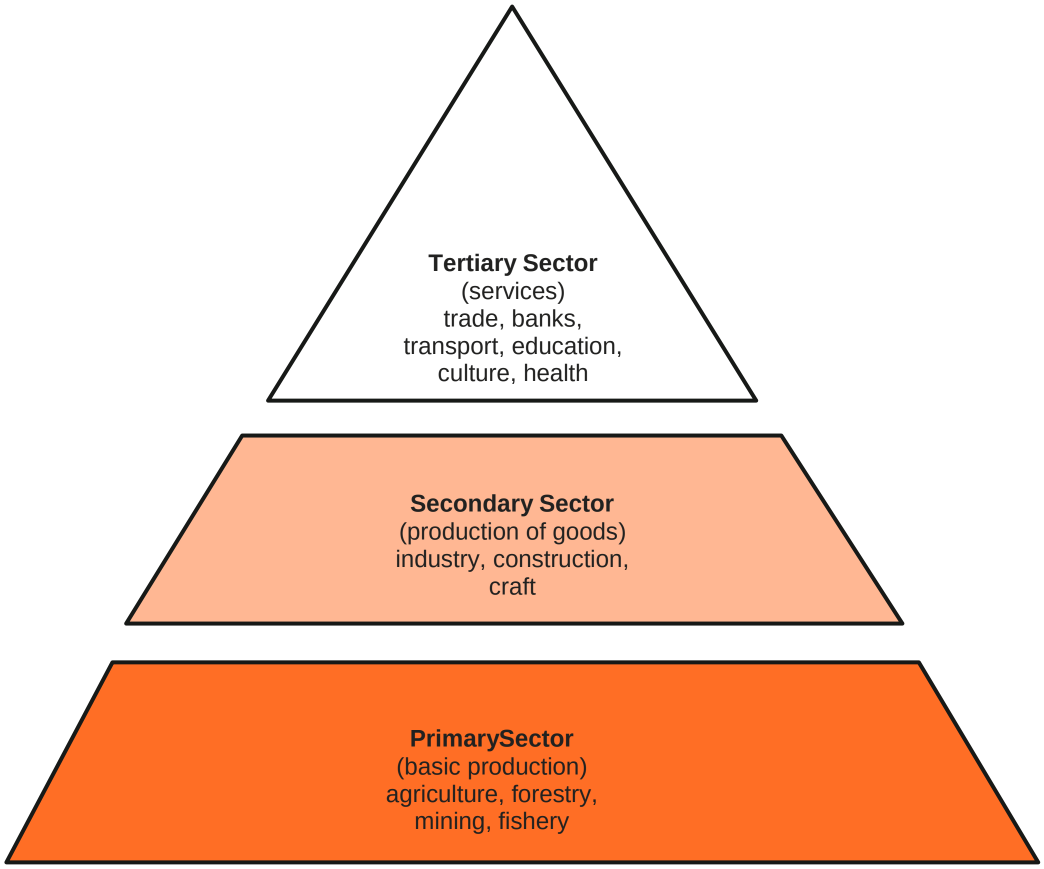



**Figure 3.2:** Sectoral structure of an economy

The primary sectors feed the secondary and tertiary sectors but also depend on products and services from these two sectors to operate efficiently.

#### 3.6.3.2 *Water Impact Model (WIM)*

The model, as is currently constructed was applied to the primary sector, and is in the form of a dynamic computerised water entitlement model which can be used to identify and quantify the following indicators:

- Economic benefits.
- Maximum possible water reduction.
- Capitalised impact.

In order to calculate the macro-economic parameters of each of the sub-basins, in terms of the irrigation agricultural sector, the water users need to be identified and their volume water need to be established. The main inputs required for the model is the water volumes and number of hectares. Specific crop production budgets were incorporated to the WIM-model underpinned by the SAM.

A WIM was constructed for the Limpopo Basin which included the identified sub-basins. The output of the model provides results of direct, indirect and induced results for the following sectors: irrigation agriculture and commercial forestry. For agriculture the model can accommodate up to twenty different products and for forestry it provides for pine, gum and wattle sub-species.

The direct, indirect and induced effects are explained for the agricultural sector as an example.

- Direct effect: refers to effects occurring directly in the agriculture sector such as the hectares cultivated.
- Indirect effects: refer to those effects occurring in the different economic sectors that link backward to agriculture due to the supply of intermediate inputs, i.e. fertilisers, seeds, etc.
- Induced effects: refers to the chain reaction triggered by the salaries and profits (less retained earnings) that are ploughed back into the economy in the form of private consumption expenditure.

The following parameters are used to determine the impacts that are estimated by the model:

- Gross Domestic Product (GDP).
- Low Income Household and Total Household, incomes
- Employment Creation.

A schematic representation is provided below to illustrate the modelling of the WIM-model.

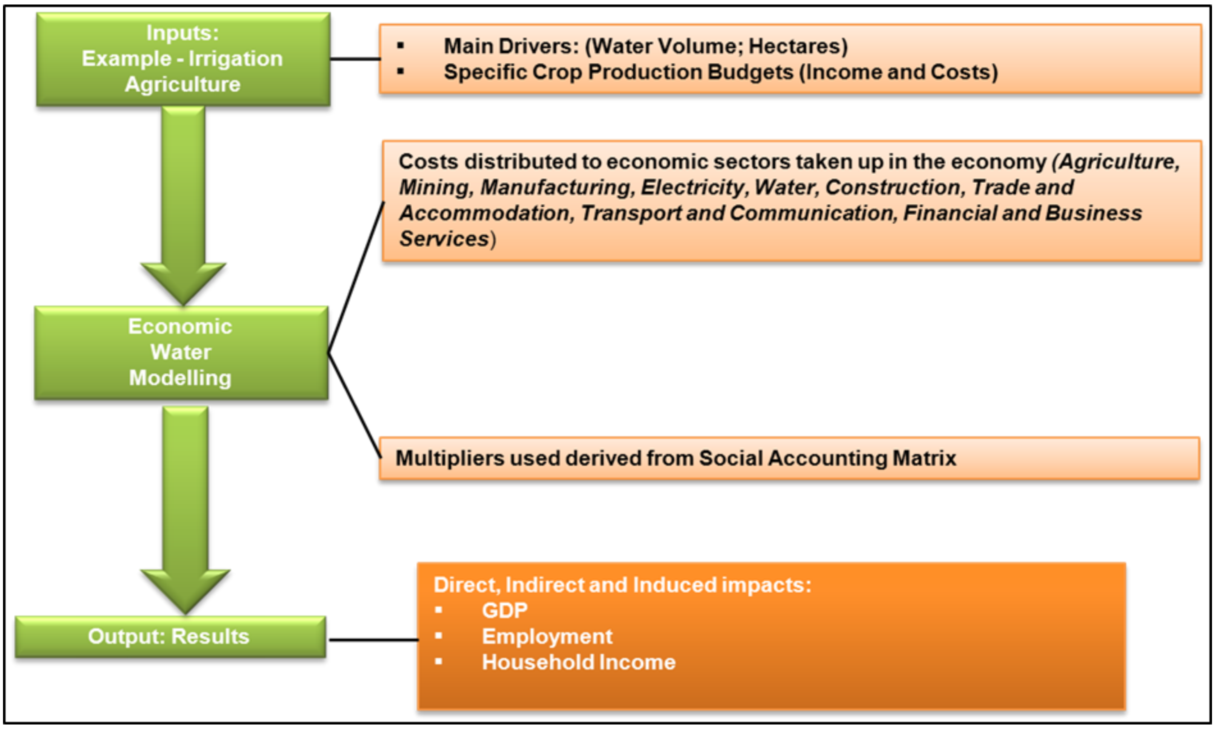



**Figure 3.3:** Modelling of Primary Sector in WIM-model

The economic impacts was converted to economic multipliers by a bridging model, comparing different water use multipliers in terms of Gross Domestic Product (GDP/m3), employment creation (number/million m3) and the income to low-income households.

### 3.6.4 Production Economic Modelling – Secondary & Tertiary

The main and large water using industries in the secondary sectors are the smelters and saw mills, as well as the ferro chrome factories. The inputs used for the production modelling for the secondary and tertiary sectors were estimated income and direct employment. For the tertiary sector, tourism impacts were determined. Inputs required were the estimated number of beds, nights sold, income per annum and direct employment created. These inputs were then added to the economic model. In the model a SAM structure that consists of the Standard Industrial Classification (SIC) synthesise the production value. This production was then multiplied by the different economic production multipliers to produce the macro - economic parameters. As in the WIM, the model outputs economic parameters of:

- Gross Domestic Product (GDP).
- Low Income Household and Total Household incomes.
- Employment Creation.

A schematic representation is provided below, illustrating the modelling of the PIM-model.

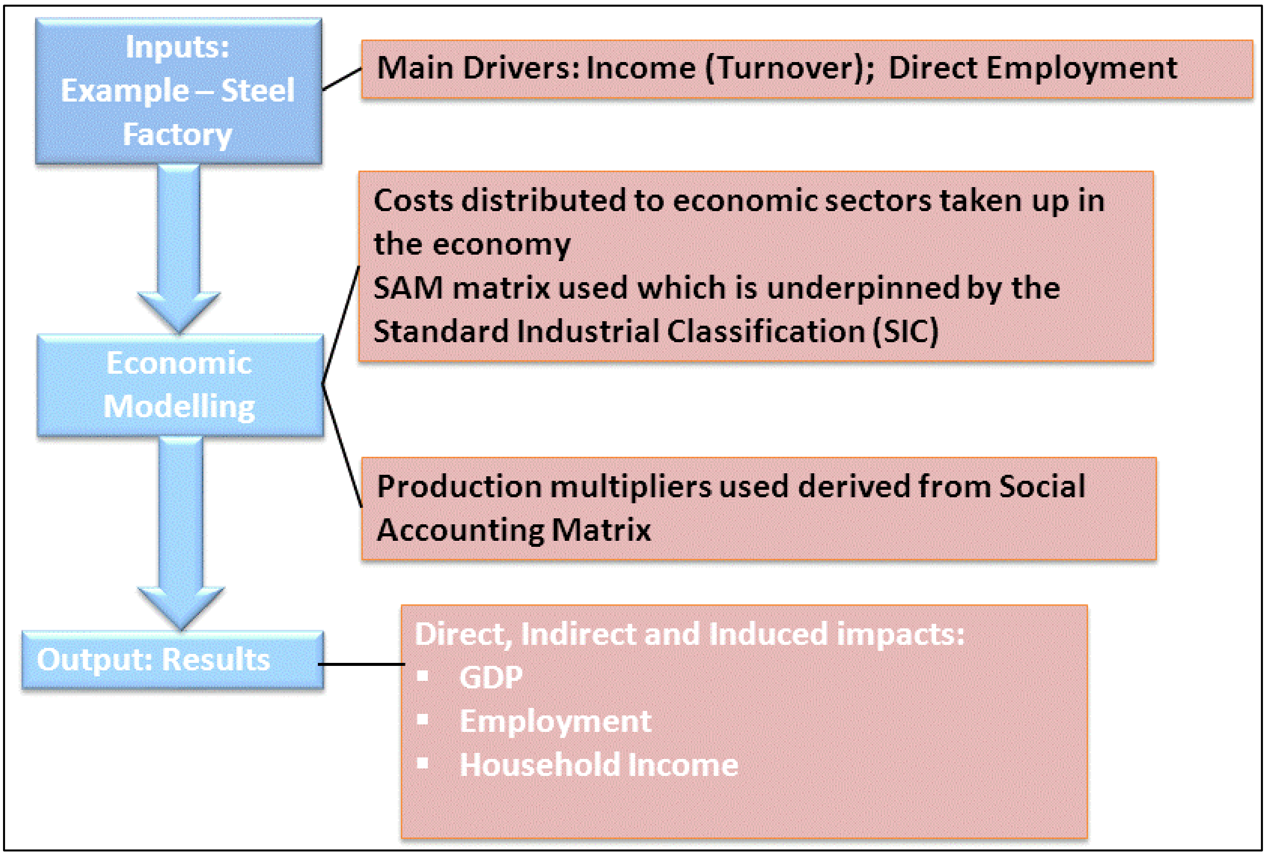



**Figure 3.4:** Modelling of the Secondary and Tertiary Sector in PIM-model

The mining, irrigation, power generation and industry are large water users whereas commercial forestry and eco-tourism use less water.

After these economic impacts are determined, a bridging model needs to be developed that converts the economic impacts to economic water use multipliers that is expressed as follows:

- Gross Domestic Product/Water Volume ($/m$^3$).
- Employment creation/ Water Volume (number/million m$^3$).
- Low-income household income/Water Volume ($/m$^3$).

### 3.6.5 Economic Activities

The impacts of the following economic activities that will be estimated in the section below are:

- Irrigation Agriculture

- Commercial Forestry
- Mining
- Power Generation
- Industry
- Eco-Tourism

The individual country data was collected in the prevailing country monetary system and converted to US$ and then run through the relevant model to attain the identified macro – economic indicators.

A number of approaches were followed in circumstances where data was readily available. In the following paragraphs a summary of the approaches followed are presented.

#### 3.6.5.1 *Irrigation Agriculture*

As far as possible the physical hectares as published by different countries were used. However with the so called crop hectares it was necessary to fall back on Google Earth pictures, local contacts and marketing data providing some insight. In the case of Moçambique and South Africa relatively good information about crop hectares were available, in the case of the other two countries the data was not available.

#### 3.6.5.2 *Commercial Forestry*

The only commercial forestry plantations that could be traced are in South Africa where physical areas for planting are controlled and it was thus possible to use that data.

#### 3.6.5.3 *Mining*

The published records of the different mining companies were used as base documents to identify the locations of the different mines and to correctly place them in the relevant sub basin. The individual ore production and employment was collected by telephone and the annual turnover per mine estimated by using the average income figures as published by the companies.

#### 3.6.5.4 *Power Generation*

Over 95% of the electricity generated in the Basin take place in South Africa, with the result that Eskom as the service provider served as the source of the South African data. In the case of the Crocodile West sub – basin there are still two power stations operating under the management of the Johannesburg and Tshwane metro municipalities. The data in Botswana was obtained from published government data.

#### 3.6.5.5 *Industry*

The relevant industries were identified and contacted to collect the relevant data.

#### 3.6.5.6 *Eco-Tourism*

Very little data was available in all four countries and it was necessary to establish a data base of all accommodation offering facilities by internet search, then placing them in a specific sub basin. They were contacted by telephone to establish the number of beds as well as the average bed occupation together with the applicable rates and number of employees. By using these, a total annual turnover per sub basin was established and by using the accepted multipliers the macro – economic indicators were calculated.

### 3.6.6 Macro-Economic Indicators

The following sections give the estimated economic water multipliers per water use sector in each of the countries in the Limpopo Basin. More detail is contained in **Technical Annexure Volume A2**.

As a summary, the indicators per water use sector are provided in **Table 3.5** for the entire basin.

**Table 3.5:** Economic Indicators per Water Use Sector

| | GDP (US$ Mil) | | | Employment (Numbers) | | | Household Income (US$ Mil) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Direct** | **Indirect and Induced** | **Total** | **Direct** | **Indirect and Induced** | **Total** | **Total** | **Medium** | **Low** |
| Irrigation | 1 742.8 | 2 120.5 | 3 863.4 | 251 194 | 153 423 | 406 618 | 2 291.7 | 1 197.5 | 1 094.2 |
| Commercial Forestry | 56.8 | 49.1 | 106.0 | 6 866 | 3 921 | 10 787 | 44.7 | 13.5 | 31.2 |
| Mining | 22 440.3 | 20 520.3 | 42 960.5 | 359 806 | 882 573 | 1 242 379 | 18 443.5 | 2 800.4 | 15 643.2 |
| Power Generation | 3 979.6 | 2 542.8 | 6 522.4 | 9 955 | 151 825 | 161 780 | 2 451.8 | 536.8 | 1 915.0 |
| Industry | 4 557.8 | 7 196.2 | 11 754.0 | 25 245 | 85 800 | 111 045 | 6 425.5 | 1 571.7 | 4 853.8 |
| Eco-Tourism | 158.1 | 139.2 | 297.3 | 9 137 | 9 187 | 18 325 | 122.8 | 36.8 | 86.0 |
| **Total** | **32 935.4** | **32 568.1** | **65 503.6** | **662 204** | **1 286 730** | **1 948 934** | **29 780.0** | **6 156.7** | **23 623.4** |

The table indicates that mining provides the most direct jobs; namely 359 806 with 882 573 indirect and induced number, and a total of 1 242 379. At four household members per employment opportunity, mining sector supports about 5 million individuals. Also emphasising the importance of the mining sector is the U$ 15 643 million annually paid to low income households (42% of the total paid out in salaries and wages) and the generation of US$ 43 million of the total 65.5 billion GDP.

The irrigation agriculture sector is the second largest employer with 251 194 direct and an estimated total of 404 618 employment opportunities.
In total, water based activities support about 1.95 million employment opportunities, the total payment to households is US$ 29.8 billion and US$ 65.5 billion of GDP is created.

#### 3.6.6.1 *Botswana*

Botswana's agricultural industry in the Limpopo basin is dominated by cattle rearing and subsistence farming. Agriculture is plagued by various factors like poor soil conditions and erratic rainfall. This is one of the main reasons behind the inability of the agricultural industry in Botswana to meet the food production required to feed the population.

Crop production is hampered by traditional farming methods, recurrent drought, erosion, and disease. Most of the land under cultivation is in the eastern region of Botswana.
The economic indicators in the following sub-basins were analysed and details will be provided in **Technical Annexure, Volume A2** which will accompany this Monograph:

- Notwane/Gaborone
- Bonwapitse

- Mahalapswe
- Lotsane
- Motloutse
- Sashe/Francistown

**Table 3.6:** Botswana Macro-Economic Indicators per Water Use Sector (2013 prices)

| | GDP (US$ Mil) | | | Employment (Numbers) | | | Household Income (US$ Mil) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Direct | Indirect and Induced | Total | Direct | Indirect and Induced | Total | Total | Medium | Low |
| Agriculture | 136.9 | 180.2 | 317.1 | 9 969 | 15 836 | 25 804 | 205.5 | 108.6 | 96.9 |
| Commercial Forestry | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mining | 303.4 | 277.4 | 580.8 | 3 303 | 15 907 | 19 210 | 248.4 | 36.9 | 211.5 |
| Power Generation | 127.0 | 81.1 | 208.1 | 570.0 | 845.0 | 5 415 | 67.7 | 6.6 | 61.1 |
| Industry | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Eco-Tourism | 22.6 | 19.9 | 42.5 | 1 306 | 314.0 | 2 620 | 17.4 | 5.1 | 12.3 |
| **Total** | **589.8** | **558.7** | **1 148.5** | **15 148** | **37 901** | **53 050** | **539.0** | **157.2** | **381.8** |

Irrigation agriculture is the largest provider of employment opportunities, 25 864in total of which 9 969 is direct and the balance indirect and induced opportunities. Payments to low income households is US$96.9 million. In total just over a US$ 200 million is paid in salaries and wages.

Overall, the water based activities supports 53 050 job opportunities and at four household members per employee at least 215 000 people are at present dependent on the activities.
The southern and eastern regions of Botswana are generally semi-arid. Besides mining, traditional rain-fed crop farming and cattle are the main activities with game farming and eco-tourism very prominent in the eastern region.
Large coal deposits occur in the area and projections predict that the mining sector will become very prominent.

### 3.6.6.2 *Moçambique*

Virtually the total area of the Limpopo Basin within Moçambique comprises of the Great Limpopo Trans-frontier Park which straddles the borders of Moçambique, South Africa and Zimbabwe and joins some of the most established wildlife areas in Southern Africa into a huge conservation area of 35 000km². Presently there is no mining, except for the mineral sands mine on the border of the area in Changane. The only large urban areas, is Xai-Xai on the coast. Rice is grown in the wide fertile plain of the Limpopo close to the coast and irrigation agriculture is present south of the Massingir Dam in the Elephants River and again further south in the Lower Limpopo River.

It is the intention that the larger trans-frontier conservation area is to include Banhine and Zinave national parks, the Massingir and Corumana areas and interlinking regions in Moçambique, as well as various privately and state-owned conservation areas in South Africa and Zimbabwe bordering on the Trans-frontier Park.

The economic indicators in the following sub-basins were analysed and details provided in Technical **Annexure, Volume A2** which will accompany this Monograph:

- Lower Olifants
- Shingwedzi (Olifants)
- Lower Middle Olifants
- Changane
- Lower Limpopo

**Table 3.7:** Moçambique: Macro-Economic Indicators per Water Use Sector (2013 prices)

| | GDP (US$ Mil) | | | Employment (Numbers) | | | Household Income (US$ Mil) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Direct | Indirect and Induced | Total | Direct | Indirect and Induced | Total | Total | Medium | Low |
| Agriculture | 153.9 | 108.1 | 262.0 | 14 645 | 8 186 | 22 831 | 115.3 | 57.6 | 57.7 |
| Commercial Forestry | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Mining | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Power Generation | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Industry | 46.1 | 41.5 | 87.5 | 850 | 2 568 | 3 418 | 36.1 | 9.9 | 26.2 |
| Eco-Tourism | 3.3 | 2.9 | 6.2 | 190 | 191 | 381 | 2.5 | 0.7 | 1.8 |
| **Total** | **203.2** | **152.5** | **355.7** | **15 685** | **10 945** | **26 630** | **154.0** | **68.2** | **85.7** |

The irrigation agricultural sector in Moçambique is the largest sector in the Limpopo Basin. Industry is estimated as a smaller while eco-tourism is the smallest. Currently the total number directly employed in the irrigation sector is around 14 645, but with the Massingir development presently being planned, the situation can change dramatically.

The water based activities support an estimated 26 630 employment opportunities with payments in salaries and wages amounting to around US$ 154 million. The total GDP created is around US$ 355 million.

It is estimated that around 125 000 people are dependent on the wellbeing of the water base activities.

It must be kept in mind that the Moçambique government is considering proposals to revive the irrigation area below the Massingir dam planting sugar cane and eventually to reopen the sugar mill in the area. If this eventually took place it will change the economic situation in the Moçambique section of the basin dramatically.

#### 3.6.6.3 *South Africa*

The economic indicators in the following sub-basins were analysed and details will be provided in **Technical Annexure Volume A2** which will accompany this Monograph:

- Marico

- Crocodile-West
- Mokolo
- Lephalale
- Mogalakwena
- Sand
- Nzhelele
- Levuvhu
- Shingwedzi
- Letaba
- Upper Olifants
- Middle Olifants
- Lower Olifants
- Steelpoort

It is necessary to mention that the water data as far as mining and industry is concerned is not providing consistent results, especially in the Upper Olifants sub-basin. In the case of coal mining it is probably due to the fact that not all producing mines have "lawful" water allocations at present, this situation is urgently being addressed by the relevant authority. Once more consistent water data is available the answers might change.

**Table 3.8:** South Africa: Macro-Economic Indicators per Water Use Sector (2013 prices)

| | GDP (US$ Mil) | | | Employment (Numbers) | | | Household Income (US$ Mil) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Direct | Indirect and Induced | Total | Direct | Indirect and Induced | Total | Total | Medium | Low |
| Agriculture | 1 263.0 | 1 572.1 | 2 835.1 | 205 674 | 111 805 | 317 479 | 1 691.3 | 886.9 | 804.4 |
| Commercial Forestry | 56.8 | 49.1 | 106.0 | 6 866 | 3 921 | 10 787 | 44.7 | 13.5 | 31.2 |
| Mining | 21 409.1 | 19 577.3 | 40 986.4 | 347 979 | 828 505 | 1 176 483 | 17 599.3 | 2 675.0 | 14 924.3 |
| Power Generation | 3 852.6 | 2 461.7 | 6 314.2 | 9 385 | 146 980 | 156 365 | 2 384.1 | 530.2 | 1 853.9 |
| Industry | 4 511.8 | 7 154.7 | 11 666.5 | 24 395 | 83 232 | 107 627 | 6 389.3 | 1 561.7 | 4 827.6 |
| Eco-Tourism | 127.4 | 112.2 | 239.5 | 7 362 | 7 403 | 14 765 | 99.2 | 29.9 | 69.3 |
| **Total** | **31 220.6** | **30 927.1** | **62 147.7** | **601 661** | **1 181 845** | **1 783 503** | **28 208.0** | **5 697.3** | **22 510.7** |

The predominant economic activity in the South African sector of the Limpopo Basin is mining followed by irrigation agriculture and much lower down the scale industry eco-tourism and power generation. The employment numbers indicate that more than of the employment in the area is dependent on mining, followed by irrigation agriculture 65% of the total. Industry is a smaller employer but important sector. In terms of payments to households nearly 70% are from the mining sector.

It is estimated that over 7.1 million people are dependent on the water based activities.

#### 3.6.6.4 *Zimbabwe*

There is limited economic contact in the Limpopo Basin with the area lying north of the study area being the more economic active region of the country.

The economic indicators in the following sub-basins were analysed and details provided in **Technical Annexure Volume A2** which will accompany this Monograph:

- Shashe
- Mzingwani
- Bubi
- Mwenezi
- Lower Middle Limpopo
- Changane

**Table 3.9:** Zimbabwe: Macro-Economic Indicators per Water Use Sector (2013 prices)

| | GDP (US$ Mil) | | | Employment (Numbers) | | | Household Income (US$ Mil) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Direct** | **Indirect and Induced** | **Total** | **Direct** | **Indirect and Induced** | **Total** | **Total** | **Medium** | **Low** |
| Irrigation | 189.1 | 260.1 | 449.2 | 20 907 | 17 597 | 38 504 | 279.5 | 144.4 | 135.1 |
| Commercial Forestry | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Mining | 727.8 | 665.5 | 1 393.4 | 8 524 | 38 162 | 46 686 | 595.9 | 88.5 | 507.4 |
| Power Generation | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Industry | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Eco-Tourism | 4.8 | 4.2 | 9.1 | 278 | 280 | 558 | 3.7 | 1.1 | 2.6 |
| **Total** | **921.7** | **929.9** | **1 851.6** | **29 710** | **56 038** | **85 748** | **879.1** | **234.0** | **645.1** |

Mining and irrigation agriculture are the main economic activities in the Zimbabwe section of the Limpopo Basin with game related eco-tourism also important.

Irrigation supports an estimated 20 907 direct job opportunities with a further 17 597 indirect and induced opportunities. The payments to low income households from agriculture is around US$ 135.1 million with a total payment to households of US$ 279 million.

Currently mining supports an estimated 8 524 direct jobs with a further 38 162 indirect and induced opportunities. The sector pays about US$ 596 billion annually in salaries and wages of which US$ 507 million is to low income households.

### 3.6.7 Economic growth projections

More precise growth projections will be possible once the future availability of water under different development scenarios is available and the multipliers can be applied. The following is therefore more a qualitative analysis and not a quantitative analysis.

- **Irrigation Agriculture:** Improved irrigation equipment and management practices would over time support increased production. The possibility exists that water availability for irrigation can be restricted and that would negatively impact on production. This however could encourage a changeover to more high value crops.
    - *Botswana:* Water from the Zambezi could become available and encourage expansion.
    - *Moçambique:* The Massingir dam and irrigable areas will come in full production.
    - *South Africa:* Water availability could become an issue but with interventions, current production should be maintained.
    - *Zimbabwe:* The basin section in Zimbabwe is not very suitable for irrigation expansion.
- **Commercial Forestry:** The most suitable areas for forestry are already being utilised by this sector. Rainfall in other areas is too low for any expansion of this sector.
- **Mining:** In all four countries large deposits of different minerals occur and the probability of expansion is a real possibility.
    - *Botswana: Coal deposits occur in the basin and they will be mined over time.*
    - *Moçambique: large coal deposits occur in the basin and already plans are afoot to start mining operations.*
    - *South Africa: 70% of the world platinum reserves occur in the basin and they would outlast at least the 40 year horizon. The coal deposits in the Waterberg region of the basin will also be mined over time. Large deposits of chrome also occur which will be mined.*
    - *Zimbabwe: Platinum and coal deposits occur in the basin and will eventually be mined.*
- **Power Generation:** Coal power stations will be operational for at least 40 years and further expansion in the basin in all four countries is a possibility.
- **Heavy Industry:** The mine depending industries will be maintained and probably increased. The further beneficiation of the mining products is more difficult to comment on as it could easily expand outside of the basin.
- **Eco-Tourism:** With the growth of the urban areas these facilities will grow. It is not so certain what the future of the game and hunting industry will be as it could reach a ceiling**.**

### 3.6.8 Macro-Economic Multipliers

In order for all stakeholders in the LRB to play a meaningful role in supporting the achievement of its economic objectives, it is important to have a proper understanding of the economic and financial rationale of investing scarce resources in economic programmes and projects and much-needed social initiatives. In order to facilitate this understanding, this project has been directed at determining various economic multipliers, derived in terms of the following macroeconomic variables:

- Value Added (GDP);
- Labour/Employment
- Household income (Low-income households, as well as all other households).

This portion of the report provides an overview of the customised Unique Water Multiplier Model system that has been developed for the purpose of calculating the economic value of water in the LRB and the application of these multipliers in evaluating different scenarios. The underlying principle of this model is the fact that water is a scarce resource. As such, the allocation of water between the environment and competing economic users (i.e. irrigation agriculture, mining and industry) needs to be structured in such a way that positive socio-economic impacts are maximised while maintaining a functioning eco-system.

The primary objective of the Water Multiplier Model is to provide a detailed description of the current water usage situation in the Basin area, i.e. the volumes of water used by various water users, and the economic and socio-economic impacts resulting from this particular usage pattern. Given the current water usage and the standard economic multipliers calculated using the Basin SAM, it is possible to determine the economic and socio-economic impacts emanating from water usage.

**Figure 3.5** describes diagrammatically the sequence followed in the determination of the unique activity multipliers.

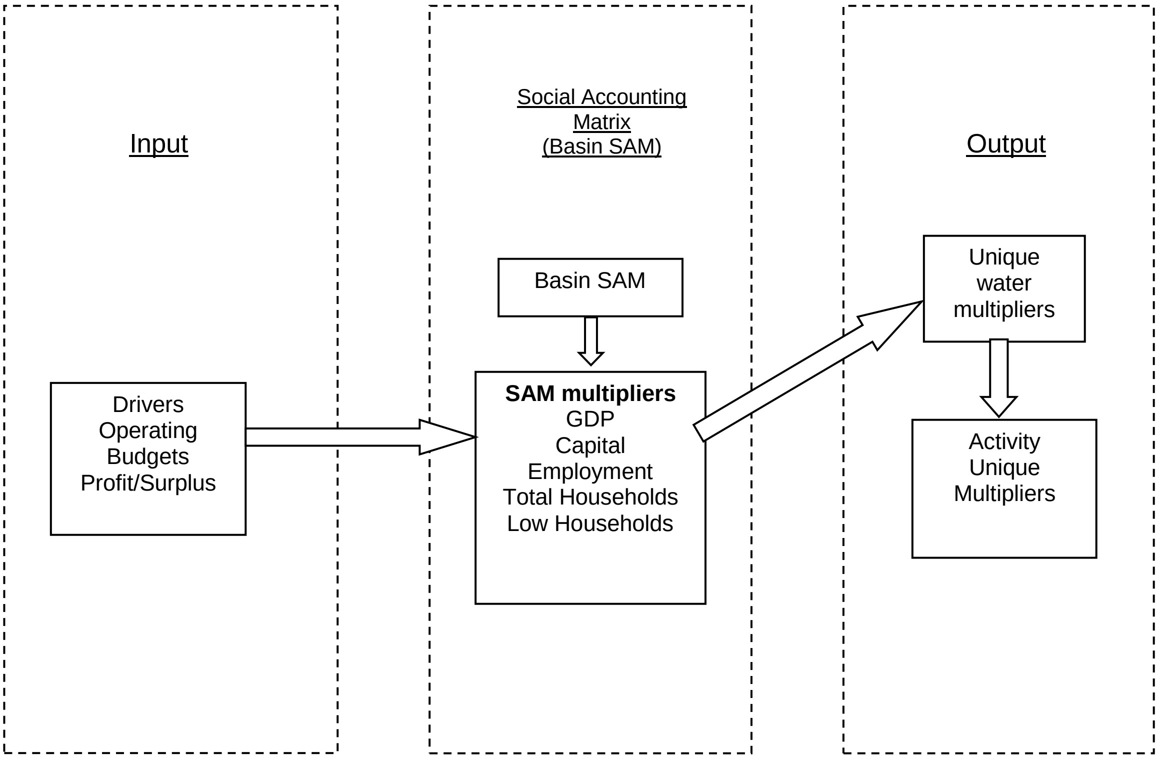



**Figure 3.5:** Pathway of developing Activity Multipliers

The major element is the specific applicable Social Accounting Matrix (SAM) which is used to determine, in multiplier form, the macro-economic impacts set out above. This is shown in the central portion of **Figure 3.5**.

The inputs which are required by the SAM model to generate these multipliers are shown in the left-hand side of **Figure 3.5** and comprise drivers (the factors of production used in each sector) and the operating budget (which reveals the surplus or profit).

These inputs enable the multipliers to be associated with changes in resources used in each sector (hectares, manpower, water, etc.), and with the operating surplus in each sector.

In compiling the operating budgets, use was made of In-house Computer Budgets developed to present water usage and financial statistics for all of the major irrigation crops grown in four countries. Gross Income (Price x Tonnage), Capital Costs and Variable Costs were compiled to determine net income derived from specific crops.

The final output from the Basin model is a set of multipliers (based in the year 2013) that characterise the economic variables for each sector. These are shown as Unique Water Multipliers on the right-hand side of **Figure 3.5.** Initially calculated in terms of the sectors present in the Basin SAM, these are then disaggregated into the specific sectors and crops which are of interest in this study. These multipliers are the so-called Activity-unique Multipliers.

The Limpopo River Basin Model has to produce forecasts which can be used, *inter alia*, for Scenario building over a period of years. To do this, in the model the economic drivers are multiplied by the activity-unique multipliers. Thus in the case of irrigation agriculture production, for example, the GDP would be calculated by multiplying the number of hectares with the agriculture multiplier. The economic analysis of the Basin involved an assessment of the direct impacts - benefits and costs - resulting from the use of the Basin's water resources, as well as indirect (positive) benefits to economic activities and the environment attributable to the river system. Thus for this analysis the Limpopo River Basin is sub-divided into sub basins. This sub-division makes it possible, by using a regional as well as sectoral approach, to attain a more insightful perspective of the impact of the various development and water use scenarios that will be evaluated as part of the overall development of an IWRM Strategy and Plan for managing the water resources of the Limpopo River Basin.

The multipliers for the entire basin and for the four countries are presented below. The different sub basin multipliers are available in **Technical Annexure Volume A2**.

#### 3.6.8.1 *Basin Multipliers*

**Table 3.10:** Total Limpopo Basin Multipliers

| Economic sector | GDP (US$ /m$^3$) | | | Employment (Number/million m$^3$) | | | Household Income (US$ /m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Direct | Indirect and Induced | Total | Direct | Indirect and Induced | Total | Total | High and Medium | Low |
| **Irrigation** | 0.8 | 1.0 | 1.8 | 114.7 | 70.1 | 184.8 | 1.0 | 0.5 | 0.5 |
| **Commercial Forestry** | 0.7 | 0.6 | 1.3 | 83.1 | 47.4 | 130.5 | 0.5 | 0.2 | 0.4 |
| **Mining** | 76.2 | 69.7 | 145.9 | 1 222.2 | 3 017.6 | 4 239.7 | 62.6 | 9.5 | 53.1 |
| **Power Generation** | 17.9 | 11.4 | 29.3 | 45.2 | 682.6 | 727.8 | 11.1 | 2.4 | 8.6 |
| **Industry** | 182.0 | 287.4 | 469.4 | 1 008.1 | 3 426.3 | 4 434.4 | 273.2 | 79.4 | 193.8 |
| **Eco-Tourism** | 138.1 | 121.6 | 259.7 | 7 981.3 | 8 025.2 | 16 006.5 | 107.3 | 32.2 | 75.1 |

The efficiency of water use for the total basin varies considerably between economic activities, in terms of the value of the water and depends on the indicators selected. In the following example the impact of two users of water is compared in terms of poverty alleviation.

**Table 3.11:** Impact of two users of water compared in terms of poverty alleviation

| Economic Activity | **Direct Employment** (Number/million m$^3$) | **Payments to Low Income Households** (US$/m$^3$) |
|---|---|---|
| Mining | 1 222.2 | 53.1 |
| Industry | 1008.1 | 193.8 |

**Table 3.11** shows that mining is more efficient in terms of job creation than industry, but in terms of payments to low income households industry is the more effective.

Eco – tourism is a very efficient user of water, but it has limitations in terms of its future growth in the basin.

Although irrigation has relative inefficient multipliers its role in providing household and national food security makes it an important role player.

#### 3.6.8.2 *Botswana Multipliers*

**Table 3.12:** Botswana Multipliers

| | GDP (US$ /m$^3$) | | | Employment (Number/million m$^3$) | | | Household Income (US$ /m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Direct** | **Indirect and Induced** | **Total** | **Direct** | **Indirect and Induced** | **Total** | **Total** | **Medium** | **Low** |
| Irrigation | 60 | 78 | 138 | 4 336 | 6 887 | 11 223 | 89 | 47 | 42 |
| Commercial Forestry | - | - | - | 0.0 | 0.0 | 0.0 | - | - | - |
| Mining | 98 | 90 | 187 | 1 065 | 5 131 | 6 197 | 80 | 12 | 68 |
| Power Generation | 71 | 45 | 116 | 317 | 2 692 | 3 008 | 38 | 4 | 34 |
| Industry | - | - | - | - | - | - | - | - | - |
| Eco-Tourism | 158 | 139 | 298 | 9 150 | 9 201 | 18 351 | 122 | 36 | 86 |

In the large water user category in terms of employment numbers, irrigation is the most efficient water user at total employment of 11 223 jobs per million m$^3$, followed by mining with 6 197 jobs per million m$^3$.

In terms of payments to low income households mining is the most efficient with US$ 68.2 per million m$^3$ followed by power generation with 34 US$ per million m$^3$. Although a very small consumer of water eco – tourism is the most efficient consumer with a contribution of 86.1 US$ per million m$^3$.

In terms of GDP creation eco-tourism is also the most efficient followed by mining and power generation.

Although irrigation performs very well if compared to others it should always be taken into consideration that this is mostly food gardens and not many commercial units.

### 3.6.8.3 *Moçambique Multipliers*

**Table 3.13:** Moçambique Multipliers

| | GDP (US$ /m$^3$) | | | Employment (Number/million m$^3$) | | | Household Income (US$ /m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Direct** | **Indirect and Induced** | **Total** | **Direct** | **Indirect and Induced** | **Total** | **Total** | **Medium** | **Low** |
| Irrigation | 21 | 15 | 35 | 455 | 684 | 1 139 | 59 | 16 | 8 |
| Commercial Forestry | - | - | - | - | - | - | - | - | - |
| Mining | - | - | - | - | - | - | - | - | - |
| Power Generation | - | - | - | - | - | - | - | - | - |
| Industry | - | - | - | - | - | - | 122.5 | 35.8 | 86.7 |
| Eco-Tourism | 158 | 1 369 | 2 98 | 9 150 | 9 201 | 18 351 | 699 | 122 | 36 |

The only two sectors currently present are irrigation and eco – tourism. It is how ever a well-known fact that mining in the Moçambique part of the basin will in the next couple of years develop dramatically. It is also anticipated that with the proposed irrigation development below the Massingir dam the sugar mill will come back into production.

### 3.6.8.4 *South African Multipliers*

**Table 3.14:** South African Multipliers

| | GDP (US$ /m$^3$) | | | Employment (Number/million m$^3$) | | | Household Income (US$ /m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Direct** | **Indirect and Induced** | **Total** | **Direct** | **Indirect and Induced** | **Total** | **Total** | **Medium** | **Low** |
| Irrigation | 0.92 | 1.14 | 2.06 | 150 | 81 | 231 | 1.23 | 0.65 | 0.59 |
| Commercial Forestry | 0.69 | 0.59 | 1.28 | 83 | 47 | 130 | 0.54 | 0.16 | 0.38 |
| Mining | 131 | 119 | 250 | 2 123 | 5 056 | 7 179 | 107 | 16 | 91 |
| Power Generation | 20 | 13 | 34 | 50 | 781 | 831 | 13 | 3 | 10 |
| Industry | 390.63 | 619.45 | 1 010.1 | 2 112 | 7 206 | 9 318 | 553.19 | 136.62 | 417.97 |
| Eco-Tourism | 133.94 | 117.97 | 251.91 | 7 743 | 7 785 | 15 528 | 148.99 | 43.44 | 105.54 |

In the large water user category in terms of employment numbers, industry is the most efficient water user at total employment of 9 318 jobs per million m$^3$, followed by mining with 7 179 jobs per million m$^3$.

In terms of payments to low income households industry is the most efficient with US$ 418 per m$^3$ followed by mining with 91 US$ per m$^3$. Although a very small consumer of water, eco–tourism is an efficient consumer with 105.5 US$ per m$^3$ paid in wages.

In terms of GDP creation industry is also the most efficient followed by mining and eco-tourism.

Although irrigation performs relatively poorly if compared to others it should always be evaluated in terms of the strategic contribution it makes to household and country food security and the role it plays in rural development.

#### 3.6.8.5 *Zimbabwe Multipliers*

**Table 3.15:** Zimbabwe Multipliers

| | GDP (US$ /m$^3$) | | | Employment (Number/million m$^3$) | | | Household Income (US$ /m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Direct** | **Indirect and Induced** | **Total** | **Direct** | **Indirect and Induced** | **Total** | **Total** | **Medium** | **Low** |
| Irrigation | 2 | 2.0 | 4 | 162 | 136 | 298 | 8 | 2 | 1 |
| Commercial Forestry | - | - | - | 0.0 | 0.0 | 0.0 | - | - | - |
| Mining | 545 | 498 | 1 043 | 6 383 | 28 574 | 34 957 | 111.5 | 18.7 | 92.7 |
| Power Generation | - | - | - | 0.0 | 0.0 | 0.0 | - | - | - |
| Industry | - | - | - | 0.0 | 0.0 | 0.0 | - | - | - |
| Eco-Tourism | 158 | 139 | 298 | 9 150 | 9 201 | 18 351 | 122.5 | 35.8 | 86.7 |

In the large water user category in terms of employment numbers, mining is the most efficient water user at total employment of 34 956 jobs per million m$^3$, followed by eco – tourism with 18 350 per million m$^{3.}$

In terms of payments to low income households mining is the most efficient with US$ 111.5 per m$^3$ followed by eco - tourism with 122.5 US$ per m$^3$.

In terms of GDP creation mining is also the most efficient followed by eco-tourism irrigation.

Although irrigation performs relatively bad if compared to others it should always be evaluated in terms of the strategic contribution it makes to household and country food security and the role it plays in rural development

### 3.6.9 Summary

The current base scenario analysis shows that in terms of employment mining is overall the largest employer with a total of 1.24 million with the number of direct employees at around 882 600. Second on the list is irrigated agriculture with a total of 404 618 and direct jobs at around 251 200.

Mining also plays a very important role in terms of payment to low income households with a total US$ 15 643 million out of total payment of all sectors to low income households of US$23 623 million, 66% of the total. This shows the importance of the sector to poverty alleviation in the basin.

As far as the efficiency of the sectors expressed as a water use multiplier mining also performs very well.

Although irrigated agriculture performs relatively poorly if compared to others it should always be evaluated in terms of the strategic contribution it makes to household and country food security and the role it plays in rural development.

# 4. ECO-SYSTEMS AND ENVIRONMENTAL WATER REQUIREMENTS

***(Refer Technical Annexure Volume B1: Water Quality)***

## 4.1 INTRODUCTION

The concept of environmental water requirements (EWRs) or environmental flows (EFs) has taken root in many countries around the world, and has become a baseline for most water resource assessments. The concept grapples with the three important components of a water resource namely quantity, quality and timing and links these with the ecological needs of the ecosystem. This concept of the EWR is well described as follows - *"the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems" (Brisbane Declaration, 2007).*

EWRs are currently being used as a management tool in the Limpopo River Basin, though this is predominantly in South Africa, where the National Water Act requires EWRs to be established for all water resources. There is also a wealth of water resource data available for many of the tributaries of the Limpopo which flow through South Africa covering all three resource components (quality, quantity and timing). This situation has come about through national initiatives such as the River Health programme, EWR assessments and DWA monitoring programmes.

In Botswana, although there is no legal obligation to implement EWRs, policies and strategies such as the National Water Master Plan (1991), and the National Development Plan call for consideration of the ecological needs of the resource and thus aim to achieve a similar objective. Unfortunately, data and information regarding water resources in the Botswana portion of the LRB is scarce. In Zimbabwe, the Water Act and the Environmental Management Act (1998) provide for the protection of water resources, but as is the case with Botswana, information and data are scarce and limited to a few projects. In Moçambique, the Water Law (1991) and Policy (2007) provide for the protection of EWRs. Implementation has however not followed on from this legal requirement and almost no data is thus available for the Moçambique portion of the LRB. This is especially true of the Limpopo estuary. Due to the importance of the estuarine environment and the lack of data, an in-depth study of the estuary has been carried out in this project. This is reported on in Section 4.5 of this report.

Because of the very uneven distribution of relevant water resource data, it is important that the method adopted to address the ecological component of the study is able to use whatever data is available, together with data gathered from very limited field work, to assess the present ecological state of the Limpopo and its tributaries, and the quantity, quality and timing of flows required to maintain or improve this state. The method adopted, and the results of the EWR study (as are thus far available) are described in detail in the following sections of this report. Sediment movement through the LRB is a particularly important component of this study and this has received particular attention in addition to a broader water quality assessment.

## 4.2 SURFACE WATER QUALITY

### 4.2.1 Approach to the Surface Water Quality Assessment

Water quality describes the physical, chemical and biological characteristics of water. Water quality in the Limpopo River Basin is highly affected by man-made activities. For example, the headwater streams of the

Crocodile (West) River is affected by sprawling urban areas of the Johannesburg/Pretoria metropolitan areas resulting in high nutrient and bacterial concentrations, the headwaters of the Olifants River is affected by many coal mining activities and acid mine drainage, large irrigation projects spread throughout the basin increase salt and agro-chemical concentrations in receiving rivers, and high sediment loads occur during flood events in non-perennial rivers. In this overview of the water quality on the Limpopo River basin, the focus of the data analysis was on the chemical water quality but where appropriate, mention was be made of other water quality concerns that have been raised in the mainstem river as well as its sub-basin.

The issue of sedimentation of rivers and reservoirs is an important consideration in the sustainable development and management of infrastructure projects such as dams in the Limpopo River Basin. In particular, an understanding of the specific river and reservoir sediment loads, sediment yields and mass balance is essential for the optimisation of the benefits from the basin. This knowledge is needed for the formulation of appropriate solutions to deal with sedimentation problems in order to achieve economic and environmental sustainability.

### 4.2.2 Methods

The water quality situation assessment consisted of the following tasks:

- Collation of available water quality data - The objectives of this task were to review the water quality data that was collected during the Scoping Phase, collate additional water quality data from the member countries that was collected since 2008 when the Scoping Phase was conducted, and to prepare the data for analysis with the Statistica statistical software package.
- Development of water quality criteria - The objective of this task was to develop standards or criteria for the assessment of fitness for use of the water for different water uses to assess the fitness of use of the water
- Analysis of the data - The objective of this task was to assess the spatial water quality trends in the LRB using collated data and information, and to assess the fitness for use, using the joint basin water quality criteria. It included the interpretation of the results and it was complemented with findings of other research and assessments in the basin
- Identification of water quality hotspots and concerns - The objective of this task was to identify water quality and environmental hotspots in the Limpopo River Basin, and develop appropriate background information for each of the identified hotspots.

Assessment of the sedimentation of the rivers consisted of a quantitative analysis of sediment transport data and mass balance with more detailed data in the part of the basin that is situated in South Africa. The total average sediment outflow from sub-basin areas within the Limpopo River basin were computed at selected river gauging stations or dam locations but it must be noted that little information existed for Botswana, Moçambique and Zimbabwe.

### 4.2.3 Results

**Water quality criteria**

Seven water quality variables were selected to describe the fitness for use of the waters in the Limpopo River Basin:

- Electrical conductivity (EC) as indicator of the salinity of the water. Salinity originates from natural sources, agricultural return flows, and industrial and mining effluents. High salinity affects the taste of water, reduce the yields of irrigated crops, and cause corrosion in irrigation, household and industrial appliances.
- pH as indicator of the acidity of the water. The pH is affected by the geology and geochemical processes, industrial discharges and acid mine drainage. It affects the solubility of metals and in turn, its toxicity to aquatic organisms.
- Fluorides originate from geological sources and high concentrations have adverse effects on the dental health of water users. Manmade sources include industrial discharges from, for example, fertiliser factories.
- Dissolved iron is affected by geological sources but also mining and industrial pollution. Its solubility is affected by the pH and dissolved oxygen concentrations. High iron concentrations affect domestic water supplied, cause staining of washing, and promote corrosion in metal appliances.
- Sulphate is a good indicator of acid mine drainage and industrial pollution impacts. High sulphate levels promote biofouling in pipes, cause noxious odours in potable water, and cause gastro-intestinal ailments at high concentrations.
- Nitrates and nitrites are nutrients and elevated levels are normally indicators of agricultural return flows and domestic wastewater discharges, often leading to eutrophication problems in rivers and reservoirs (also see phosphates). Very high nitrates in domestic waters can cause infantile methemoglobinemia in babies.
- Phosphates are nutrients and elevated levels are normally indicators of agricultural return flows and domestic wastewater discharges, often leading to eutrophication problems in rivers and reservoirs (nuisance algal blooms and excessive growth of aquatic plants), which in turn has negative impacts on domestic water supplies (taste and odours), block irrigation equipment, and toxic algae can cause livestock deaths.

Fitness for use can range from ideal for a specific use to unacceptable. Four descriptions (and colours) were selected to express a judgement of fitness for use:

- Good (blue) – Complies with all guidelines and standards for a specific use, and the use of water is not affected in any way, it is regarded as 100% fit for use.
- Tolerable (green) – Complies with the second most stringent standards or guidelines for a specific use. Slight to moderate problems can be encountered.
- Poor (amber) – Complies with the least stringent standards. Moderate to severe problems are encountered, usually for a limited period only.
- Unacceptable (red) – complies with none of the standards for a specific use and the water cannot be used for its intended use under normal circumstances.

To set boundary values, the guidelines and standards applicable for various water uses in the four basin countries were considered. The uses considered were domestic water supply, agricultural water supply (irrigation and livestock watering), and aquatic ecosystems (eutrophication potential). The following boundary values were set and used to classify the fitness for use, see **Table 4.1.**

**Table 4.1:** Boundary values that were set for selected variables to classify the fitness for use of waters in the Limpopo River Basin

| Variable | Units | Good | Tolerable | Poor | Unacceptable | Sensitive user |
|---|---|---|---|---|---|---|
| EC | $m^S/m$ | 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 |

**Surface water quality assessment**

The focus of the quantitative assessment was on the main stem Limpopo River and the lower reaches of its tributaries. Summary statistics for the present water quality status was calculated for the key variables at selected monitoring points and compared to the fitness for use criteria to assess the suitability for use. This judgement was based on the 75th percentile statistic, meaning that 75% of the samples had a concentration less or equal to the calculated value. The water quality was then classified using generic assessment terms ('good', 'tolerable', 'poor', 'Unacceptable or Blue, Green, Amber, Red) (**Table 4.2**).

**Table 4.2:** Overview of Water Quality in the Limpopo River Basin using the 75th percentile values and Classifying the Quality using Domestic and Agricultural Guideline Values

| Sub-Basins | 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** | | | | | | | | | |
| Notwane | Makgophana Bridge | 71.00 | 6.94 | 7.35 | 0.79 | 1.78 | 28.06 | 11.410 | 65.420 |
| Mahalapye | All points | 38.00 | 7.03 | 7.60 | 0.27 | 0.54 | 9.00 | 4.200 | 13.400 |
| Motloutse | All points | 138.00 | 6.73 | 8.38 | 0.09 | 0.35 | 529.34 | 0.000 | 21.270 |
| Letlakane | All points | 338.70 | 6.95 | 7.33 | 2.00 | 1.86 | 238.00 | 0.500 | 105.920 |
| **Moçambique** | | | | | | | | | |
| Limpopo | E-31 at Pafuri | 42.50 | 6.70 | 7.90 | | | 53.27 | | 5.000 |
| Limpopo | E-33 at Combumune | 60.80 | 6.80 | 7.94 | | | 42.80 | | 6.810 |
| Limpopo | E-372 at Ald. Baragem Montante | 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/Elephants | E-546 d/s of Massingir Dam | 53.90 | 7.07 | 7.80 | | | 151.86 | | 5.000 |
| **South Africa** | | | | | | | | | |

| Sub-Basins | Station | EC | pH | pH | Fluoride | Iron | Sulphate | Ortho-phosphate | Nitrate |
|---|---|---|---|---|---|---|---|---|---|
| | | mS/m | Lower | Upper | mg/l | mg/l | mg/l | mg/l | mg/l |
| Marico | A3R004Q01 at Molatedi Dam | 29.25 | 8.23 | 8.48 | 0.41 | | 17.67 | 0.031 | 0.040 |
| Crocodile (West) | A2H132Q01 at Paul Hugo Dam | 83.90 | 7.95 | 8.37 | 0.48 | | 82.59 | 0.259 | 1.609 |
| Matlabas | A4H004Q01 at Haarlem East | 9.79 | 7.28 | 7.77 | 0.24 | | 1.50 | 0.005 | 0.025 |
| Mokolo | A4H013Q01 at Moorddrift/Vught | 11.10 | 7.57 | 7.70 | 0.35 | | 1.50 | 0.005 | 0.025 |
| Lephalale | A5H008Q01 at Ga-Seleka Village | 16.19 | 7.40 | 7.94 | 0.34 | | 6.22 | 0.200 | 0.550 |
| Mogalakwena | A6R002Q01 at Glen Alpine Dam | 24.32 | 7.71 | 7.98 | 0.36 | | 6.05 | 0.031 | 0.070 |
| Nzhelele | A8R001 at Nzhelele Dam | 33.63 | 8.12 | 8.35 | 0.23 | | 3.01 | 0.006 | 0.055 |
| Levuvhu | A9H011Q01 at Pafuri | 18.40 | 7.76 | 8.04 | 0.21 | | 3.00 | 0.018 | 0.050 |
| Shingwedzi | B9H002Q01 at Silvervis Dam/KNP | 26.70 | 7.67 | 7.90 | 0.23 | | 3.81 | 0.131 | 0.031 |
| Letaba | B8H018Q01 at Engelhardt Dam / KNP | 50.90 | 7.95 | 8.55 | 0.26 | | 8.61 | 0.018 | 0.067 |
| Olifants | B7H015Q01 at Mamba weir/ KNP | 56.00 | 8.08 | 8.45 | 0.43 | | 67.14 | 0.015 | 0.511 |
| Limpopo (upper) | A5H006Q01 at Sterkloop | 58.20 | 7.92 | 8.16 | 0.47 | | 54.00 | 0.057 | 0.179 |
| Limpopo (middle) | A7H008Q01 at Beit Bridge | 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 |
| Mzingwane (middle) | BR16 | 24 | 7.62 | 8.07 | | 0.29 | 12 | 0.064 | 0.371 |
| Mzingwane (lower) | BL8 (Zhove Dam) | 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 |

*Notes: Colour classification: Blue = Good, Green = Tolerable, Amber = Poor, Red = Unacceptable*
*No data available for open cells.*

The water quality status is summarised for each variable:

- Salinity (Electrical conductivity) – EC's in Botswana appears to be elevated which is probably an indication of the ephemeral nature of the rivers (high evaporation and accumulation of salts). In Moçambique salts are elevated but still within a tolerable range. In South Africa salts are elevated in the Crocodile (West), Lebata, Olifants and upper and middle Limpopo rivers. High salts in the Limpopo River appear to originate from the Crocodile (West) River. In Zimbabwe salts are in a good category.

- pH – In general, pH values recorded in the Limpopo River Basin fall within a good category (between 6.5 and 8.5) although there are pockets that are affected by Acid Mine Drainage (AMD).
- Fluoride – In general fluoride concentrations fall within a good category (< 0.7 mg/l) although elevated concentrations have been recorded in Notwane and Letlakane Rivers in Botswana.
- Iron – Iron concentrations are not routinely recorded in South Africa and Moçambique. Some elevated concentrations have been recorded in the Letlakane River in Botswana.
- Sulphate – Sulphate values of less than 10 mg/l is generally recorded in rivers not impacted by AMD. However, in rivers affected by AMD, elevated sulphate concentrations occur even though they are still categorised as in a good class. The elevated sulphates in the upper and middle Limpopo River appears to originate in the Crocodile (West) River with some contributions from the Motloutse and Letlakane rivers. The Olifants River in South Africa and Moçambique also shows elevated concentrations and the impacts of AMD.
- Nutrients – Nitrate values in Botswana and Moçambique appear to be very high but it might be related to the lower detection limits of the analytical methods used in the laboratories. In South Africa and Zimbabwe, nitrates fall in a good category. Elevated phosphate concentrations occur more often in the basin indicating that eutrophication may be a problem throughout the basin.

The quantitative assessment only reflects part of the water quality status and in the Synthesis section, water quality concerns raised in other research and assessment reports are highlighted.

**River and reservoir sedimentation**

The total average sediment outflow from sub-basin areas within the Limpopo River basin were computed at selected river gauging stations or dam locations. **Figure 4.1** shows the schematic representation of the annual sediment load for selected stations from this data. Sediment yield values for station numbers 28 and 34 were obtained from the Joint Limpopo Basin Study (1991). The data for Massinger Dam was obtained from Sedimentation Study (2002). The sediment loads for the stations that have been typed in bold letters are based on observed data. The rest of the sediment loads have been estimated based on the analytical method in WRC (2012).

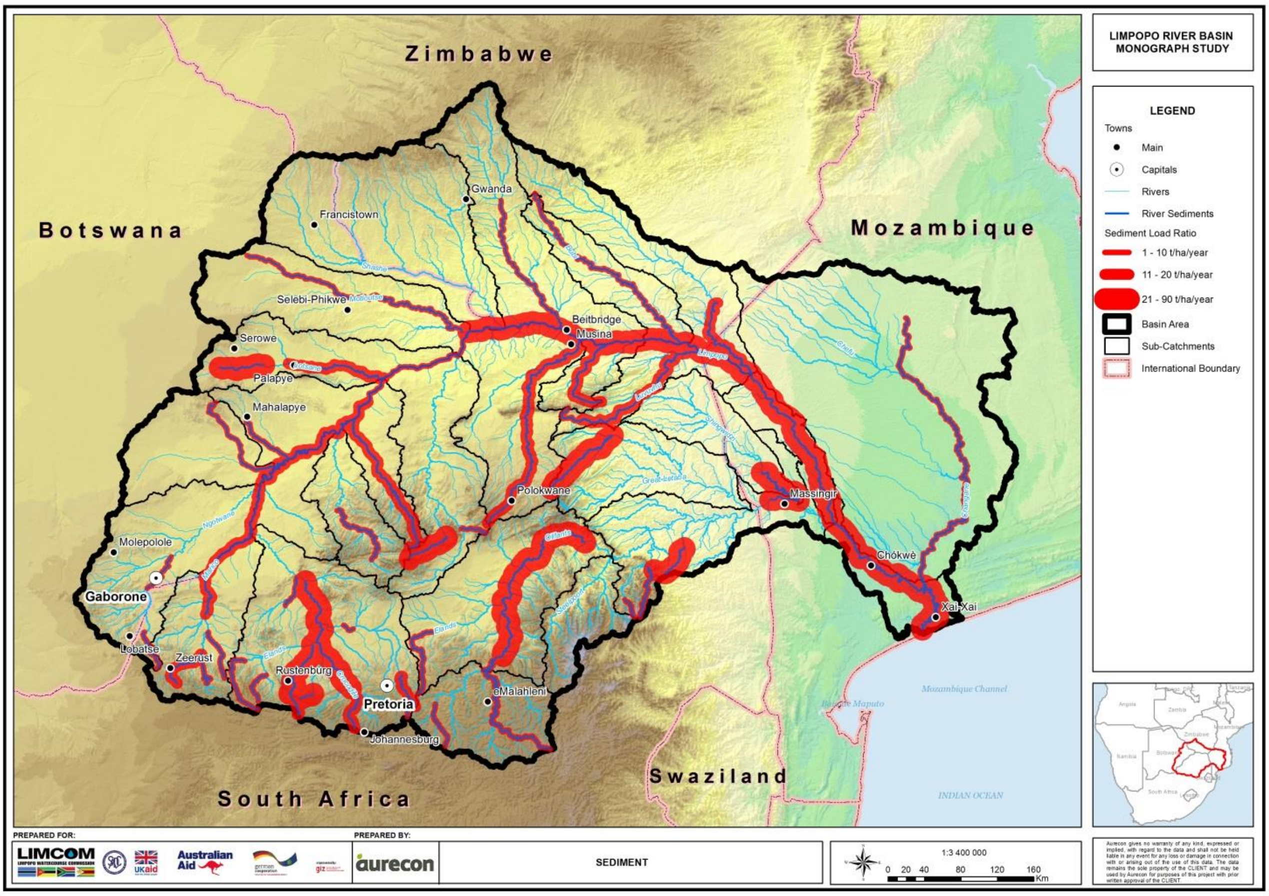



**Figure 4.1:** Sediment loading rates of the Limpopo River Basin

### 4.2.4 Synthesis

#### 4.2.4.1 *Water quality situation in Botswana*

The rivers in Botswana only contribute flow to the Limpopo River during floods. Baseline water quality data is probably not a fair reflection of the water quality that reaches the Limpopo River and it would probably be fair to say that they do not have a significant impact on the water quality in the main stem Limpopo River.

**Notwane sub-basin** - Gaborone is located in the upper reaches of the Notwane River. Treated wastewater is discharged to the river but it is used for irrigation and other agricultural purposes before it can impact on the Limpopo River. Flow in the lower reaches of the Notwane River is very intermittent and there is little water available to assess the quality of water that reaches the Limpopo River. Most of the sampling on the Notwane River appears to be focussed in the upper reaches around Gaborone and Mochundi. This quality is still regarded as acceptable for agricultural purposes and tolerable for aquatic ecosystems although elevated nutrients have been recorded.

**Bonwapitse sub-basin** - There is no water quality monitoring data for the Bonwapitse sub-basin. Water quality in this sub-basin is probably largely natural and impacts would be restricted to those associated with cattle and game farming. Suspended sediment is probably elevated during the rainfall months. This river is highly ephemeral.

**Mahalapswe sub-basin** - There are a number of monitoring points associated with the Mahalapye River but it appears that most are associated with water supply from the river bed or along the river course. Although elevated nutrients were recorded in the Mahalapye the water is regarded as good for agricultural. Suspended sediment is probably elevated during the rainfall months.

**Lotsane sub-basin** - Flow in this sub-basin is very intermittent and there is no data available to assess the quality in the lower reaches of these sub-basins.

**Motloutse sub-basin** - Flow in this sub-basin is intermittent and there is some data in the upper reaches to assess the quality. This is regarded as still ideal for agricultural purposes and acceptable for aquatic ecosystem requirements.

#### 4.2.4.2 *Water quality situation in South Africa*

Rivers originating from South Africa probably has the greatest impact on water quality in the Limpopo River. A number of "hard working" South African rivers are located in the Limpopo River Basin, notably the Crocodile (West) River, one of the headwater tributaries, and the Olifants River, a tributary of the lower Limpopo River.

**Marico sub-basin** - The water quality in the Upper Marico River is relatively good with localised impacts from land based activities. Some tributaries are impacted by slate mining activities and agricultural impacts. Turbidity and erosion are the main water quality issues. The Marico Bosveld Dam impacts on the water quality in the river through reduced outflows (return flows are not diluted) and lower turbidity (sediment retained in the dam). Water quality of the Klein Marico River catchment is good in the upper reaches but it deteriorates in the middle and lower reaches as a result of urbanisation. Water quality of the middle and lower Marico River is of fair to poor quality with certain areas being impacted by nutrients, erosion and salinisation. There are also concerns about increased levels of agrochemicals in the middle reaches of the river. Water quality in the Lower Marico River is poor due to high nutrients (seepage of fertiliser), and elevated salinity from high agricultural return flows.

**Crocodile (West) sub-basin** - Water quality concerns are mainly related to nutrient enrichment and salinity impacts due to wastewater discharges and flow regulation in the sub-basin. Irrigation return flows also contribute to nutrient enrichment. Microbial water quality concerns appear to be localised and associated with high density urban areas and settlements, failing sewerage infrastructure, and effluent water quality not meeting water quality standards. Water quality of the Upper Crocodile (West) River is highly impacted by urbanisation (large areas of the Johannesburg and Pretoria metropolitan areas fall in this sub-basin) and large volumes of wastewater discharges (WWTWs and industrial). Water quality in the rivers is relatively poor with high levels of nutrients and salt concentrations. The middle and lower reaches of the Elands River are of a fair quality with intensive mining activities in the sub-basin impacting on the river. Water quality in the Apies/Pienaars sub-basin is of poor quality and is impacted by elevated nutrients and salts from thirteen point source discharges from industries and wastewater treatment works into this sub-basin. The Lower Crocodile (West) River is deteriorating in terms of water quality and salts and nutrient concentrations are high. There are also increased levels of toxicants in the middle reaches of the river. A number of concerns have been identified in the Crocodile (West) sub-basin, mostly related to the transfer of water from other river systems into the headwaters of the Crocodile (West) system, and the wastewater return flows resulting from these transfers. Sprawling urban areas in the south-east of the sub-basin and the wastewater return flows contribute to the deterioration of water quality and enrichment of rivers and reservoirs with nutrients. The higher than natural flows in the Crocodile (West) River has stimulated irrigation agriculture near the river resulting in return flows that are high in salts, nutrients, and agrochemicals. Mining in the middle reaches of the Crocodile (West) River has also increased salt concentrations and trace metals. The result is poor quality water exiting the Crocodile (West) River especially during the low flow months.

**Mokolo sub-basin** - Water quality is generally good upstream of the Mokolo Dam except for elevated nutrient concentrations. Water quality downstream of the Mokolo Dam is still good with the exception of elevated phosphates. There are concerns about future acid mine drainage impacts when intensive mining of the coal reserves in this sub-basin commence. The new Mokolo pipeline from the lower Crocodile (West) River could potentially result in water quality changes in the Mokolo sub-basin due to the addition of poorer quality from the Crocodile (West) River. Concerns have also been expressed about the rapid and uncontrolled growth of informal settlements in the upper Mokolo River (around Vaalwater and Alma).

**Lephelala sub-basin** - Water quality is good but concerns have been raised about elevated pH, phosphates and sulphates. Land use of the Lephalale River is mainly agriculture. Witpoort is a small town where the waste water treatment works is not operating efficiently.

**Mokgalakwena sub-basin** - Water quality monitoring is poor but water quality is affected by the towns where waste water treatment works are not meeting discharge standards. There are large also platinum mines in the upper sub-basin creating nitrate problems from blasting and elevated turbidity from runoff. Other problems associated with mining are elevated trace metal and dissolved salt concentrations.

**Sand sub-basin** - Water quality monitoring in this sub-basin is very poor. There are coal mines in the sub-basin that have the potential for acid mine drainage and sulphate contamination. There are also many areas of sand mining. Water quality is also impacted by effluent from three WWTWs in the sub-basin and intensive agricultural activities contribute to elevated nutrient levels in the river.

**Nzhelele sub-basin** - The Nzhelele sub-basin is dominated by agriculture (citrus) both up and downstream of the Nzhelele Dam. The discharges from sewage treatment works do not meet appropriate discharge standards.

**Upper and middle Limpopo** - Elevated salts and sulphate concentrations have been recorded in the upper and middle Limpopo River. There have also been recorded outbreaks of cholera in the Limpopo River around the Messina area. The Beit Bridge town's infrastructure completely collapsed and there are concerns about localised bacteriological pollution of the Limpopo River. Similar concerns have been expressed about Messina town.

**Levuvuhu sub-basin** - The water quality status of the Levuvuhu River is driven by intensive agriculture of sub-tropical fruits and afforestation in the upper sub-basin, the urban sprawl of Thohoyandou in the middle reaches and the Kruger National Park in the lower reaches. Elevated nutrient concentrations that occur all the way into the Kruger National Park are the result of fertiliser use from intensive agriculture, nutrient loads from waste water treatment plant effluent, and the lack of formal wastewater treatment for the dense urban sprawl outside the Kruger National Park. The Luvuvhu River is subject to on-going research into the human health and fish impacts associated to the use of DDT for malaria control in the sub-basin. The intensive irrigated agriculture in the Letaba and Luvuvhu River has resulted in the use of a wide range of pesticides over the past decades.

**Shingwedzi sub-basin** - The majority of this sub-basin falls within the Kruger National Park and the Transfrontier Park. Outside of the Parks the land use is mainly subsistence agriculture and informal urban settlements. Concerns have been raised about poor land use practises that take place into the flood plain of the river. There is an improvement in water quality as the river flows through the national park areas.

**Letaba sub-basin** - Water quality concerns in the Letaba sub-basin are driven by diffuse pollution, such as afforestation in the upper sub-basin (turbidity, fertilisers), agricultural runoff from intensive cultivated lands, mainly bananas and citrus (fertilisers, salts, nutrients, pesticides), dense communities close to rivers (microbiological, litter, turbidity), and animal grazing and watering (microbiological, turbidity). The point sources are effluents from wastewater treatment works at Tzaneen and Giyani. Concerns about nutrient enrichment are associated with the use of fertilisers for the intensive agriculture and a lesser extent, waste water treatment plant effluents. In the lower sub-basin the main land-use is irrigation agriculture, namely citrus plantations (mangos and bananas) and afforestation. Water quality impacts are related to salinisation, the release of pesticides / herbicides into the environment and elevated nutrient levels. The Klein Letaba River is affected by dense settlements and agriculture above the Middle Letaba Dam and upper Klein Letaba River.

**Olifants sub-basin** – The Olifants River is regarded as one of the “hardest working” rivers in South Africa and water quality is highly affected by man-made activities. Salinity related impacts are due to mining, power generation and industries in the upper areas of the sub-basin. Very high salt concentrations in the lower reaches of the Elands River are due to irrigation return flows and a concentration effect due to evaporation of water during low flows. Low pH values occur in the sub-basin. There are however localised acid conditions in sub-sub-basins associated with AMD. This generally emanates from defunct coal mines.

There is particular concern about coal mining activities in the upper areas of the Olifants sub-basin. The activities are extensive and are still growing. The impacts are known as AMD which is acidic water, usually containing high concentrations of metals, sulphides and salts. Many mines are reaching the end of their economic lives and the mine workings are filling up with water and will ultimately decant into rivers and streams. This water is polluted and the volumes can be large enough to impact significantly on the regional water quality. A number of schemes are under development to mitigate the impacts of AMD.

The trophic status in dams is generally moderately enriched. However, eutrophic conditions and blooms of blue-green algae have been observed in Loskop Dam. The eutrophic conditions in the dam were due to high nutrient inputs from upstream WWTWs. The majority of the wastewater treatment works associated with the local municipalities was producing an effluent which did not meet their licence requirements. The works are discharging water which contains high organic, nutrient and microbiological loads to the river systems. Unacceptable phosphate concentrations were also a concern in the Selati and in the lower Olifants below the Selati confluence. These were associated with sewage return flows and effluents from the mining and industrial activities around Phalaborwa. Agricultural runoff also contributed nutrients and toxic organic chemicals associated with herbicides and pesticides to the Olifants sub-basin. There was limited information on heavy metal concentrations but available data showed unacceptably high levels in parts of the sub-basin. High aluminium concentrations have been cited as a possible cause of the fish deaths in Loskop Dam.

#### 4.2.4.3 *Water quality situation in Zimbabwe*

Water quality data was only available for the Mzingwane River and in general, the quality appeared to be good although elevated phosphates have been recorded in the river. Eutrophication related problems may therefore occur. The Mzingwani, Shashe, Bubi and Mwenzi sub-basins form the Mzingwani River System and the water quality was reviewed in the Mzingwane River System Outline Plan that was prepared in 2009. Concerns were expressed about point and non-point sources of pollution. Point sources were identified as sewage treatment works, industrial sources, and mines (both formal and informal gold panning in river courses). It was concluded that pollution of rivers that passed through large towns were associated with sewage and municipal landfills. Examples were Amanziamyama in Gwanda and the Limpopo River at Beitbridge. Rural rivers were affected by mining activities where they occurred and by extensive gold panning. Concerns associated with these activities were elevated iron, manganese, sulphate, nitrate, and suspended solids concentrations. It was also found that the water quality in majority of the reservoirs that supply Bulawayo (Upper Mzingwane) was good. This was confirmed by the assessment of water quality for aquatic ecosystem requirements that was undertaken by Chibi in 2007 (Chibi, 2007). In that study it was found that water quality was not compromised even though there have been toxic spills from the How mine in 2001. In Zhove Dam (Lower Mzingwane) the water quality was high in alkalinity and total dissolved salts. Water quality in Blanket and Mtshabezi dams (Shashe) that supply water to Gwanda was good but there were concerns about the hardness and fluoride concentrations. The quality of water in Ingwizi and Mhlanga dams (Shashe west) that supply Plumtree was good, low in turbidity, but there were concerns about elevated concentrations of alkalinity and hardness.

It was reported that the Mzingwane River System is characterised by an array of small, medium and large-scale mining schemes most of which are located in the Shashe and upper Mzingwane sub-basins. These mostly impact groundwater through seepage from the slimes dams which would probably surface in streams draining these mining areas. Runoff from gold panning activities also affected water quality along rivers such as the Lower and Upper Ncema River, Mzingwane River and Insiza River.

#### 4.2.4.4 *Water quality situation in Moçambique*

Moçambique is situated at the downstream end of most of the Limpopo River and its east flowing tributaries. Many of the water quality concerns therefore originate outside of their borders.

**Olifants/Elephants sub-basin** – Elevated sulphate concentrations and salinity have been recorded in the Elephants River downstream of Massingir Dam; a legacy of the intensive use of the river in South Africa.

**Lower Limpopo sub-basin** - Chilundo et al. (2008) found elevated salinity concentrations at the end of the dry season but they were reduced flow in the Limpopo River. Elevated metal concentrations were found which in some cases exceeded Mozambican standards. However, there was a general reduction in metal concentrations in a downstream direction, probably due to sedimentation and adsorption onto sediment particles. It was speculated that the metals originated from upstream mining areas. Moçambique has a number of sampling points in the lower Limpopo River, E31 at Pafuri, E33 at Combumune, E372 at the Barrage near Chokwe and E36 at Chibuto/Sicacate, and E-38 at Xai-Xai. The electrical conductivity shows a steady increase in a downstream direction even though the quality is still classified as tolerable for domestic water supply and irrigation. However, the elevated sulphate concentrations at Chibuto indicate that there might be sea water intrusion up to that point from time to time.

**Changane sub-basin** - Chilundo et al. (2008) found that the Changane sub-basin was polluted, amongst other, with effluent discharges. It was found that river reaches were characterised by low dissolved oxygen and high total dissolved solids, electric conductivity, total hardness, sodium adsorption ratio and low benthic macro-invertebrates taxa. An increase in salinity in a downstream direction was observed but these were ascribed to the natural geology of the region. Concerns were also expressed about elevated nutrient concentrations and the risks associated with eutrophication. Metals were found to decrease in a downstream direction and low at the confluence with the Limpopo River.

#### 4.2.4.5 *Water quality hotspots and concerns*

The objective of this component was to identify water quality and environmental hotspots. For this report hotspots were defined as an area or region within the Limpopo River Basin where significant land-use activities are impacting on water quality and the aquatic environment to the detriment of communities dependent on those water resources. The assessment was undertaken at a high level and based on water quality data and environmental observations, and concerns raised in various reports on the basin. A map was compiled that shows the areas of water quality and environmental concerns (**Figure 4.2**).

Water quality and pollution concerns have been grouped into following categories:

- Acid mine drainage - AMD is highly acidic water, usually containing high concentrations of metals, sulphides, and salts as a consequence of mining activity. The major sources of AMD include drainage from underground mine shafts, runoff and discharge from open pits and mine waste dumps, tailings and ore stockpiles.
- Sedimentation - Sedimentation refers to the erosion, wash-off and silt load carried by streams and rivers. This has been further amplified land based activities such as construction projects, sand mining in the river channel, poor agriculture and silviculture practices, over-grazing, destruction of the riparian vegetation, and the physical disturbance of land by industry and urban development.
- Nutrient enrichment and eutrophication - Nutrient enrichment refers to the accumulation of plant nutrients in rivers and dams in excess of natural requirements resulting in nutrient enrichment or eutrophication. The direct impact is the excessive growth of algae and macrophyte (rooted and free-floating water plants) leading to aesthetic impacts, the presence of toxic cyanobacteria, the presence of taste- and odour-causing compounds in treated drinking water, and difficulty in treating the water for potable and/or industrial use.
- Salinisation - Salinisation refers to the increase in the amount of salts or dissolved solids in the water, as well as the accumulation of salts in soils, to the detriment of cultivated crops. It can also pose a threat to the ecological integrity of the river and interfere with the desirable uses of the water.
- Agro-chemicals and irrigation return flows - Agrochemicals refer to the pesticides and herbicides residues in surface waters that are harmful to aquatic ecosystems and/or users of the water. It includes pesticides or their residues such as chlorpyrifos, endosulfan, artrazine, deltamethrin, DDT & penconazole.
- Bacterial pollution - Microbial pollution is the presence of micro-organisms and parasites which cause diseases in humans, animals and plants. Most waterborne pathogens occur in human or animal faeces and enter waterways via various pathways. Micro-organism includes protozoa (e.g. Giardia & Cryptospridium), bacteria (e.g. E. coli), bacterial infections (e.g. shigella), viruses (e.g. hepatitis) and helminthes.

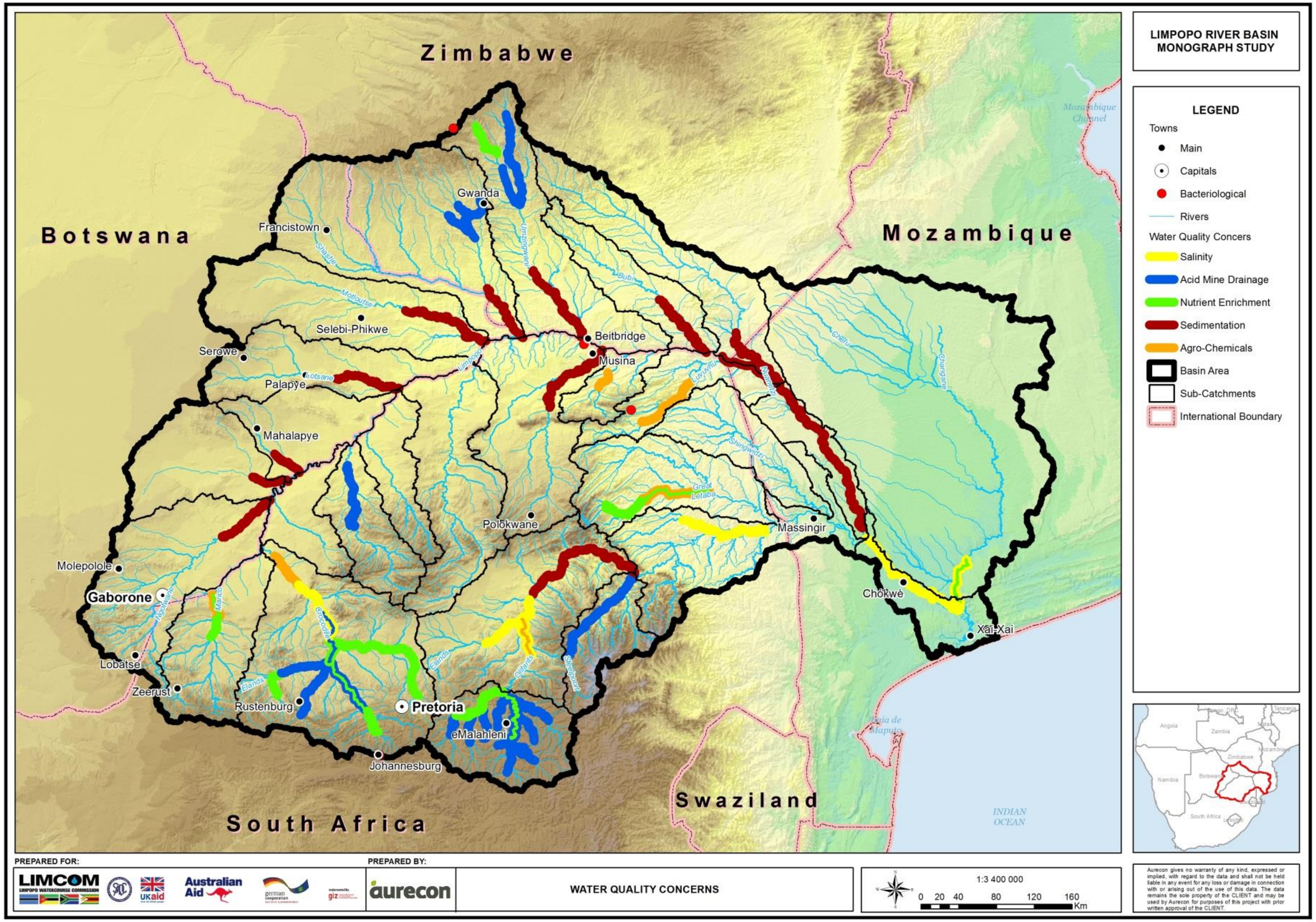



**Figure 4.2:** Map showing the location of key water quality concerns in the Limpopo River Basin

#### 4.2.4.6 *River and reservoir sedimentation*

This review was aimed at providing an insight into issues of sedimentation in the Limpopo River basin, particularly sediment loads and mass balance considering historical data and to predict future trends. The impacts of river and reservoir sedimentation cannot be ignored in this basin considering the calculated losses in storage for some of the reservoirs in the basin particularly those situated in South Africa, for which data was readily available. Already, the water quality in rivers and reservoirs has been greatly affected by an increase in suspended sediment concentration resulting from massive land degradation and other intensive anthropogenic activities. Some reservoirs have lost significant volumes of their original storage capacity due to sedimentation. This loss in storage reduces the ability for the reservoirs to meet human needs such as domestic and industrial water demand and irrigation requirements.

Considering the beneficial advantages of reservoirs for the storage of water for drinking, irrigation, recreation, hydropower production and flood control, sedimentation could result in serious socio-economic losses, and environmental and aesthetic problems. Food production from irrigated agriculture can be affected by reduced water volumes in reservoirs. The retention of sediment by large dams could also affect the equilibrium conditions of the lower river reaches and estuary.

Analysis of the general results showed that the average annual storage loss due to sedimentation in all reservoirs throughout South Africa is approximately 0.3%. The average annual loss in the Limpopo Basin (in South Africa) is 0.6%. It is almost twice the average South African value. This scenario adversely affects the long term sustainability of the reservoirs within the Basin.

## 4.3 CONSERVATION AREAS AND WETLANDS

### 4.3.1 Conservation Areas

The Limpopo River basin contains some of Africa’s largest and most renowned conservation areas, such as the Kruger National Park (South Africa) and Great Limpopo Transfrontier Park (Moçambique and South Africa) as well as the Gonarezhou National Park (Zimbabwe) and Banhine National Park (Moçambique). There are additionally adjacent a great number of smaller reserves, wildlife management areas and privately owned conservation areas / game farms as shown in **Figure 4.3**.

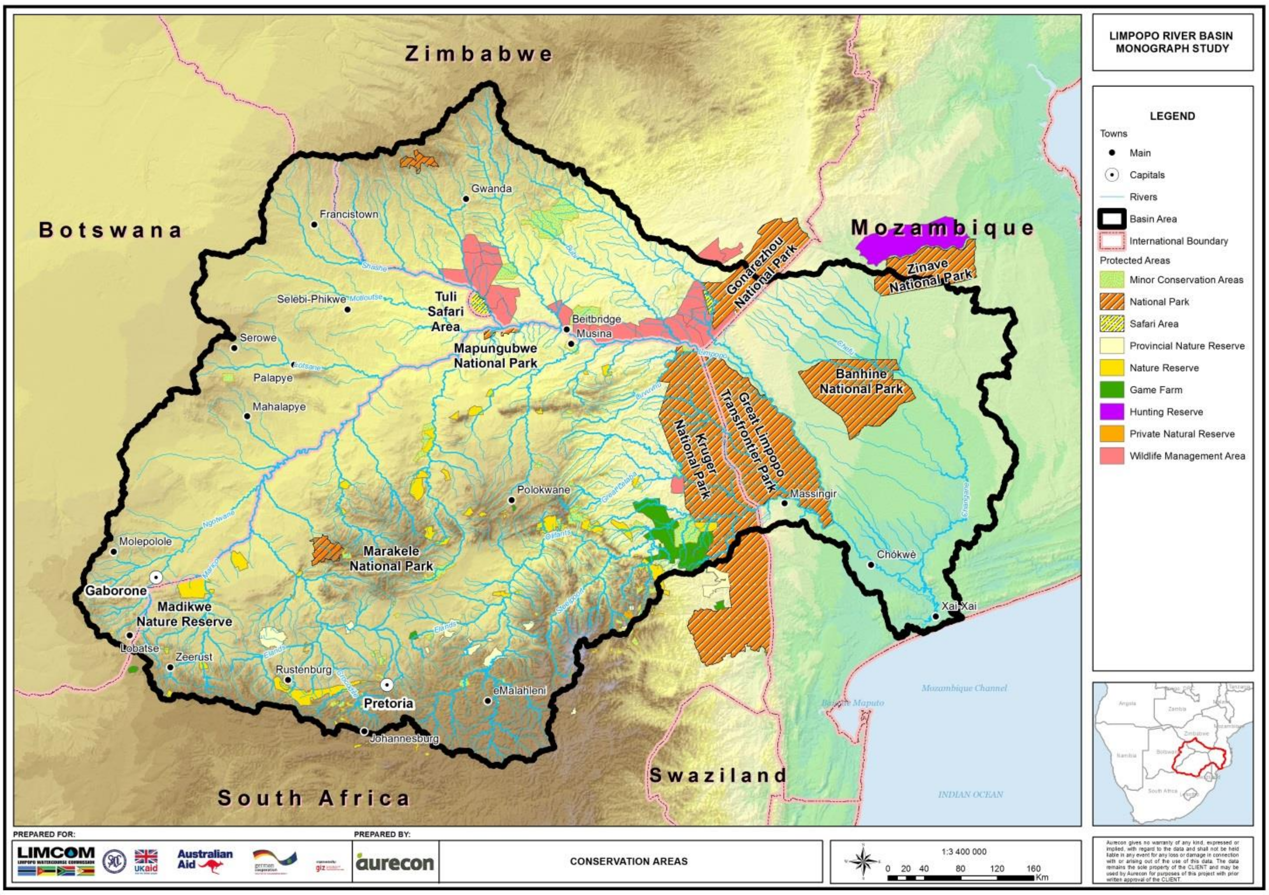



**Figure 4.3:** Conservation areas in the Limpopo River Basin

The Boundless Southern Africa, a regional tourism development integration initiative was recently launched in which nine SADC countries can participate in Transfrontier Conservation Areas (TFCAs). The seven TFCAs envisaged in the 2010 strategy are shown in **Figure 4.4**. The TFCAs which are within or straddle the Limpopo River Basin are:

- KAZA Transfrontier Park – to be collaborately managed by Angola, Botswana, Namibia, Zambia and Zimbabwe
- The Limpopo / Shashe Transfrontier Park – (now called the Greater Mapungubwe Transfrontier Park) – to be collaborately managed by Botswana, South Africa and Zimbabwe
- Great Limpopo Transfrontier Park – to be collaborately managed by Moçambique, South Africa and Zimbabwe

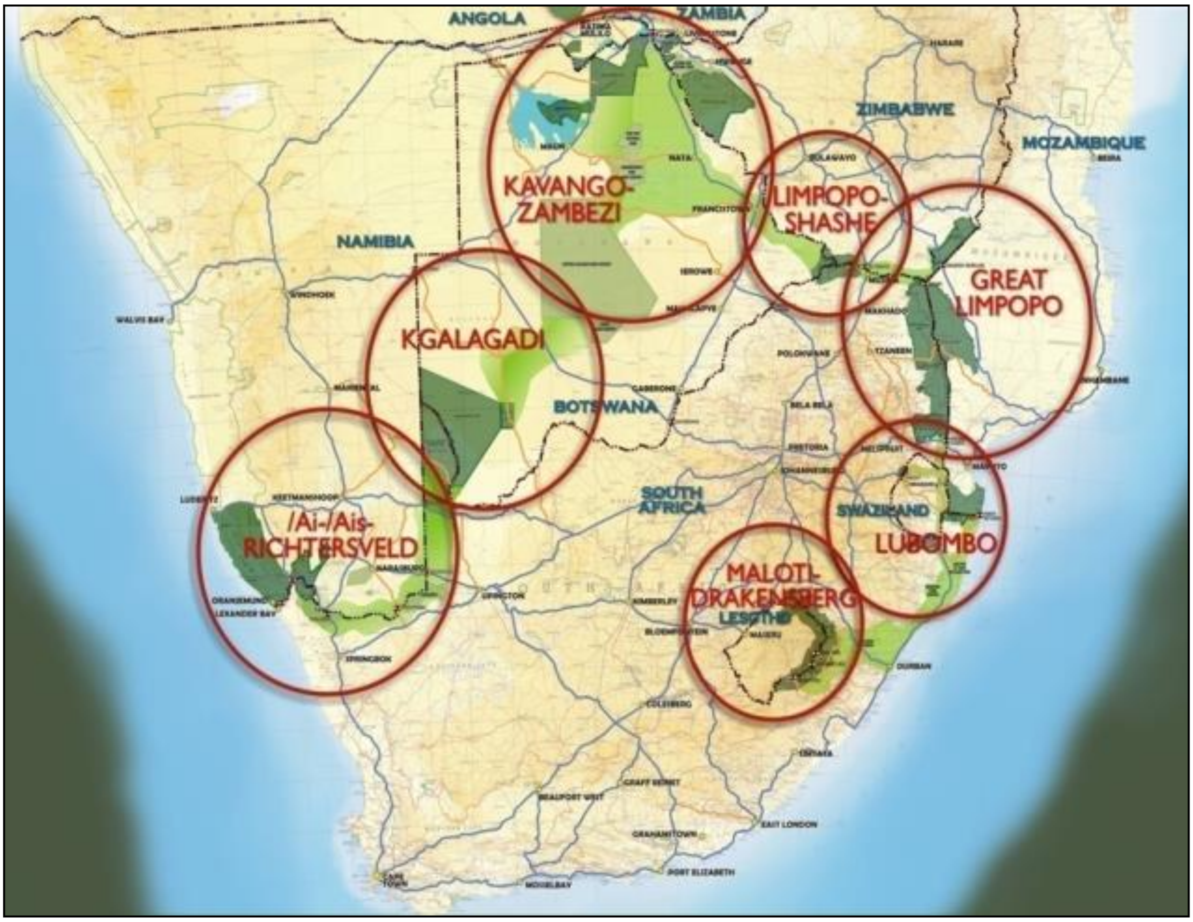



**Figure 4.4:** Envisaged Transfrontier Conservation Areas

### 4.3.2 Wetlands

The important role that wetlands play in any catchment is well documented. The Limpopo River basin wetlands are however not well documented and reasonably fine scale data is only available for the South African portion of the catchment. In order to broadly identify important wetland areas in the catchment, wetlands data for the greater Limpopo catchment was extracted from the Global Lakes and Wetlands Database (http://worldwildlife.org/pages/global-lakes-and-wetlands-database.) The database was generated as follows:

"Drawing upon a variety of existing maps, data and information, WWF and the Centre for Environmental Systems Research, University of Kassel, Germany created the Global Lakes and Wetlands Database (GLWD). The combination of best available sources for lakes and wetlands on a global scale (1:1 to 1:3 million resolution), and the application of GIS functionality enabled the generation of a database which focuses in three coordinated levels on (1) large lakes and reservoirs, (2) smaller water bodies, and (3) wetlands. Level 3 (GLWD-3) comprises lakes, reservoirs, rivers and different wetland types in the form of a global raster map at 30-second resolution".

This database indicates obvious large areas of wetlands in the flat low lying areas of Moçambique extending northwards from the Limpopo estuary along the Changane River, to Zinave National Park, and up along the floodplain of the Limpopo river itself. The available data is shown on **Figure 4.5**.

Fine scale wetlands data is available for South Africa from the National Freshwater Ecosystem Priority Area (NFEPA) database. This indicates a high density of wetlands in the upper catchments of the Olifants, Letaba and Luvuvhu Rivers. Unlike the vast coastal plain wetlands of Moçambique, the wetlands of the upper catchments are vast in number but smaller in size.

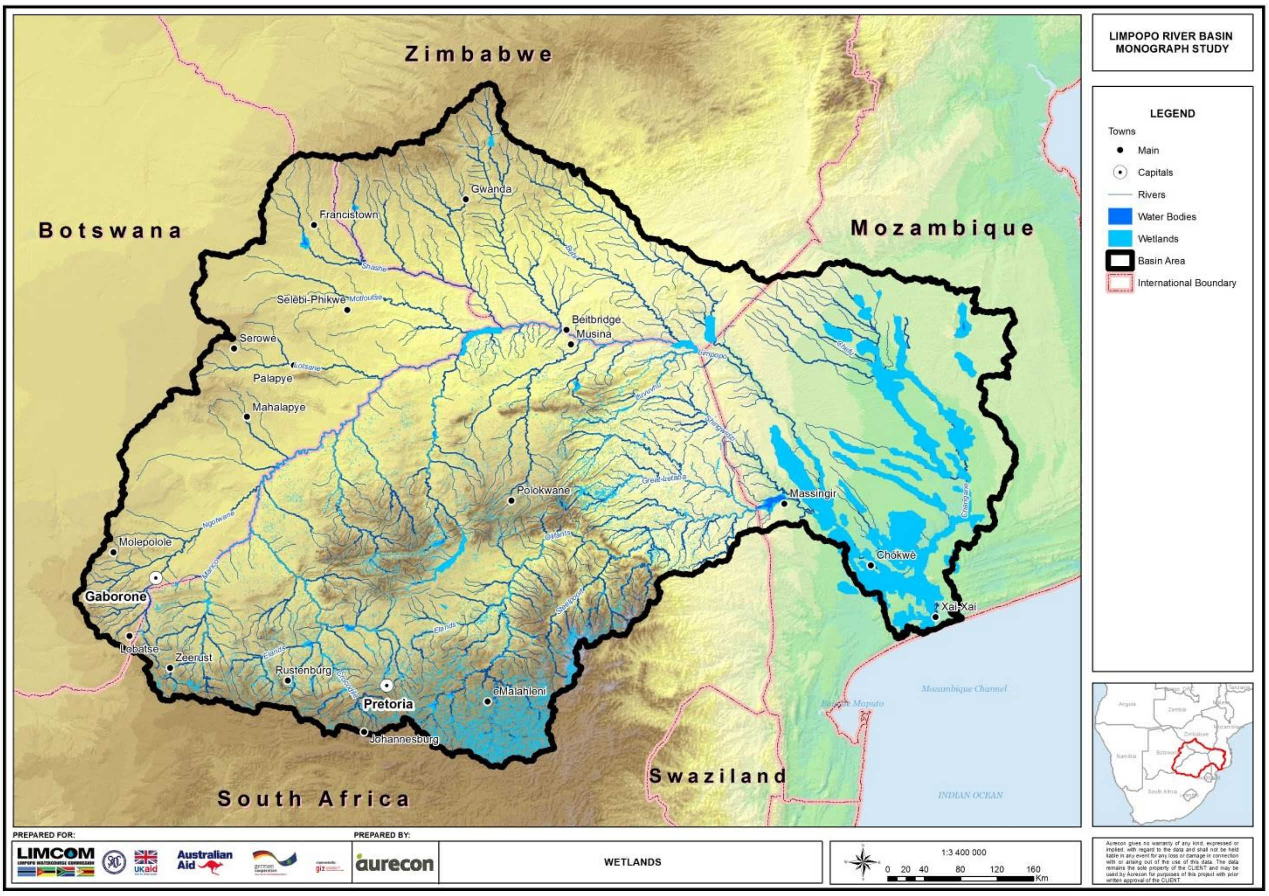



**Figure 4.5:** Wetlands in the Limpopo Basin (Global Lakes and Wetlands Database**,** http://worldwildlife.org/pages/global-lakes-and-wetlands-database)

## 4.4 ENVIRONMENTAL WATER REQUIREMENTS OF THE LIMPOPO RIVERS

***(Refer Technical Annexure Volume B2: Environmental Water Requirements)***

### 4.4.1 Approach to determining PES and EWRs

The approach adopted to the determine the Environmental Water Requirements (EWRs) termed the Ecological Reserve in South Africa, for the Limpopo basin follows the South African Department of Water Affairs (DWA) method for the rapid determination of the Ecological Reserve (as described below). This includes modelling the site under a variety of flow situations using a hydraulic cross section and relating the resulting flow scenarios to the ecology of a number of response organisms.

Present Ecological State (PES) is determined at each of the sites selected as a representation of a particular reach of river. This is done using the DWA eco-status model and using categorisations of PES for both fish and macro-invertebrates. From this information, the EWR for each site is determined using the methods as described below.

### 4.4.2 Methods

#### 4.4.2.1 *Site Selection*

It is important to select sites (reaches) that are representative of the variety of aquatic ecosystems that are found in the catchment, and that represent variations in flow down the river's course.

Primarily, selected sites need to represent the variety of ecologically distinct regions or 'eco-regions' that are found in the catchment. Aquatic eco-regions have been mapped for South Africa, but unfortunately not for the other three countries in the catchment. A global aquatic eco-region dataset was sourced, but proved to be too coarse for the purposes of this project. For this reason, surrogate datasets have been used to approximate eco-regions in these countries, and have been conjoined to the South African eco-regions map as shown in **Figure 4.6**. Surrogate sets of data include:

1. vegetation type (which is a good indicator of geology, soil type and climate), and
2. altitude.

The Limpopo basin downstream of the confluence of the Marico and Crocodile (West) Rivers is characterised by semi-arid bushveld vegetation, with the vast majority strongly dominated by Mopani Bushveld. Two steep descents mark the mid-portions of the Limpopo's course, dividing its length into three altitudinal belts, before the river flows onto the flat low lying areas on the coastal plain of Moçambique. Sites have thus been selected to represent these changes in ecosystem and altitude.

Site selection also needs to consider variations in flow found down the catchment as tributaries join the main stem. Sites have thus been preferably located so as to be able to capture / represent reaches where flow variations are likely to occur as major tributaries contribute significant quantities of water.

Sites that have been surveyed as part of other EWR studies (in South Africa) are included in this study and their locations have been considered in the site selection process, informing the selection of new sites in need of assessment. These sites and their selection have been fully described in other reports (which are too many to reference in this text, but are available from the South African Department of Water Affairs) and are thus not described here. New sites (8 of them) selected and surveyed as part of this project thus deliberately targeted the main-stem river and "other" countries with most new sites being located in Moçambique. Descriptions of all new sites surveyed are provided in **Technical Annexure Volume B2.**

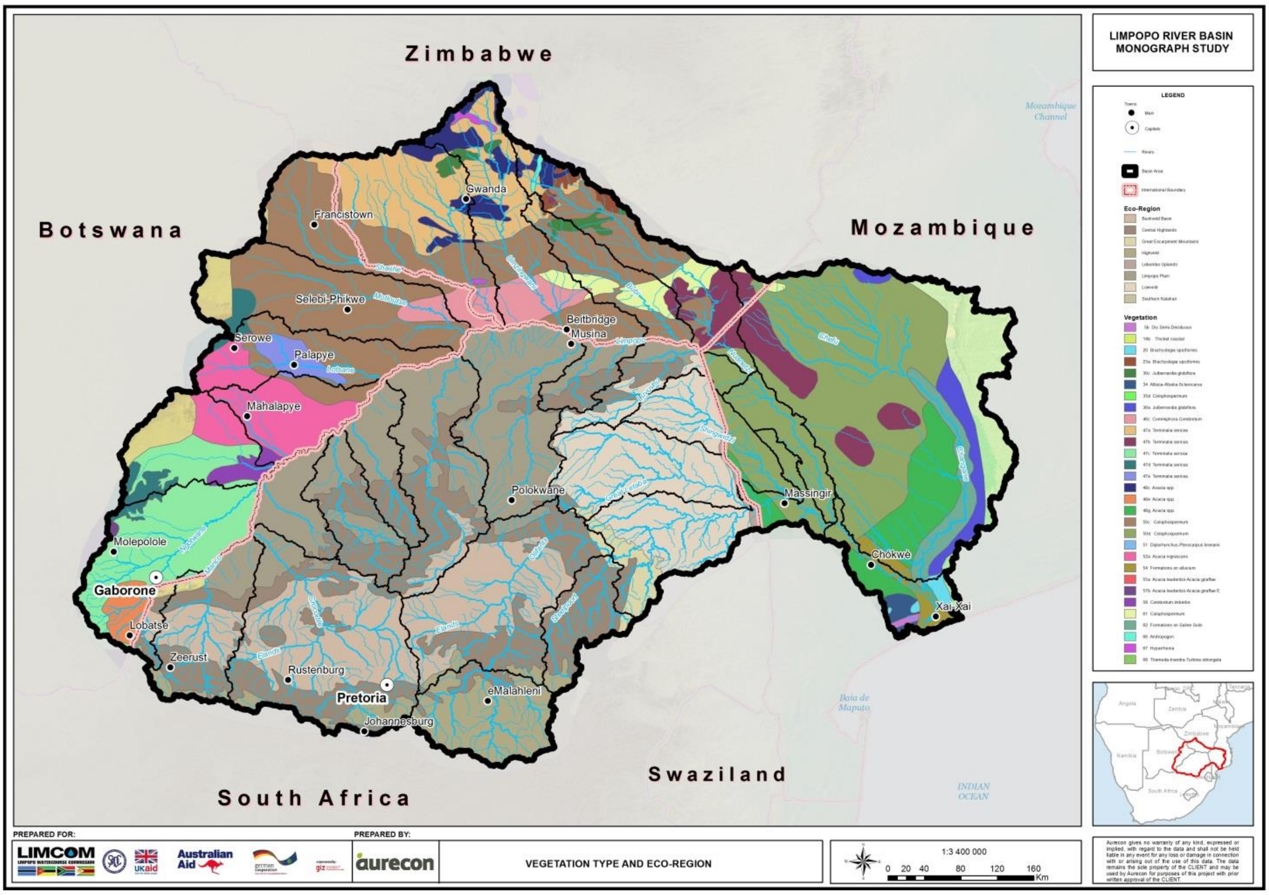



**Figure 4.6:** Vegetation types and Aquatic Eco-regions of the Limpopo basin

Within each eco-region and at a finer scale, specific sites are selected for assessment based on a set of criteria determined by the requirements of the specialists involved. Preferred sites on the Limpopo and tributaries were selected which:

1. contained a single channel for all discharges of interest,
2. were located on a reach with constant gradient and channel cross-section shape,
3. had no major hydraulic control downstream other than channel resistance and,
4. contained suitable habitat for the biota of interest.

The new sites that were eventually selected as part of this project are listed in **Table 4.3**. The positions of all sites surveyed in the study together with those from previous studies for which the results were used, are shown in **Figure 4.7.**

**Table 4.3:** New sites selected for the EWR assessment of the Limpopo River catchment

| Site Location | River | Site Number | Latitude | Longitude |
|---|---|---|---|---|
| Spanwerk | Limpopo | LmEWR01r | -23.944697 | 26.930778 |
| Poachers Corner | Limpopo | LmEWR02r | -22.184190 | 29.405240 |
| Malipati | Mwanedzi | LmEWR03r | -22.063900 | 31.423120 |
| Pafuri | Limpopo | LmEWR04r | -22.459600 | 31.503000 |
| Combomune | Limpopo | LmEWR05r | -23.471730 | 32.443810 |
| Shingwedzi | Shingwedzi | LmEWR06r | -23.144094 | 31.472816 |
| Chokwe | Limpopo | LmEWR07r | -24.500180 | 33.010390 |
| Changane | Changane | LmEWR08r | -24.114160 | 33.783870 |


**Figure 4.7:** Location of all sites to be used in the determination of EWRs in the Limpopo Catchment

### 4.4.3 Method of Assessment – Present Ecological State

Details of the methods used for those aspects presented below are given in **Technical Annexure Volume B2.**

#### 4.4.3.1 *Hydraulics*

The cross section of the 8 river sites were surveyed as illustrated in **Figure 4.8.** This information is used to describe the hydraulic habitat associated with that site and is pivotal for the determination of the EWR of the response indicators e.g. fish and invertebrates.

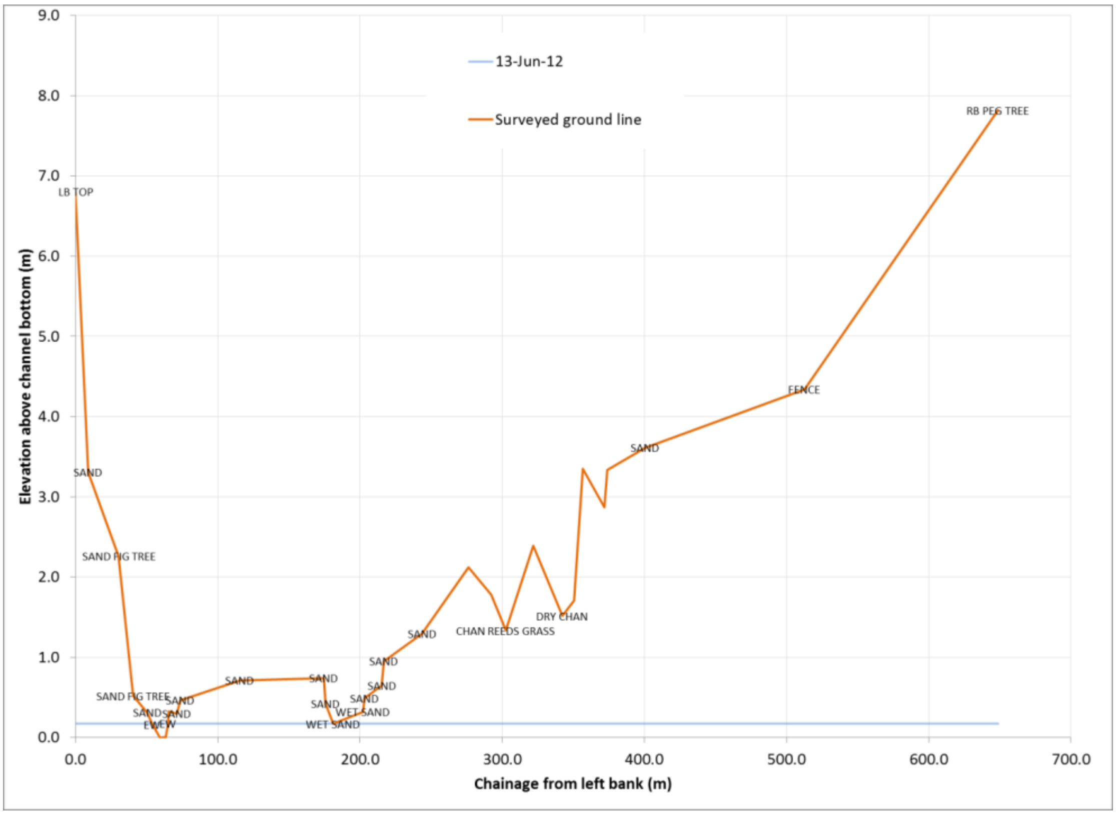



**Figure 4.8:** The cross section surveyed at site LmEWR05r (Combomune)

#### 4.4.3.2 *Fish*

The approach adopted to assess the present ecological state of the fish communities includes the use of the Fish Response Assessment Index (FRAI) (Kleynhans and Louw, 2007). This approach makes use of a multi-criteria decision analyses tool. The outcomes of the assessment include the determination of the present ecological category of the fish community within the study area, relevant to each site, and then the assessment of flow and non-flow related impacts that may be influencing the state of the fish community (Kleynhans, 2007). Much of the assessment is done relative to a Reference Condition i.e. how the fish community would look in undeveloped circumstances.

#### 4.4.3.3 *Macro-invertebrates*

Aquatic macro-invertebrate communities and assemblages are a good indicator of the prevailing flow regime and water quality in a river. The Macro-Invertebrate Response Assessment Index MIRAI model (Thirion, 2007) determines the ecological condition of the river by integrating the ecological requirements of the invertebrate communities and assemblages. The changes and responses are determined by comparing the present community and assemblage with that of a reference community and assemblage. The South African Scoring System SASS5 (Dickens and Graham, 2002) method was employed to collect invertebrate information and feeds into the MIRAI.

### 4.4.4 Present Ecological State (PES) or Eco-Status

A PES category (Eco-Status) was determined for each site based on PES assessments of fish and macro invertebrates. The PES results are reported below. **Table 4.4** provides a guide to the Ecological Categories that are used in this report.

**Table 4.4:** Ecological Categories used to classify the ecological condition or Eco Status of the components of the river and also of the overall river site

| ECOLOGICAL CATEGORIES | NAME | DESCRIPTION | COLOUR |
|---|---|---|---|
| A | Natural | Unmodified natural: Modifications to the natural abiotic template should be negligible to small. | Blue |
| 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. | Green |
| C | Fair | Moderately modified: A moderate risk of modifying the abiotic template and exceeding the resource base may be allowed. | Yellow |
| D | Poor | Largely modified: Large risk of modifying the abiotic template and exceeding the resource base may be allowed. | Red |
| E | Seriously modified | Seriously modified | Purple |
| F | Critically modified | Critically or extremely modified | Black |

#### 4.4.4.1 *Fish*

During the survey from 4 to 21 June 2012, 46 sampling efforts were carried out which resulted in the collection of 1 501 fish from the eight sites selected for the study, **Figure 4.9.** Twenty one species were collected in the study. Only the cichlids Oreochromis mossambicus and Tilapia rendalii were collected at all eight sites. Other cosmopolitan species included the sharptooth catfish (Clarius gariepinus) and tank goby (Glossogobius giuris) which were obtained at six and five sites respectively.

*Oreochromis mossambicus*

*Tilapia rendalii*

*Clarius gariepinus*

*Glossogobius giuris*

**Figure 4.9:** The four fish species most commonly sampled during the Limpopo monograph EWR field visit

The highest diversity of fishes (12 species) was obtained at Site LimEWR01r. Thereafter between seven and nine species were obtained at sites LimEWR02r, LimEWR03r LimEWR04r, LimEWR05r and LimEWR07r. Only six species of fishes were collected at LimEWR06r and four were collected from site LimEWR08r. Relatively good abundances of fish ranging between 122 and 485 individuals were obtained from all of the sites. The explanatory data obtained from each site showed that substrate, habitat and cover features as well as depths and velocities varied considerably between sites. This data was used in the FRAI and multivariate community structure assessment to arrive at an eco-status or PES category for each site based on the generic categorisation (Kleynhans & Louw) **(Table 4.5).**

**Table 4.5:** Fish and Invertebrate PES / Eco Status scores for the eight new sites

| Site | Name | Fish PES* | Invertebrates based PES | |
|---|---|---|---|---|
| | | | PES | Condition Class |
| LmEWR01r | Spanwerk | C (67%) | B (80.95%0 | Good |
| LmEWR02r | Poachers Corner | C/D (61%) | B (87.25%) | Good |
| LmEWR03r | Malipati | C (66%) | C (74.47%) | Fair |
| LmEWR04r | Pafuri | D (49%) | D (49%) | Fair |

| Site | Name | Fish PES* | Invertebrates based PES | |
|---|---|---|---|---|
| | | | PES | Condition Class |
| LmEWR05r | Combomune | D (57%) | B (83.92%) | Good |
| LmEWR06r | Shingwedzi | D (52%) | D (57.31%) | Poor |
| LmEWR07r | Chokwe | C (71%) | D (50.87%) | Poor |
| LmEWR08r | Changane | C/D (62%) | E (21.62%) | Seriously modified |

* FRAI scores adjusted after the operator evaluated the automated score of each metric to reflect the realistic conditions observed during the survey.

Although rapid, the survey carried out on the eight sites in the Limpopo Catchment was sufficient to allow for the assessment of the FRAI and fish community structures using multivariate statistical techniques. The findings indicate that the fish communities in the study area are in a moderate to largely modified ecological state (See **Table 4.5**).

The seasonal nature of the rivers in the Limpopo catchment suggests that the stressed state of fish communities encountered on the low flows field survey may be natural. Adjusting the FRAI scores to account for flow impacts however revealed that this is not the case. The absence of many species known to be tolerant to low and no flow conditions and corresponding absence of species intolerant to water quality alterations suggests that the rivers in the study area are being impacted by both flow and water quality alterations.

These impacts increase as one moves down from the remaining refuge areas in the upper reaches of the catchment (LimEWR01r) into the middle of the catchment resulting in the ecological integrity of the system deteriorating and then improving again in the lower portions of the study area at site LimEWR07r.

The statistical assessment of fish community structures using redundancy analyses (RDAs) supports these arguments showing that a significant relationship exists between PES scores and the community structures. These findings also show that large shifts occur in the community structures of fishes in the study area. These differences seem to be largely driven by flows and the availability of depth classes, which were seen to be key features of refuge areas where fish populations were being maintained.

These results when compared to historical data suggest that the fish communities of the Limpopo are dynamic and may shift in accordance with the perenniality changes of areas in the catchment. As such when some areas of the Limpopo Catchment become seasonal and episodic other areas act as refugia for fishes. Historically, fish communities have been able to shift across the catchment in response to these changes. These communities can thus be considered to be relatively more intolerant to anthropogenic impacts than communities that have stable refuge areas.

It thus appears that due to existing water quality and flow impacts emanating, predominantly from South Africa which appear to be affecting the upper south and eastern parts of the Limpopo Catchment, the importance of the northern, western and lower parts of the catchment has increased.

#### 4.4.4.2 *Macro-invertebrates*

The results of the invertebrate assessments undertaken at each site are reported in **Table 4.6** in terms of the number of taxa sampled, the SASS5 score achieved by those taxa, and the average SASS5 score per taxon achieved per site.

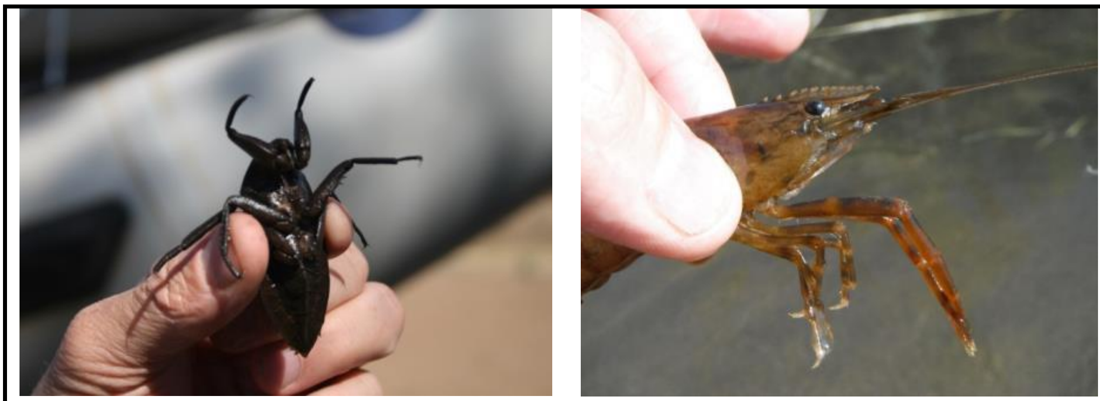
**Table 4.6:** Results of SASS5 macro-invertebrate sampling undertaken at each site

| Site no. | SASS score | No. Taxa | Average score per taxon (ASPT) |
|---|---|---|---|
| **LmEWR01** | 112 | 21 | 5.33 |
| Comment | No highly sensitive taxa present. Only *Baetidae with more than two species* with high water quality requirement, present. | | |
| **LmEWR02** | 109 | 20 | 5.45 |
| Comment | No highly sensitive taxa present. No stones habitat present. | | |
| **LmEWR03** | 101 | 23 | 4.39 |
| Comment | No highly sensitive taxa were present. Half of the taxa present had preferences for very slow flowing water and the majority of the taxa present had low or no preference for water quality. | | |
| **LmEWR04** | 110 | 19 | 5.79 |
| Comment | *Heptagenaiidae* and >2sp *Baetidae* present with high water quality requirements. The sensitive taxa *Palaemonidae* and *Heptageniidae* present but in very low abundances. | | |
| **LmEWR05** | 121 | 21 | 5.76 |
| Comment | The sensitive taxa *Palaemonidae* and *Heptageniidae* present in low abundances. Only taxon with high water quality requirement present was *Heptageniidae*. | | |
| **LmEWR06** | 64 | 14 | 4.6 |
| Comment | No sensitive taxa present. Invasive *Thiaridae* present in large numbers. | | |
| **LmEWR07** | 61 | 12 | 5.08 |
| Comment | Invasive *Thiaridae* present in large numbers. *Palaemonidae* present at site. No stones habitat present. | | |
| **LmEWR08r** | 13 | 3 | 4.33 |
| Comment | Invasive *Thiaridae* present in extensive numbers. No stones habitat or sensitive taxa present. | | |

Using the MIRAI model, the data was compared to expected reference conditions and a condition class was calculated based on the presence or absence and abundance of expected taxa (See **Table 4.7** below).

**Table 4.7:** Condition categories determined through an assessment of the macro-invertebrates present at each site

| Site | Name | PES | Condition Class |
|---|---|---|---|
| LimEWR01r | Spanwerk | B (80.95%) | Good |
| LimEWR02r | Poachers Corner | B (87.25%) | Good |
| LimEWR03r | Malipati | C (74.47%) | Fair |
| LimEWR04r | Pafuri | C (78.83%) | Fair |
| LimEWR05r | Combomune | B (83.92%) | Good |
| LimEWR06r | Shingwedzi | D (57.31%) | Poor |
| LimEWR07r | Chokwe | D (50.87%) | Poor |
| LimEWR08r | Changane | E (21.62%) | Seriously modified |



*Belostomatidae spp* *Palaemonidae spp*

**Figure 4.10:** Two of the macro-invertebrate taxa sampled during the Limpopo EWR field visit.

#### 4.4.4.3 *Overall Eco-Status*

The overall Eco-Status for each site was determined using the DWA eco-status model based on the results of the macro-invertebrate, fish and habitat assessments (Kleynhans and Louw, 2008). This model combines the PES for the fish, invertebrates and considers other habitat conditions including the riparian vegetation. It produces a single PES for the river at that site. The results of this process are reported in **Table 4.8.**

**Table 4.8:** Ecological categories calculated for the eight sites surveyed during this project

| EWR site | River | PES | Explanation |
|---|---|---|---|
| LmEWR1r | Limpopo at Spanwerk | B/C | Good / Fair |
| LmEWR2r | Limpopo at Poachers Corner | B/C | Good / Fair |
| LmEWR3r | Mwanedzi at Malapati | C | Fair |
| LmEWR4r | Limpopo at Pafuri | C | Fair |
| LmEWR5r | Limpopo at Combomune | C | Fair |
| LmEWR6r | Shingwedzi d/s Kanniedood Dam | B/C | Good / Fair |
| LmEWR7r | Limpopo at Chokwe | C | Fair |
| LmEWR8r | Changane | B/C | Good / Fair |

#### 4.4.4.4 *Wetlands of the Limpopo Basin*

While it was not the task of this project to evaluate the EWR of the wetlands of the Limpopo Basin, their location is illustrated in **Figure 4.5** in **Section 4.3.2.** Determination of the EWR for wetlands is a very different task to rivers, essentially as most wetlands are to some extent discreet and independent of other surface water resources. Thus, the EWR would need to be determined for each individual wetland, of which there are many thousand. As can be seen from **Figure 4.5** in **Section 4.3.2**, the bulk of the wetlands occur in the upper Olifants Catchment, with some large systems in Moçambique.

### 4.4.5 Environmental Water Requirements (EWRs)

During an EWR workshop, a process was followed where the demands for flow by each of the response components are documented and evaluated. A Recommended Ecological Category (REC) and an Ecological Importance and Sensitivity (EIS) category is calculated for each site to assist with the determination of the EWR.

The REC is determined as a target against which the EWR is calculated. This is based on the importance of the site from an ecological point of view and on its present ecological state. I n general, the REC is set as being the same as the PES, but where the ecological importance and sensitivity justifies the improvement of the condition of the site, the REC is set at a condition better than PES.

The EIS category is a measure of the important and sensitive ecological features of the site, including different species and its regional importance as a migratory corridor. This calculation is based on the presence of the following:

- Rare and endangered species
- Unique species (isolated or endemic)
- Intolerant species (of flow or flow related water quality impacts)
- Species / taxon richness
- Diversity of habitat types
- Refugia
- Migratory corridors
- Important conservation areas

From these the EWRs for each site can be determined using the Desktop Reserve Model (DRM – Hughes and Hannart, 2003) (SPATSIM, version 2.12). Target months for determination of the maintenance flows were usually September (low flow month) and February (high flow month). Outputs of the model are tested by the specialist ecologist and adjusted where necessary based on site specific knowledge. These EWR results are used to produce the assurance table or EWR rule curves. These curves specify the frequency of occurrence relationships of the defined maintenance and drought flow requirements for each month of the year. The tables thus specify the % of time that defined flows should equal or exceed the flow regime required to satisfy the environmental flow requirements.

The results are summarised in **Table 4.9** and illustrated in

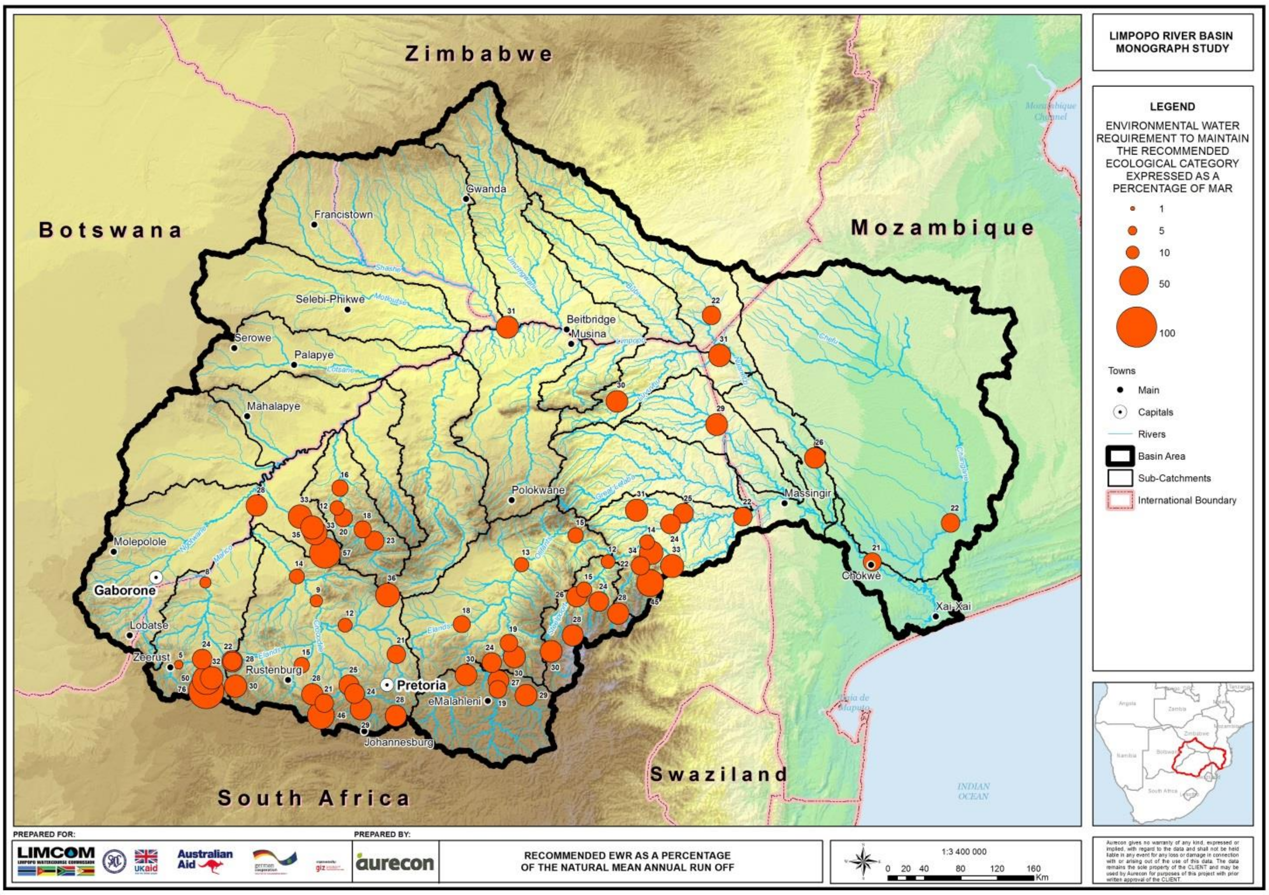



**Figure** 4.11 for all sites.

**Table 4.9:** Summary results of the Recommended EWRs for new sites on the Limpopo River and its tributaries

| EWR site | River | Quat catchment | PES | EIS | REC | nMAR ($10^6 m^3$) | %EWR (REC) |
|---|---|---|---|---|---|---|---|
| LmEWR1r | Limpopo at Spanwerk | A41D | B/C | High | B/C | 591.49 | 27.60 |
| LmEWR2r | Limpopo at Poachers Corner | A71L | B/C | Moderate | B/C | 1 683 | 30.90 |
| LmEWR3r | Mwanedzi at Malapati | Zimbabwe | C | Moderate | B/C | 282.73 | 22.00 |
| LmEWR4r | Limpopo at Pafuri | Moçambique | C | Moderate | C | 2 792 | 30.90 |
| LmEWR5r | Limpopo at Combomune | Moçambique | C | Moderate | C | 3 087 | 26.20 |

| EWR site | River | Quat catchment | PES | EIS | REC | nMAR ($10^6 m^3$) | %EWR (REC) |
|---|---|---|---|---|---|---|---|
| LmEWR6r | Shingwedzi d/s Kanniedood Dam | B90H | B/C | Moderate | B | 81.63 | 28.80 |
| LmEWR7r | Limpopo at Chokwe | Moçambique | C | Moderate | C | 5 572 | 20.60 |
| LmEWR8r | Changane | Moçambique | B/C | | B/C | | 21.80 |

***Note:*** *A table including the data from the many previous studies, mostly located on tributaries of the Limpopo, is to be found in the* ***Technical Annexure Volume B2****. PES=Present Ecological State {A-pristine, F-severely degraded}; EIS=Ecological Importance and Sensitivity; REC= Recommended Ecological Category (recommended from an ecological point of view as being reasonably attainable); nMAR=natural Mean Annual Runoff; %EWR (REC)=the percentage of the nMAR that forms the EWR at the recommended ecological category.*

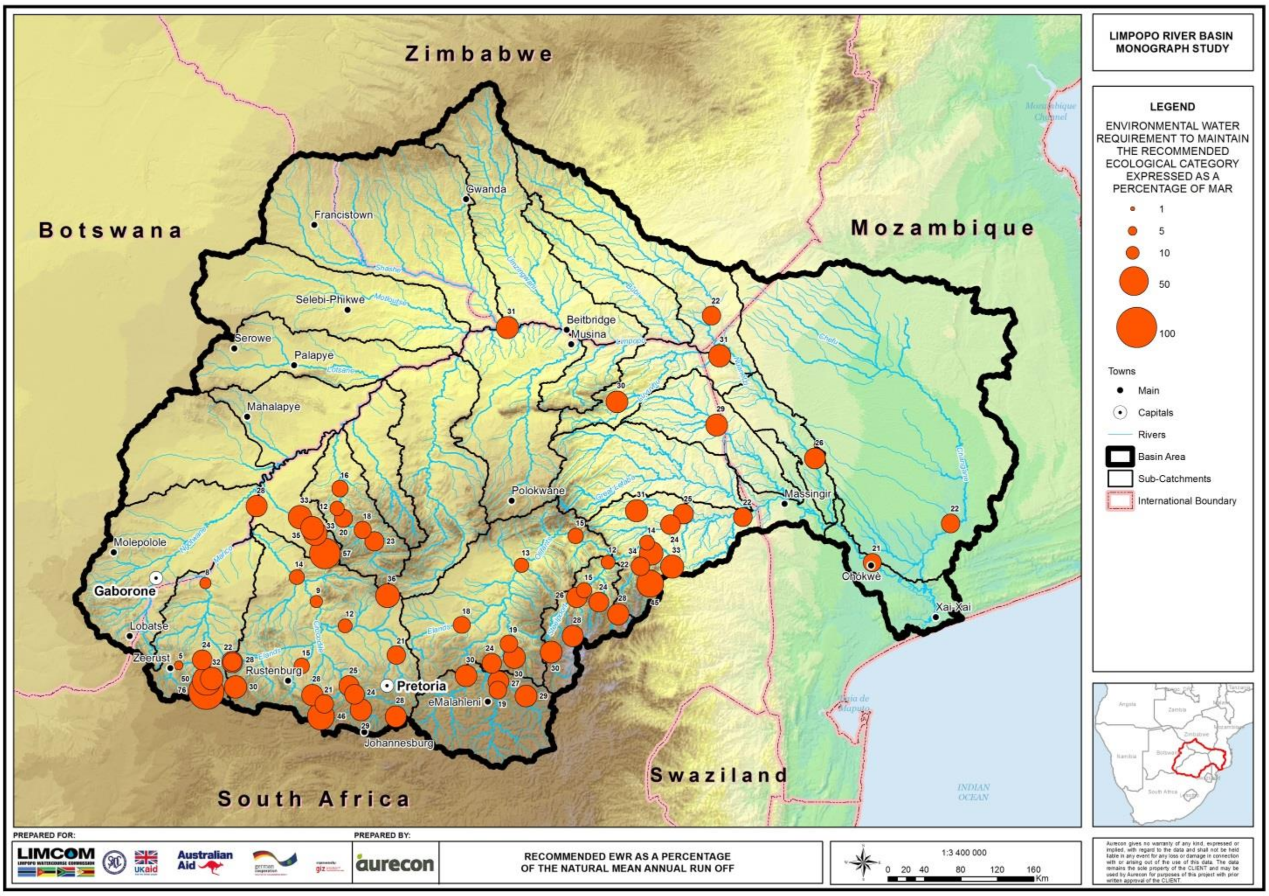



**Figure 4.11: Recommended EWR as a percentage of the Natural Mean Annual Runoff (nMAR) for all sites**

## 4.5 ESTUARY

### 4.5.1 Approach to determining PES and EWRs

Estuaries potentially play a critical role in determining water allocation in a catchment. In order for an estuary to retain a reasonable level of function, some river reaches in the catchment will inevitably have to be in high ecological categories. If the estuary is to be in a higher class, this can have major implications in limiting the potential for water use in the entire catchment.  Some estuaries may require as much as 90% of the natural MAR to remain functional, which may be difficult to justify in the face of the social and economic requirements upstream.  However, the evaluation of the ecological infrastructure of an estuary and the linkage of this to the various goods and services which this sustains may well argue for greater water allocation rights for a particular estuary.

The approach adopted to determine the EWR of the Limpopo estuary is outlined in **Figure 4.12.**  The steps included for this survey are discussed below and included field surveys and sampling, the delineation and determination of the estuary area to be included in this assessment, and determination of the PES for the entire resource unit (the estuary).

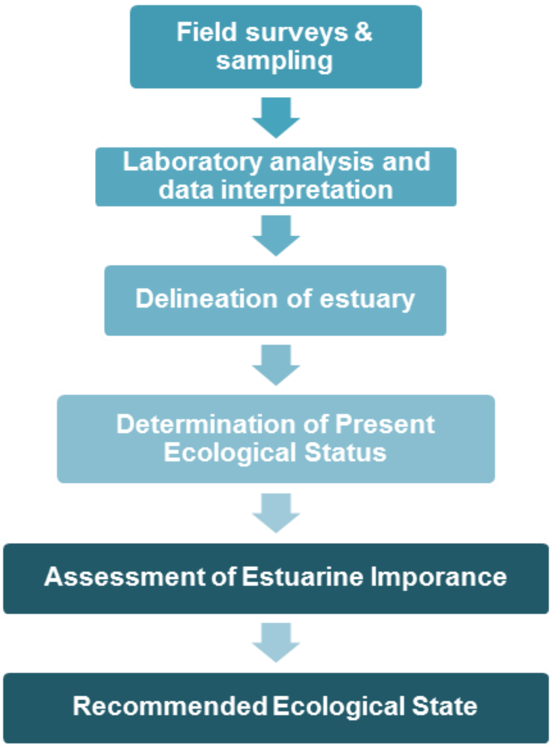



**Figure 4.12:** Steps followed to determine the Present Ecological State of the Limpopo Estuary

In estuaries, river inflow patterns show strong correlation with important hydrodynamic and sediment characteristics, such as state of the mouth, amplitude of tidal variation, water circulation patterns and sediment deposition/erosion.  However, the relationships between these characteristics and river inflow are generally complicated to interpret, owing to the influence of the sea, i.e. state of the tide and associated seawater intrusion.  The manner in which these characteristics are influenced by river flows is often not the result of a single flow event, but rather that of characteristic flow patterns occurring over weeks or months.  It should be noted that unlike the river reaches of any particular system, the estuary may have a much larger buffer or delay-effect between river inflow patterns and their effect on abiotic parameters.

### 4.5.2 Study Area in Brief

The Limpopo Estuary can be categorised as a large permanently open system situated 130 km North East of the city of Maputo, fed by a catchment of 411 000 km2.  River flow in the system is highly seasonal, with the highest flows occurring during the wetter summer months. River flow changes have a pronounced impact on seasonal physico-chemical conditions, but do not affect mouth condition as the open mouth is tidally driven. Saline intrusion continues for approximately 35 km upstream of the mouth, with significant mangrove stands up to 20 km from the lower reaches. The channel is largely linear and steeply incised, with depths reaching up to 15 m (data from the survey undertaken during this study). The channel is lined with mangroves, predominantly Avicenna marina, reed beds dominated by Phragmites australis, and relatively small sections of shoreline mudbanks (utilised extensively by subsistence fishers). Intertidal sand/mudbanks are small and localised, indicative of the considerable fluvial and tidal forces that characterise this system.

### 4.5.3 Methods

#### 4.5.3.1 *Site Selection*

The selection of sites for the specialist surveys is closely related to the size of the estuary and type of habitats which may be represented within the study unit. The data collection for all components involves working along the full extent of the estuary using the same sampling stations for different techniques and methods wherever possible. These sites are usually selected once the upper limit of the estuary has been determined and spaced to allow a representative sampling along the longitudinal axis of the system. The sites are labelled in terms of distance from mouth. Nine sites were selected along the length of the estuary to represent the upper, mid and lower reaches of the estuarine environment. The positions of the sites were ultimately selected on their suitability for application of the chosen assessment methods and informed during the field surveys by in-situ physico-chemical analyses. The in situ physico-chemical processes were also used to determine the upper limit of the estuary, at 35 km from the mouth.

The positions of all sites used in the study are shown in Figure 4.13 below.

**Figure 4.13: The positions of the estuarine sampling sites**

### 4.5.3.2 *Parameters assessed*

The following parameters were measured, procedures followed, samples collected or animals counted at each site. (Details are provided in Technical Annexure Volume B2)

- *In situ* depth profile measurements of salinity, turbidity, dissolved oxygen, pH and temperature with a multi-parameter probe.
- Riparian, floodplain and estuarine vegetation
- Macro-benthic invertebrates
- Fish
- Water birds

### 4.5.3.3 *Hydrodynamics*

The hydrodynamics of an estuary concerns the main driver processes that control the physico-chemical conditions and thereby influence the overall ecosystem functioning. It deals with factors such as:

- Tidal and terrestrial flows and their role as drivers of mixing, advection, sediment suspension/transport, and mouth dynamics.
- water levels, turbulence and wind-wave dynamics for their role in bio-physical interactions (e.g. as turbidity drivers).
- surf-zone sediment processes and their role in long-shore and cross-shore sediment transport in the littoral zone, drivers of beach morphodynamics, and the estuary inlet mouth dynamics.

Available data concerning the hydrodynamics of the Limpopo system is very limited. Some limited and poor quality data of terrestrial inflows is available, but other basic information such as reliable data on physical characteristics (bathymetry, mouth state, etc), wave climate, tidal exchange characteristics, beach morpho-dynamics, etc were not available. The survey carried out in August 2012 focused mainly on understanding the drivers of the mouth dynamics for the Limpopo system. In particular the aim was to measure the tidal exchange flows under conditions of low terrestrial flows and during a spring tide phase in order to evaluate the state of the inlet in terms of its stability with respect to flow changes.

**Mouth morphology**

No precision GPS (survey grade differential GPS) and/or depth sounding equipment were available to survey the inlet area during the field visit. However a series of Landsat images were retrieved for dates ranging from 1984, 1999, 2000, 2003, 2010. These images allow the effects of the large (estimated 100-year return period) floods of 2000 on the mouth morphology to be documented. They also give an indication of the near-shore sediment dynamics in the area.

### 4.5.3.4 *Vegetation*

The study area for the assessment of vegetation included the land contiguous with the tidal parts of the estuary, parts of the floodplain and the contiguous coastal dunes **Figure 4.14** that could be affected by rising water levels.

**Figure 4.14:** View over the Limpopo River floodplain

#### 4.5.3.5 *Macro-invertebrates*

As the extent of the estuary prior to the survey was unknown the first step taken was aimed at establishing the extent of saline penetration as a guideline to the limits of the estuary. As the survey was undertaken during winter it was assumed that river flow would be minimal and conversely the extent of seawater penetration would be maximal. The investigation took place over a spring tide period which should have maximised tidal effects but due to the size of the system and project constraints it was not possible to extend upstream investigations over several days. Macro-benthic invertebrates were sampled using internationally accepted techniques, detailed methods will be provided in **Technical Annexure, Volume B2**.

#### 4.5.3.6 *Fish*

No published information could be sourced for the Limpopo estuary with regards the fish community. The high use of this resource and the high numbers of fishers using the estuary throughout its longitudinal extent meant that a ready source of information existed to allow an assessment of the fish community composition and to some extent species abundance. The records of taxa observed in subsistence fishers catches (seine and gill nets) were recorded as presence / absence data during the August 2012 field visit. **(Technical Annexure, Volume B2).**

#### 4.5.3.7 *Birds*

The estuarine associated aquatic birds on the Limpopo estuary were assessed by surveying the species and numbers of birds using different zones within the estuary. The total number of individuals was recorded by two or more observers operating from a boat at low tide. The numbers and species were recorded as well as time, position and habitat. The species were grouped into seven functional groups;

- resident diving piscivores,

- migratory diving piscivores,
- pursuit swimming piscivores,
- wading piscivores,
- resident waders and
- herbivorous water fowl.

### 4.5.4 Results

#### 4.5.4.1 *Estuarine Ecological Health Assessment*

The sampling conducted on the estuary during August 2012 provides the basis for an assessment of estuarine health. The assessment provides a description of the estuary in its present state and quantifies its health in terms of an Estuary Health Index. This index provides a description of the characteristics and functioning of all major abiotic and biotic aspects of the system and their relationships to one another. In addition, it is then possible to investigate the flow- and non-flow related pressures and impacts on the system.

The components assessed were as follows:

- Abiotic (or driving components):
  - Physical dynamics (measured in terms of seasonal river inflow patterns, floods, mouth dynamics, water level variations, water movement patterns, changes in sediments and deposition and erosion areas)
  - Water quality (measured in terms of system variables, nutrients and toxic substances) (microbiological contaminants - linked to human health - are excluded as it does not pertain to the ecological component).
- Biotic (response) components:
  - Estuarine flora (microalgae and macrophytes)
  - Estuarine fauna (invertebrates, fish and birds)

This estuary health assessment provides for the determination of the Present Ecological Status (PES) of an estuary using a simple scale of A to F. The Present Ecological State (PES) is determined for the entire resource unit i.e. the estuary using the estuarine health index method described above. The status of the Limpopo estuary was established using the data which were available from the August 2012 survey and using specialist knowledge to score the components for which it was not possible to collect data or for which no data exists.

### 4.5.5 Abiotic Components

#### 4.5.5.1 *Present hydrological health*

This score is calculated based on the extent to which current inflow patterns resemble those of the Reference state estimated from two parameters, as in Table 4.10: (a) general inflow patterns, highlighting the changes in low flows, and (b) the frequency and magnitude of flood events. The relative weighting of these two parameters (60:40) is set according to their assumed importance as drivers of the estuarine system. This may alter a priori for particular systems, with justification.

**Table 4.10:** Calculation of the hydrological health score

| Variable | Score | Motivation | Conf |
|---|---|---|---|
| a.% Similarity in period of low flows | 50 | Considered that baseflows have been reduced by 40% (score would therefore be 60) but scored 50 to reflect the extensive damming and abstraction impacts on baseflows | M |
| b.% Similarity in mean annual frequency of floods | 70 | Most floods will reach the estuary but some change related to the impact of instream dams | L |
| Hydrology score | | **58** | |

#### 4.5.5.2 *Channel topography*

The most significant features of the Limpopo estuary in relation to the more southerly east coast systems was the large size as measured by the water depth, the width of the channel and the extent of marine influence. To a large degree these features can be related to the position of the estuary on the wide, low-lying Moçambique coastal plain with its very shallow gradient extending from the coast to 200-300 km inland. Coarse sediments arising from the catchment which includes some relatively arid areas, although subject to flood events, are less likely to be transported through to the lower reaches of these rivers, the estuaries and ultimately the sea, than in the much more steeply sloping coastal environment in the KwaZulu-Natal province of South Africa which lies south of this coastal plain. Channel widths upstream declined steadily from about 500 m in the lower reaches to about 100 m at the top sites some 35 km upstream. Water depths measured at the sample sites ranged from 1.5 to 15 m. These depths do not necessarily correspond precisely with the actual grab positions as the boat was allowed to drift slowly with either the tidal currents or wind while the grab samples were being taken. The maximum depth of 15 m was recorded approximately 25 km upstream. Deep areas of 8 – 10m were common and also noted just upstream of the mouth. Another obvious and noticeable feature was the generally deeply incised nature of the channel. There were few exposed sand or mudbanks during low tide periods and the sides of the channel typically dropped off steeply.

#### 4.5.5.3 *Sediments*

Sediments are conventionally described as shown in **Table 4.11** below.

**Table 4.11:** Relationship between sieve mesh size and particle description

| Sieve mesh size (mm) | 2 | 1 | 0.5 | 0.25 | 0.125 | 0.063 | <0.063 |
|---|---|---|---|---|---|---|---|
| Phi category | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
| Description | Gravel | Very coarse sand | Coarse sand | Medium sand | Fine sand | Very fine sand | Mud/ silt and clay |

The lowest sampling site consisted of a mix of coarse and medium sand with some addition of fine sand. This was to be expected on the basis of the large tidal prism and the strong tidal currents which would have scoured away finer material. Site 2 consisted of mainly medium and fine sand. Virtually all samples collected at sites 3-7 in the central regions of the estuary were muddy, being dominated by sediments <0.063 mm in size which often contributed 80 to more than 90% of the sample. Fine to very fine sands re-appeared at Sites 8 and 9 in combination with muddy sediments. This pattern of a dominance of muddy sediments in the mid regions of the estuary followed by the re-appearance of coarser sediments in the upper reaches is typical of estuarine sediment distribution patterns.

**Table 4.12: Organic content of the sediments at nine sites in the Limpopo Estuary in August 2012.**

| **Site No.**<br>**Distance from mouth (km)** | **1**<br>0.8 | **2**<br>3 | **3**<br>5.6 | **4**<br>8.9 | **5**<br>11.5 | **6**<br>17.3 | **7**<br>20.7 | **8**<br>29.6 | **9**<br>34.6 |
|---|---|---|---|---|---|---|---|---|---|
| Mean (%) | 0.22 | 0.64 | 2.2 | 3.09 | 2.4 | 3.74 | 1.2 | 1.52 | 0.62 |
| Range (&) | 0.14-0.26 | 0.05-2.17 | 1.21-3.41 | 2.22-4.52 | 1.6-3.21 | 2.63-5.2 | 0.37-1.9 | 1.03-2.25 | 0.36-1.07 |

*Note: Five samples were taken at each site*

The organic content of the sediments increased upstream of the two lowest sites at sites three to eight before declining again at site nine. This was in keeping with the particulate nature of the sediment which was relatively coarser at sites 1, 2 and 9 and relatively muddier at sites 3-8. Muddy conditions are typically associated with higher organic contents.

#### 4.5.5.4 *Salinity*

Salinities at the time of sampling at the first four sites, i.e. up to about 9 km upstream (Table 4.12) approximated sea water. There was then a steady decline from about 25 at site five to five to ten at site eight and about one at site nine which was taken as the upstream limit of the estuary. Some layering occurred with maximum differences between surface and bottom of about 10.

#### 4.5.5.5 *Temperature*

Temperatures were very constant ranging between 19 and 21°C at all sites and depths.

#### 4.5.5.6 *Dissolved Oxygen*

There was no indication of oxygen depletion and in all cases saturation levels exceeded 90% and often 100%.

#### 4.5.5.7 *Turbidity*

Turbidity levels were typically low, <10 N.T.U, (Nephelometric Turbidity Units) at all sites and depths except for the uppermost site where the influence of fresh water was greatest and the NTU rose to ca. 100.

**Table 4.13: Summary of changes and calculation of the water quality health score**

| | **Variable** | **Summary of change** | **Score** |
|---|---|---|---|
| **1** | **Salinity** | | |
| | Similarity in salinity | ⇧ penetration and residence due to decrease in flow | **60** |
| **2** | **General water quality in the estuary** | | |
| **a** | N and P concentrations | ⇧ due to nutrient enrichment from diffuse sources within the catchment | 90 |
| **b** | Water clarity (measured as suspended solids/turbidity/transparency) | Slight ⇧ associated with erosion in catchment | 90 |
| **c** | Dissolved oxygen (mg/l) concentrations | No marked changes | 95 |
| **d** | Toxic substances | ⇧ accummulation from inputs from nearby town, accumulated inputs from a large catchment with a variety of land uses. | 85 |

| | Variable | Summary of change | Score |
|---|---|---|---|
| **General water quality (minimum A – D)** | | | **85** |
| **Water quality health score[2]** | | | **75** |
| **Confidence** | | | **L** |

The physical habitat health scores are included in **Table 4.14** below.

**Table 4.14:** Calculation of the physical habitat score and adjusted score (net of non-flow impacts)

| Variable | | Change from natural | Score | Conf |
|---|---|---|---|---|
| **a** | Supratidal area | Very similar to Reference. Some loss of supra-tidal area due to the road and infilling around the bridge. | 90 | M |
| **b** | Intertidal area | Very similar to Reference. Probably very slightly more muddy from Reference. Slight loss of intertidal area due to the road and infilling around the bridge. | 70 | L |
| **c** | Subtidal area | Very similar to Reference. Probably very slightly more muddy from Reference. Probably very small loss of sub-tidal area. | 80 | L |
| **d** | Water column volume | The total volume loss (due to the small infillings) is estimated to be < 5% of the total estuarine w.c. volume. Thus, score 100% (data/resolution insufficient to robustly score in smaller than 5% steps). | 90 | M |
| **Physical habitat score[1]** | | | **80** | |
| % of impact due to non-flow factors | | | **90** | |
| Adjusted score | | | **98.5** | |

1 $Score = \mathrm{mean}\left((\min(\ ), mean\ (a\ t)\right)$

## 4.5.5.8 *Hydrodynamics*

***Tidal flows***

The key features of the results are:

- The semi-diurnal M2 tidal component (period T = 12.42 hrs) is attenuated from an amplitude of about 1.65m in the sea to about 1.00m within the estuary. This indicates a strongly dissipative inlet with just over 50% of the tidal energy lost during propagation into the inlet.
- There is a delay of 90 – 120 minutes between slack tide in the sea and the estuary.
- No indication of temporal asymmetry in the tide was observed implying that the estuary tide is neither ebb nor flood dominant.
- The measured peak flows during the spring tide were about 1 000 $m^3/s$ with average flows Q = 2P/T = 760 $m^3/s$.
- Assuming a sinusoidal temporal flow distribution, integration indicates a spring tide prism of about 17.1 $Mm^3$.

Typical data from the Acoustic Doppler Current Profiler ADCP transects show that the average cross-sectional area measured by these transects was approximately 1 000 $m^2$

***Inlet Stability***

Given the measured tidal prism and channel cross-sectional areas obtained from the ADCP transects, it is possible to place these inlet characteristics in the context of the classical O'Brien (1931, 1969) equilibrium P – The relationship indicates the Limpopo estuary falls within the range expected of an equilibrium tide dominated inlet, with C = P/A = $5.9 \times 10^{-5}$ $m^{-1}$. The average tidal velocity for the inlet U = 2P/AT = 2C/T = 0.76m/s (T = 14.24hrs) is typical of tidal inlets in a state of quasi-stable equilibrium.

***Mouth Morphology & Dynamics***

To gain some insight into the sediment budget for the inlet system, aerial photographs were used to approximate the areas and volumes of specific morphological components associated with the system. In particular, the up-drift spit platform is a prominent feature of the system that clearly indicates the predominant littoral transport from the NE to SW. This spit can be significantly changed or removed entirely during large episodic flood events. Observations of that process and the subsequent recovery period can be used to estimate the long-shore sediment transport volumes. The most recent available aerial imagery from 2010 suggests that the volume in the up-drift spit platform was about 2 millionm$^3$ (area about 0.5km$^2$, average height 4m) relative to the situation immediately after the 2000 floods. The down-drift re-attachment bar seems to have a similar volume.

A series of Landsat images was analysed. These images straddle a major flood event in Feb 2000 (return period of order 100yrs) and clearly illustrate the extent to which major flood events can reset the inlet morphology. The flood flows severely scoured the down-drift shoreline and entirely removed the up-drift spit platform. The recovery of the inlet morphology during the decade 2001 – 2010 can also be clearly seen. The development of the down-drift re-attachment bar and re-building of the up-drift spit platform are features of particular interest. The image sequence suggests that most of the recovery took place within a 5-year time period. An estimated recovery time of 5 years implies an accumulation rate of approximately 400 000m$^3$/yr. Allowing for some sediment bypassing suggests that the net long-shore transport rate at this location is of order 500 000 m$^3$/yr from the NE. A range 250 000 – 750 000 m$^3$/yr allows for some of the uncertainties. This suggests a P/M ratio (i.e. the long-shore transport regime) for the inlet in the range 20 < P/M < 60 which implies a stable but variable inlet morphology.

***Hydrodynamic and water quality health***

**Table 4.15:** Calculation of the hydrodynamics score

| Variable | Score | Motivation | Conf |
|---|---|---|---|
| Mouth condition and abiotic states | 90 | Saline penetration occurs further upstream, n**o change in mouth status from reference** | M |
| Hydrodynamics and mouth conditions score | 90 | | M |

### 4.5.6 Biotic Components

#### 4.5.6.1 *Vegetation*

The botanical communities relevant to an estuarine assessment and found in the Limpopo estuary are listed below:

- Open surface water area (potential habitat for phytoplankton)
- Submerged macrophytes *

- Intertidal sand and mudflats (potential habitat for intertidal benthic microalgae) *
- Macroalgae *
- 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
- Coastal forest

  * communities either not found or not intensively sampled.

Extensive mangrove communities occur within the estuary. The extent has been mapped and is estimated at 461 hectares. The species richness is, however, low and is lower than reported for many other estuaries in Moçambique (Barbosa *et al.* 2001; Beentje & Bandeira 2007). A number of mangrove tree species present in other estuaries appear to be absent or alternately are so small in occurrence that their presence was not detected during the survey. The mangrove communities are dominated by *Avicennia marina* (White Mangrove), estimated to comprise between 80 and 90 % of the tree growth. This is the most common mangrove in southern Africa, and has greatest ability to establish vigorously in less protected conditions. This dominance by *Avicennia marina* and limited presence of other species, or their absence, is consistent with the estuary's physical profile and in particular the high flow character.

Most other hygrophytic vegetation is also not diverse, although wetland areas within the floodplain away from tidal influence may support a wider range of species, particularly sedges. Much of the floodplain has, however, been transformed or degraded by anthropogenic activities that have likely occurred over a long period of time and are increasing. As a result, most open vegetation is secondary. The greatest diversity within the study area is on a dryland substrate, including thicket and smaller areas of forest which is to be expected. There is still notable species richness and abundance in many parts of this thicket vegetation, but this is being reduced by surrounding populations through settlement, cultivation, burning and felling of trees, and to a lesser extent by development in the vicinity of the Zongoene Lodge.

Open areas subject to tidal infiltration often comprise bare sandy or muddy flats and lack herbaceous plant cover. Non-herbaceous constituents include *Juncus kraussii*, some other *Juncus* and Cyperaceae (sedge) species, and grasses, the most abundant of which is *Sporobolus virginicus*. Only one small salt marsh area (well under 1 ha) was found to contain an obligate salt marsh herbaceous element, this being an unidentified *Arthrocnemum* species. It is likely, however, that other similar, small salt marsh areas are nested within the floodplain near the river. This confirmation would require more extensive investigation by foot.

Extensive, uniform stands of *Phragmites australis* occur along the banks of the estuary, particularly travelling further inland. These stands can also often be found on the landward side of mangrove communities. There is a smaller presence of *Phragmites mauritianus* within the estuary. *Phragmites*-dominated communities have been mapped in proximity to the banks of the river. However, interpretation and identification of all occurrences by reference to aerial photography is made difficult elsewhere within the study area, where recent burning obscures differentiation from surrounding vegetation, particularly grassland. The extent of this component is therefore likely to be somewhat greater than mapped. This mapping includes very small, aggregated instances of the conspicuous large sedge *Schoenoplectus scirpoides* along the river banks. The extent of reedbeds and small flanking sedge communities (mainly comprised of *Schoenoplectus scirpoides*) is mapped as 688 hectares.

There is some presence of alien plants, which could become more significant in future. There are consolidated stands of eucalypts (*Eucalyptus* sp.) mainly on dunes on the north bank of the estuary. Other alien trees include *Casuarina equisetifolia* (mainly in closer proxmity to the mouth), *Terminalia catappa* and *Psidium guajava*, the latter two as only scattered trees. Overall, however, the presence of alien plants is considered small. Certainly, this state of affairs is very different from extensive alien plant invasion of coastal vegetation seen to the south in South Africa. However, small numbers of *Eichhornia crassipes* (Water Hyacinth) were seen within the estuary, likely from more significant infestations up-river, and this presence could increase in future.

#### 4.5.6.2 *Description of factors influencing Macrophytes*

The factors influencing the different macrophyte habitats are summarised in **Table 4.16**. Based on these considerations, the expected influence of the different abiotic states on macrophytes is described in **Table 4.17.**

**Table 4.16:** Effect of abiotic characteristics and processes, as well as other biotic components on macrophytes

| Process | Macrophytes |
|---|---|
| Mouth condition (provide temporal implications where applicable) | The mouth of the estuary is not expected to close, if this were to happen, fresh conditions would encourage expansion of reeds and sedges. Macroalgae would also grow in response to the calm sheltered. Additionally, lack of tidal exchange would result in a loss of mangroves.<br><br>The configuration of the whole system – fairly straight channels with strong flows influences the distribution of the macrophytes. There is a currently a large reed and sedge area on the northern bank together with some mangroves. In early aerial photographs when the mouth was open to the north this area bare indicating the dynamic nature of the macrophyte habitats and mouth area.<br><br>High flow prevents the establishment of submerged macrophytes such as *Stuckenia pectinata* (pondweed). Open mouth and saline conditions allow for the growth of mangroves which appear to have colonised during one large event as the older trees are similar in height. |
| Retention times of water masses | Greater water retention time would provide better opportunities for nutrient uptake by macrophytes thereby favouring their abundance. High flow and frequent flooding currently prevents the establishment of submerged macrophytes and macroalgae which is typical of a strong flowing river mouth type estuary. |
| Flow velocities (e.g. tidal velocities or river inflow velocities) | Low flow velocities would encourage the growth of macroalgae and reeds and sedges. Fringing reeds and sedges are removed by floods which scour the banks and deposit sediments. |
| Floods | Floods are important for resetting the estuary and removing accumulated sediment and macrophyte growth. Reduced flooding will result in reed encroachment. Floods would also deposit rich organic mud in the estuary |

| Process | Macrophytes |
|---|---|
| | thus having an important nitrifying effect. |
| Salinity | Dominant species in the upper estuary more indicative of low salinity water while the salinity increases and tidal effects in the mid and lower estuary encourage mangrove establishment. |
| Turbidity | The Liimpopo is a high flow naturally turbid system; these conditions prevent the growth of submerged macrophytes. |
| Dissolved oxygen | Thick mud layers in the lower reaches on the south bank of the estuary were anoxic. |
| Nutrients | Catchment and surrounding land use changes have introduced nutrients to the estuary. This would encourage macrophyte growth; however the high flow conditions possibly restricts nutrient uptake. |
| Sediment characteristics (including sedimentation) | Increased sedimentation and a reduction in water depth would increase macrophyte growth. |

**Table 4.17:** Response of macrophytes to different abiotic states

| State 1<br>Significant saline penetration | State 2<br>Intermediate saline penetration | State 3<br>Limited saline penetration | State 4:<br>Freshwater dominated |
|---|---|---|---|
| If this state persisted then there would be die-back of reeds and sedges. They will persist where salinity is less than 15 ppt. | Representative of current conditions where reeds, sedges and swamp forest are dominant. | Representative of current conditions where reeds, sedges and swamp forest are dominant. | High flow and water level conditions would limit macrophyte growth. |

**Table 4.18:** Similarity scores of macrophytes in the Present condition relative to the Reference condition.

| Variable | Change from natural | Score | Confidence |
|---|---|---|---|
| 1. Species richness | Invasive species potentially displaced some species. Species have been lost because of the less dynamic environment. | 75 | M |
| 2. Abundance | There has also been a loss of reed, sedge and floodplain habitat due to development and disturbance. In the reference condition macrophytes would cover 81 ha, now they cover 51 ha which represents a 37% loss of habitat. There has been a 6 ha gain in reeds and sedges since reference conditions due to change in mouth configuration, sediment and nutrient input. | 80 | M |
| 3. Community composition | Destruction of existing species and the invasion alien species have altered the community composition. | 75 | M |
| **Macrophyte health score** | | **75** | |
| % of impact non-flow related | | 80 | |
| Adjusted score | | **95** | |

### 4.5.6.3 *Invertebrates*

The physical topography of the system whereby intertidal areas are dominated by mangroves and the estuary channel has relatively steeply sloping sides means that there are relatively small exposed areas of intertidal mud and sandbanks and consequently little development of species such as fiddler crabs *Uca* spp. and soldier crabs *Dotilla fenestrata*. Sand banks at the mouth are unstable and low in organic content so would not provide a suitable habitat for these species. There was no indication of any submerged vegetation.

A total of 35 macrobenthic taxa was 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. The sub-tidal benthic fauna was low in both diversity (approximately 35 taxa) and abundance in comparison with the very limited number of other southern Moçambique systems such as the Inhambane lagoon and Morrumbene estuary where 404 macrobenthic species were recorded during sampling in January and July 1954 and January 1968 (Day 1974b). The surveys of Inhaca Island (Macnae & Kalk 1958) were not included for comparison as this was seen as a totally marine environment. Nevertheless the greater than tenfold difference recorded between the Morrumbene and Limpopo requires comment and possible explanation. To some degree this could be attributed to the limited sampling effort in time and space that was possible in the Limpopo. The absence of a summer survey would also limit the findings but in addition the composition of the Limpopo benthic fauna also reflects the strong contrast in the relative natural physico-chemical variabilities and habitat diversity of the two systems. The Limpopo has a catchment of approximately 400 000 $km^2$ versus 650 $km^2$ (Day 1974b) for the Morrumbene system and is subject to periodic major floods which result in sustained periods of low salinity and sediment instability. By contrast minimal salinities recorded at the two lower Morrumbene sites during summer and winter were 31 and 22.8 respectively. Habitats sampled in the Morrumbene included mangroves, sea grasses a small rocky shore and extensive sheltered sand and mudbanks (Day 1974b). Of these habitats only mangroves were a major component of the Limpopo estuary which could not be sampled in the time available.

These contrasts also occur, albeit on a smaller scale, in South African systems where estuarine bays such as Durban Bay (Day & Morgans 1956) and Knysna (Day, Millard & Harrison 1952) with their strong marine influence and habitat diversity, largely an historical condition in the case of Durban Bay, support by far a greater species diversity than systems such as the South African Mkhomazi, Mzimkulu and Mzimvubu (MER, unpublished) where the benthos has also been shown to be generally depauperate and characterised by small, pioneering species such as the polychaetes with a paucity of larger, slower growing species such as burrowing bivalves and thalassinid crustaceans. Such systems do however frequently play a highly significant role in linking catchment processes with inshore marine processes such as sediment provision and nutrient inputs. Estuarine health status assessments critically need to incorporate these broader aspects of riverine, estuarine and inshore marine processes in coastal environments.

The most obvious observed inter-tidal species was the mangrove climbing whelk Cerithidea decolate which formed broad bands on the trunks of the mangrove in keeping with their behaviour during spring tide periods which coincided with the survey.

Invertebrate species occurring in estuaries typically utilise and depend on a particular suite of biotic and abiotic parameters which determine their relative abundance and distribution throughout the system. In order to predict a response in the invertebrate community structure to changes in these parameters, the estuarine invertebrate macrofauna needs to be classified according to their relative dependence on these parameters.

The classification used in this study is shown in **Table 4.19** where the parameters influencing each category are shown provides a summary of the invertebrate groupings responses to various abiotic and biotic processes.

**Table 4.19: Classification of South African estuarine invertebrate fauna and the parameters influencing their abundance and distribution. POM = particulate organic matter, MPR = Microphytobenthos**

| # | Description | Influencing factors/requirements |
|---|---|---|
| 1 | Polychaetes - estuarine resident (*e.g. Ceratoneries keiskamma*) | Medium to fine sediments; detritus; other edible invertebrates |
| 2 | Polychaetes - marine (*e.g. Arenicola*) | Med to coarse sediments; detritus; open mouth; saline water |
| 3 | Amphipods | Finer sand/mud; shelter; detritus; POM; reduced salinity |
| 4 | Isopods | Coarse sediments; higher salinity; dead matter |
| 5 | Gastropods - marine dominated species (detritivores, scavengers & predators *e.g. Bullia* spp.) | Detritus; open mouth; MPB; higher salinity |
| 6 | Gastropods - resident sediment living grazers, detritivores & predators (*e.g. Hydrobia sp.*; Assiminea spp.,*Natica sp.*) | Shelter; submerged macrophytes; MPB; detritus |
| 7 | Gastropods - grazers associated with macrophytes (*e.g Neritina spp., Cerithidea decollata)* | Shelter; submerged macrophytes; MPB |
| 8 | Bivalves - estuarine residents (*e.g. Dosinia hepatica)* | Med-fine sediments; submerged macrophytes; POM |
| 9 | Bivalves - marine (e.g. *Donax spp./Tellina spp.*) | Med-coarse sediments; open mouth; POM |
| 10 | Crabs - resident estuarine (e.g. *Spiroplax spiralis, Hymenosoma spp.)* | Med-fine sediments; (presence of burrowing prawns for *S. spiralis*) |
| 11 | Crabs - marine migrants (e.g. *Scylla serrata*) | Open mouth; favours finer sediments and turbid conditions. |
| 12 | Caridean shrimps - marine (e.g. *Palaemon peringueyi*) | Medium-fine sediments; detritus; open mouth; high salinity; submerged macrophytes |
| 13 | Carid shrimps - resident (e.g. *Betaeus jucundus*) | Medium-fine sediments; detritus |
| 14 | Saltmarsh intertidal invertebrates, *e.g.* marsh crabs | Saltmarsh |
| 15 | Insect larvae (*e.g.* Chironomidae, Ceratopogonidae) | Lower salinities |
| 16 | Thalassinid mudprawns (e.g. *Upogebia africana*) | Fine sand/mud; open mouth; POM |
| 17 | Thalassinid sandprawns (e.g. *Callianassa kraussi*) | Sand; not extended fresh water conditions (>17 to breed); POM |
| 18 | Zooplankton - marine | Phytoplankton; open mouth |
| 19 | Zooplankton – estuarine resident | Phytoplankton; extended residence time |

**Health of the invertebrate component**

Health scores for the invertebrate component are provided in **Table 4.20.**

**Table 4.20: Similarity scores for the invertebrate fauna in the Present condition relative to the Reference condition**

| Variable | Change from natural | Score | Confidence |
|---|---|---|---|
| 1. Species richness | Historical descriptions going back 150 years indicate little if any change in the estuarine environment. While some habitat reduction may have occurred through localised infilling it is highly unlikely that any habitat within the estuary has been totally lost or significantly compromised and consequently it is equally unlikely that species richness has been reduced. | 80 | H |
| 2. Abundance | It is possible that abundance may have been reduced due to some loss of intertidal habitat. | 90 | H |
| 3. Community composition | Based on the comments already made in the boxes above there is no indication and no compelling reason to propose a significant change in the community composition. | 90 | H |
| **Invertebrate score** | | | **80** |
| Degree to which deviation from natural is due to non-flow related impacts | | | 20 |
| **Adjusted score** | | | **84** |

### 4.5.6.4 *Fish*

The fish fauna of the Limpopo were assessed to inform the the determination of the environmental flow requirements for the Limpopo River Estuary. The information presented here provides the relevant context to the scoring and assessment of the Present Ecological State of the estuary and the water requirements accompanying this state were determined at a Rapid level with Medium Confidence.

During the August 2012 sampling a total of 22 species were identified from gill and seine subsistence catches. The most abundant taxa, in descending order, were the Orangemouth Anchovy *Thryssa vitrirosis,* the Saddle Grunter *Pomadasys maculatus*, the Threadfin Silverbiddy *Gerres filamentosous*, and the Deep Pugnose Ponyfish *Secutor ruconius*. The reference community constructed from the National fish survey, includes a total of 27 taxa that have been recorded in at least 70% of the permanently open subtropical South African estuaries. The Mugilidae family is by far the most dominant with 9 taxa recorded in open system at the 70% threshold. The Carangidae, Clupeidae, Gobiidae, and Sparidae families were each represented by two species.

As per the reference community, mugilids are likely to represent a prominent component of the fish community. Traits that contribute to the prominence of this group in estuaries include extended spawning seasons which guard against recruitment failure during unfavourable conditions, strong euryhalinity, and a detritus based diet, which in the case of estuaries essentially represents a perennial food source (Cowley *et al*. 2001). Food webs in South African estuaries consist of relatively few, but high energy pathways (Whitfield 1998). The number of energy pathways is directly linked to the stability of the system, and as a result permanently open systems with strong fluvial forces (e.g. the Limpopo Estuary) are likely to have a detritus based food web. In most estuaries, the detrital food web represents the major energy pathway (Schlacher and Wooldridge 1996), and consequently represents the major food source for estuarine associated fish (Yarez-Arancibia 1986; Whitfield 1998).

The filter feeding species *Thryssa vitrirostris* was the most abundant fish noted in the seine and gill catches. In South African systems *Gilchristella aestuaria* and *Ambassis natalensis,* which occupy a similar niche are generally more abundant. Presumably, however, the larger and more mobile *Thryssa vitrirostris* maintains a competitive advantage over its counterparts in the dynamic Limpopo system. Strydom *et al*. (2002), in a study of two warm temperate estuaries, showed that despite the more abundant food sources in the Great Fish Estuary, *G. aestuaria* densities were still lower than the Kariega Estuary. Strydom *et al*., (2002) found larvae and juvenile densities of *G. aestuaria* to be inversely related to river flow, citing the flushing out of larvae and early juveniles in the Great Fish as a possible explanation. Furthermore, Blaber (1988) noted that *T. vitrirostris* was more abundant than *G. aestuaria* in the larger coastal lake systems of Southern Arica.

Both the records from the August 2012 survey and the reference community suggest that category II estuarine dependant marine species dominate the Limpopo's estuarine fish fauna. The concept of estuarine dependence is well established from a South African perspective, with approximately 61 marine species utilising estuaries at some stage in their lifecycle (Whitfield 1998). In contrast, the majority of juvenile marine species that utilise estuaries in Europe and North America are also found in nearby inshore marine waters, and can therefore not be classified as truly estuarine dependent (Haedrich 1983; Elliott and Dewailly 1995). A similar situation exists in Western Australian estuaries and as such these taxa are referred to as estuarine opportunists rather than estuarine-dependent (Lennanton and Potter 1987). Presumably the highly dynamic nature of the South African coastline (same applies for the Limpopo system) prevents the utilisation of inshore marine environments as nursery areas, thereby emphasising the importance of these estuaries to fish species.

Given the lack of information on the fish fauna of Mozambican estuaries, a strong emphasis has been placed on the use of data from permanently open subtropical South African systems. The danger with this approach is the potential under representation of more tropical species which would occur at these lower latitudes. The significant catches of *P. maculatus* by subsistence fishers provided an immediate indication of the difference between the areas. *P. maculatus* is generally absent from South African systems, with a greater proportion of the Spotted Grunter *P. commerosonnii* at higher latitudes. Day's (1974) study on the ecology of Morrumbene Estuary was presented in order to provide an indication of more tropical taxa associated with the region and in order to compare expected diversity. Day (1974) recorded an impressive 114 species during the study, figures that can be attributed to the diversity of habitats (intertidal sandbanks, sea grass beds, extensive mangrove swamps etc) and strong marine influence that characterise the system. Expected diversity in the Limpopo system is far lower, due to fewer habitat types and stronger freshwater influence, however, given its size, tropical location and salinity gradient it is likely to support a higher diversity than any of the permanently open subtropical South African systems.

Estuaries provide an extremely important habitat for fish in southern Africa. The vast majority of coastal habitat in southern Africa is directly exposed to the open ocean, and as such is subject to intensive wave action throughout the year (Field & Griffiths 1991). Estuaries in southern Africa are thus disproportionately important relative to other parts of the world, in that they constitute the bulk of the sheltered, shallow water inshore habitat in the region. Juveniles of many marine fish species in southern Africa have adapted to take advantage of this situation, and have developed the necessary adaptations to enable them to persist in estuaries for at least part of their life cycles. There are at least 100 species that show a clear association with estuaries in South Africa (Whitfield 1998). Most of these are juveniles of marine species that enter estuaries as juveniles, remain there for a year or more before returning to the marine environment as adults or sub-adults where they spawn, completing the cycles. Several other species also use estuaries in southern Africa, including some that are able to complete their entire life cycles in these systems, and a range of salt tolerant freshwater species and euryhaline marine species. Whitfield (1994) has developed a detailed classification system of estuary associated fishes in southern Africa. He recognised five major categories of estuary associated fish species and several subcategories (**Table 4.21**).

**Table 4.21:** Classification of South African fish fauna according to their dependence on estuaries (Whitfield 1994)

| Category | Description |
|---|---|
| I | Truly estuarine species, which breed in southern African estuaries; subdivided as follows: |
| Ia | Resident species which have not been recorded breeding in the freshwater or marine environment |
| Ib | Resident species which have marine or freshwater breeding populations |
| II | Euryhaline marine species which usually breed at sea with the juveniles showing varying degrees of dependence on southern African estuaries; subdivided as follows: |
| IIa | a. Juveniles dependant of estuaries as nursery areas |
| IIb | b. Juveniles occur mainly in estuaries, but are also found at sea |
| IIc | c. Juveniles occur in estuaries but are more abundant at sea |
| III | Marine species which occur in estuaries in small numbers but are not dependant on these systems |
| IV | Euryhaline freshwater species that can penetrate estuaries depending on salinity tolerance. Includes some species which may breed in both freshwater and estuarine systems. Includes the following subcategories: a. Indigenous b. Translocated from within southern Africa c. Alien |
| V | Obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments |

The present day health of the fish component was assessed and the scores provided in **Table 4.22**.

**Table 4.22:** Similarity scores of fish in the Present condition relative to the Reference condition.

| Variable | Change from natural | Score | Confidence |
|---|---|---|---|
| 1. Species richness | Significant reduction in numbers of marine migrant species in the estuary under present state (estuary associated marine species as well as marine vagrants) | 80 | M |
| 2. Abundance | Significant reduction in abundance and biomass of fish in the estuary due to mostly associated with reduced numbers of marine migrant species in the estuary under present state (estuary associated marine species as well as marine vagrants) | 10 | L |
| 3. Community composition | Significant change in community composition from a fish community that was almost certainly dominated (>75% contribution) by marine migrants species to one that is now dominated by estuarine resident species | 50 | L |
| **Fish score** | | **10** | |
| % due to non-flow related impacts<br>Mainly due to reductions in overall marine populations; a small amount of fishing. | | 95 | |
| **Adjusted score** | | **96** | |

**Factors driving Waterbird community structure and abundance**

Some of the main influencing factors to be considered in estimating the bird community under reference conditions and the alternative scenarios are listed in **Table 4.23.**

**Table 4.23:** Effect of abiotic characteristics and processes, as well as other biotic components on bird groupings

| Factor | Cormorants & wading piscivores | Kingfishers & fish-eagle | Waterfowl | Waders, gulls and terns |
|---|---|---|---|---|
| **Mouth condition** | Indirectly, through influence on water level and fish | | Indirectly, through influence on macrophytes | Mouth closures has negative effect on preferred sandbanks in lower estuary |
| **Salinities** | | | Certain species of waterfowl prefer lower salinities | |
| **Turbidity** | Negatively affects visibility for foraging | | Negatively affects visibility for foraging | |
| **Intertidal area** | | Waders rely mostly on intertidal areas for feeding. | | |

The present state of the bird fauna of the system is provided in **Table 4.24.**

**Table 4.24:** Similarity scores of birds in the Present condition relative to the Reference condition

| Variable | Change from natural | Score | Confidence |
|---|---|---|---|
| 1. Species richness | Unlikely and no records to indicate that species loss has occurred. | 50 | M |
| 2. Abundance | Possibly some reduction through human disturbance and loss of marginal habitats. | 70 | M |
| 3. Community composition | No real indication of species loss, change in relative abundance or appearance of species that could be attributed to human influence. | 70 | M |
| **Bird score** | | **50** | **M** |
| % impact due to non-flow related impacts | | 95 | |
| **Adjusted score** | | **98** | |

### 4.5.7 Assumptions and Limitations

This study was undertaken with the following assumptions and limitations:

- No reliable or accurate mouth data exist for this estuary.
- The overall confidence in the hydrodynamics of the estuary and therefore the overall assessment is medium. This is because of:
    - The lack of historical water level records;
    - The lack of good records of the state of the mouth (open or closed); .

The accuracy of the predicted abiotic states for the Mzimkhulu Estuary (and hence biotic characteristics) and the distribution of these states under the Reference condition, present state depends largely on the accuracy of the simulated runoff data and measured flow data.

Criteria for confidence limits attached to statements in this study were as per **Table 4.25**.

**Table 4.25:** Criteria for confidence limits

| Limit | Degree of Confidence |
|---|---|
| Very Low | If no data were available for the estuary or similar estuaries (i.e. <40% certain) |
| Low | Limited data were available and estimates could be out by >60% (40% certain of estimate) |
| Medium | If reasonable data were available for the estuary and estimates could be out by 20-60% (i.e. 40-80% certain of estimate). |
| High | If good data were available for the estuary and estimates are probably not more than 20% out (i.e. >80% certain of estimates) |

#### 4.5.7.1 *Geographical Boundaries assessed for the Limpopo Estuary*

The boundaries for the Limpopo Estuary used in this particular study are indicated in the aerial photograph. (See **Figure 4.15).**


**Figure 4.15:** Geographical boundaries for the Limpopo Estuary

### 4.5.8 Present Ecological Status of the Limpopo Estuary

#### 4.5.8.1 *Estuarine Health Index Score*

In its present state the Estuary Health Index (EHI) was scored at 65 and accordingly given a C category status (scoring range 61 - 75) on a scale from A to F reflecting a ‘moderately modified’ system.

The Estuarine Health Index Scores allocated to the Limpopo Estuary were as per **Table 4.26.**

**Table 4.26:** Estuarine Healt Index Scores for the Mzimkhulu Estuary

| Variable | Weight | Score | Weighted score |
|---|---|---|---|
| Hydrology | **25** | 58 | 15 |
| Hydrodynamics and mouth condition | **25** | 90 | 23 |
| Water quality | **25** | 75 | 19 |
| Physical habitat alteration | **25** | 80 | 20 |
| **Habitat Health Score** | | | **76** |
| Macrophytes | **25** | 75 | 19 |
| Invertebrates | **25** | 80 | 20 |
| Fish | **25** | 15 | 4 |
| Birds | **25** | 50 | 13 |
| **Biotic Health Score** | | | **55** |
| **ESTUARINE HEALTH SCORE** | | | **65** |
| **Present Ecological Status** | | | **C** |

The EHI score for the Limpopo River Estuary, was 65, translating into a PES of Category C. The range of EHI scores and their corresponding Present Ecological State (PES) and descriptions are detailed in **Table 4.27** below.

**Table 4.27:** Range of EHI Score and corresponding PES Descriptions

| EHI Score | PES | Description |
|---|---|---|
| 91-100 | A | Unmodified, natural |
| **76-90** | **B** | **Largely natural with few modifications** |
| 61-75 | C | Moderately modified |
| 41-60 | D | Largely modified |
| 21-40 | E | Highly degraded |
| 0-20 | F | Extremely degraded |

### 4.5.9 Importance of the Limpopo Estuary

It was acknowledged that the importance of the Limpopo estuary was extremely difficult to score given that work on Moçambique estuaries has been limited, and there are no comparable systems in South Africa for comparison. The Orange is the only system of similar size but falls within a completely different ecoregion and has. Size considerations also need to be integrated with length and volume relative to other systems. This system is the second biggest after the Zambezi, and one of the largest in the sub.

The large tidal range (which controls the mouth) imparts a high nursery function to the system, as it is always open (and therefore always available) providing extensive habitat with the addition of mangroves which are well known as important food and shelter habitats for juvenile invertebrates and fish.

It was estimated that this system represents about 2.5% of the total volume of the estuaries of the subtropical region.

The estuary is river dominated in summer and tidally dominated in winter; a unique situation. It was considered that this meant the estuary did not sit easily within the current classification of estuaries along the subtropical east coast. This means that for zonal type rarity, it is one of a kind and therefore was allocated the maximum score possible. In addition it was noted that sediment delivery to the marine environment by this system is very likely sustaining beaches adjacent to it for significant distances along the coast and in particular to the south. The loss of this function could result in extensive erosion of the coastline in this area.

The Estuarine Importance Score (EIS) allocated to the Limpopo Estuary were as per **Table 4.28.**

**Table 4.28:** Estuarine Importance Scores (EIS) for the Limpopo Estuary

| Criterion | Score | Weight | Weighted score |
|---|---|---|---|
| Estuary Volume | 100 | 15 | 15 |
| Zonal Rarity Type | 100 | 10 | 10 |
| Habitat Diversity | 100 | 25 | 25 |
| Biodiversity Importance | 90 | 25 | 23 |
| Functional Importance | 100 | 25 | 25 |
| **ESTUARINE IMPORTANCE SCORE** | | | **98** |

The EIS for the Limpopo Estuary, based on its present state, is 98, i.e., the estuary is **Highly Important.**

### 4.5.10 Recommended Ecological Category

#### 4.5.10.1 *Recommended Ecological Category*

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The degree to which PES needs to be elevated depends on the level of **importance** and level of **protection or desired** protection of a particular estuary: The Limpopo Estuary has been identified with a score of 98 as an extremely significant and important estuary along the sub-tropical. This importance related to its service to the inshore marine environment. The physical specialist highlighted in the workshop discussions the important provision of sediments and nutrients in massive pulses to the coastal environments. In particular provision of sediments to shorelines south of the mouth and cues of freshwater and land derived nutrients which are important cues for estuarine invertebrates and fish.

**Table 4.29:** Level of importance and level of protection / desired protection of a particular estuary

| Current status and estuary importance | Recommended Ecological Category | Policy basis |
|---|---|---|
| Protected area | A or BAS* | Protected and desired protected areas should be restored to and maintained in the best possible state of health |
| Desired Protected Area (based on complementarity) | | |
| Highly important | PES + 1, min B | Highly important estuaries should be in an A or B category |
| Important | PES + 1, min C | Important estuaries should be in an A, B or C category |
| Of low to average importance | PES, min D | The remaining estuaries can be allowed to remain in a D category |

* BAS = Best Attainable State

In addition to being categorised as a 'Highly Important estuary', the Limpopo Estuary should also be flagged by the relevant Moçambican authorities to be provided some level of protection to achieve the countries biodiversity targets as well as being characterised as irreplaceable on the sub-tropical east African coastline within any formal regional conservation plan. Therefore, it is recommended that the condition of the estuary should be elevated to a Category B or as per the rule table Present Ecological State + one category.

To test whether the REC was achievable the scores were assessed to establish the changes in present state (compared with reference conditions) that are not as a result of changes in flow, but rather as a result of other anthropogenic activities. The table below indicates the impacts of the removal of non-flow related changes (i.e. fishing pressures, floodplain development with no buffers to the estuary etc) on the estuarine health score.

The Estuarine Health Index Scores derived from the calculation of the score with the non-flow related change included are provided in.

**Table 4.30:** Estuarine Health Index Scores

| Variable | Weight | Score | Weighted score |
|---|---|---|---|
| Hydrology | 25 | 58 | 15 |
| Hydrodynamics and mouth condition | 25 | 100 | 25 |
| Water quality | 25 | 75 | 19 |
| Physical habitat alteration | 25 | 98 | 24 |
| **Habitat Health Score** | | | **83** |
| Macrophytes | 25 | 95 | 19 |
| Invertebrates | 25 | 84 | 17 |
| Fish | 25 | 96 | 19 |
| Birds | 25 | 98 | 20 |
| **Biotic Health Score** | | | **74** |
| **ESTUARINE HEALTH SCORE** | | | **79** |
| **Present Ecological Status** | | | **B** |

These scores indicate that with the removal of many of the pressures and impacting activities to improve sustainability of the resources the PES could be raised to a high B. The complete removal of these impacts is considered unlikely but it does provide a clear indication that more careful management of these aspects could result in an increase in health status.

- It was noted that there is a strong dependence of the local community directly on the estuary in the absence of other economic activities. It is recommended that some exploration of additional economic alternatives, is investigated to remove some of the pressure on the system.
- Increasing to a B would ensure that the provisioning of ecological services would increase, thereby increasing the delivery of these services to people.
- It was noted that significant abstraction would drive estuarine conditions further upstream, and that this would increasingly compromise the irrigation potential for adjacent land, and therefore put increasing pressure on the estuary and other coastal resources through increased utilisation.
- Given the impacts identified by the team, and the sensitivity testing done at the end of the workshop, it was agreed that through the implementation of some control of selected anthropogenic impacts, it would

be possible to bring the system back up to a B. It was acknowledged this would not be an easy task given the extreme poverty in the immediate area of the system.

#### 4.5.10.2 *Further discussion of selected impacts on the Estuary*

It is estimated that the estuary receives approximately 66% of its natural mean annual run off due to abstraction activities in the catchment. Changes in flow conditions have not influenced mouth state to date as the open mouth is largely tidally driven. Changes in flow could, however, begin to have an effect on mouth status and have definitely had and could increase changes to the physico-chemical conditions of the system (currently salinity is most affected). Reduced flows, amplified during low flow periods, would lead to reduced nutrient and sediment input to the coastal zone and extension of the salinity wedge further upstream. While the increase in salinity may lead to greater diversity as more marine migrants would be able to utilise the system, abundance is likely to decrease with reduced primary and secondary production. In addition, olfactory cues and coastal processes would be negatively impacted. It has been anecdotally reported that small scale farmers on the floodplain are beginning to see an increase in salinity within the irrigation water in areas previously fresh. This would need to be confirmed and tested by further work.

Subsistence fishing at its current levels represents the greatest threat to the sustainable utilisation of fish, and to a lesser extent the larger crustacean and bird fauna of the Limpopo Estuary. Fishing techniques observed included: hand lines, seine netting and gill netting. The former takes place in the lower reaches of the system, while seine and gill nets were deployed everyday throughout the length of the estuary. Gill nets remained in the estuary for long periods and at times were strung along the width of the estuary forming a continuous obstacle to upstream/downstream movement by fish fauna. These impacts have undoubtedly had a major impact on the structure, fish community and abundance, with the possible exception of the truly benthic species that are not targeted by these techniques. Fishing effort levels in their current state are unsustainable with no apparent culture for conserving small or non-targeted fish species. This is clearly translated into the low score calculated for this component.

#### 4.5.10.3 *Evaluation of Water Use Scenarios and determination of the Environmental Water Requirements*

It was not possible within this study to establish the EWR for the estuary as this would require the evaluation of a number of different water use scenarios to calibrate the estuary responses and test the sensitivity of the different abiotic and biotic components to varying flow regimes.

### 4.5.11 Recommendations arising from this Study

The significance of the estuary Importance to the local community as a provider of essential resources including a significant source of protein (fish) and building materials (mangroves) should not be underestimated given the high level of utilisation observed during the limited period of sampling. Changes in the freshwater flow regimes have likely already altered the extent of saline penetration to the lower riverine reaches and may ultimately result in changes to mouth functioning. These impacts may significantly affect the provisioning of the ecological goods, and disrupt of the flow of freshwater and land derived sands to the coastal environment south and north of the estuary

This investigation was conducted with the benefit of only a winter survey and it is recommended that a summer survey of the system be undertaken in the future to provide further confidence around the assumptions, and allow greater resolution of the predictions and changes to the system in response to different flow regimes.

### 4.5.12 Recommendations for further work

The lack of a summer survey to assess more completely the significance of the system to estuarine dependent fish species and utilisation by tourist visitors would need to be addressed by conducting a estuary and immediate inshore coastal waters assessment. The scale and impact of this would need to be assessed during the summer season. This survey should be conducted in collaboration with the local communities i.e. travel and log the fish and invertebrate catches with them. Any data currently on the database of the Moçambique Fisheries Department with regards fishing in the Limpopo would provide extremely important and useful context for analysis of recent data and should be sourced for future work on the system.

More detailed water quality data should be collected to assess the status of the estuary. Further assessments of the estuarine floral and faunal community's response to changes in flow would be essential for calibration and sensitivity testing and determination of the Environmental Water Requirements.

# 5. WATER RESOURCES

***(Refer Technical Annexure Volume C1: Hydrology Assessment)***

## 5.1 INTRODUCTION

A high-level overview of surface and groundwater analysis approaches, methodologies, models and related input data and results are presented in this Chapter. Comprehensive scientific and technical accounts of the details of the work underlying this Chapter will be provided in **Technical Annexures** which will accompany future versions of the Monograph.

## 5.2 SURFACE WATER SOURCES

### 5.2.1 Analysis Approach

The application of a monthly catchment modelling package - formally known as Water Resource Simulation Model (WRSM2005) - which incorporates the well-known Pitman Model for rainfall-runoff simulation, forms the foundation of the analysis of the surface water resources of the LRB. Monthly modelling input data, comprising rainfall, evaporation and historical water-use information, was compiled for selected gauged sub-basins across the Botswana, Zimbabwe and Moçambique portions of the LRB. WRSM2005 was configured for these selected gauged sub-basins and the Pitman Model parameters were then calibrated against the observed streamflows in each case. Calibrated parameter values were transferred to un-gauged sub-basin in a “fit-for-use” manner. The input data for all these configurations has been prepared up to the 2010 hydrological year.

For the South African sub-basins, WRSM2005 configurations, input data and Pitman parameters, inherited from the well-known WR2005 Study as well as from recent studies commissioned by the RSA Department of Water Affairs, were implemented. Where necessary, this inherited information was supplemented by additional years of input data to bring all the RSA configurations up to date for the 2010 hydrological year.

Missing values in the monthly rainfall records were patched by means of the CLASSR and PATCHR software, while missing monthly streamflow values were patched by means of the PATCHS software.
To be completed.

### 5.2.2 Rainfall and Evaporation Data

#### 5.2.2.1 *Botswana*

Monthly rainfall records for 38 rainfall stations and 3 evaporation pan evaporation stations were supplied by the Botswana Department of Meteorological Services. Records at 5 rainfall stations were not considered, because of insufficient data. In total, records for 33 rainfall stations were patched and, of these, 8 stations have long records up to the current-day and are utilised as “driver stations” in the patching process, as well as in the catchment modelling process. The three evaporation stations adequately represent the spatial distribution of evaporation across the Botswana portion of the LRB.

The locations of rainfall and evaporation monitoring stations in Botswana used in this Study are presented in

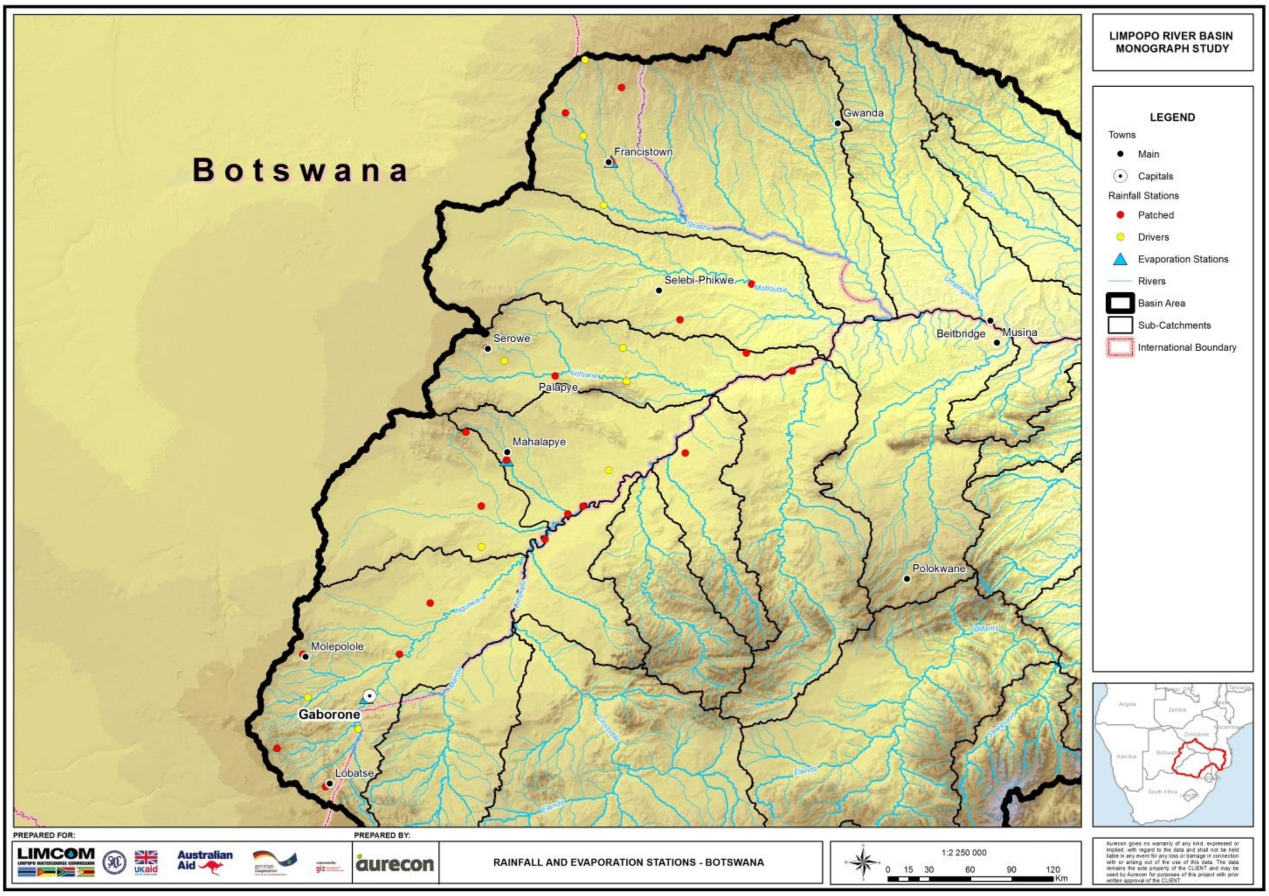



**Figure** 5.1**.**

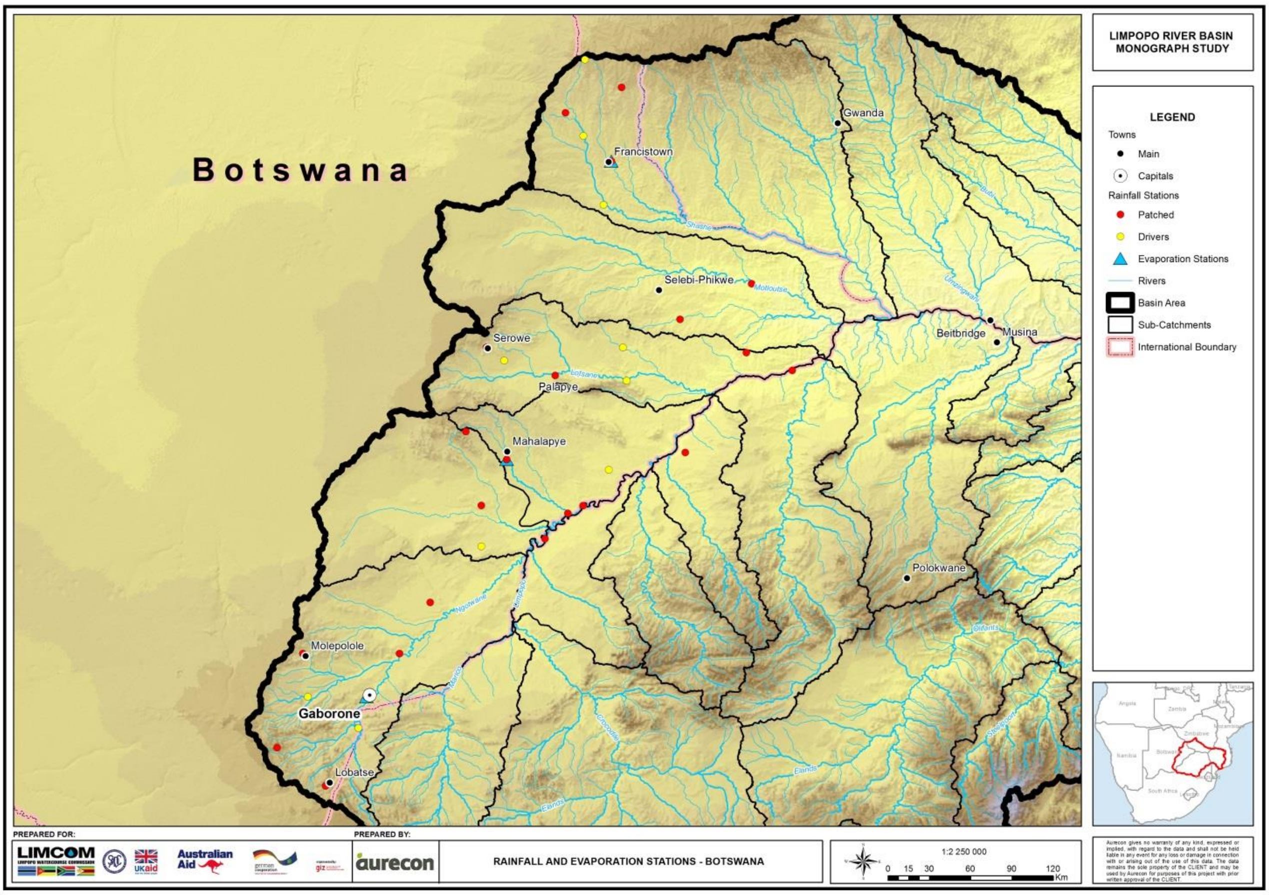



**Figure 5.1:** Rainfall and Evaporation Stations in Botswana portion of the LRB

### 5.2.2.2 *Moçambique*

Of the 52 monthly rainfall records that were received from Moçambique (ARA-Sul) only 22 records were included in this Study, given the severity of the extent of missing data in the rest. Most stations have missing data between 1970 and 1985 and this period required patching. Five stations have long records up to the current-day and are utilised as “driver stations” in the patching process, as well as in the catchment modelling process.

Monthly open pan evaporation data from a single station at Massingir Dam was received from ARA-Sul. Although evaporation does not vary significantly across the Moçambique portions of the LRB, it would be desirable to obtain data at a second location in the Changane catchment. The locations of rainfall and evaporation stations in the Moçambique portion of the LRB are presented **Figure 5.2**.

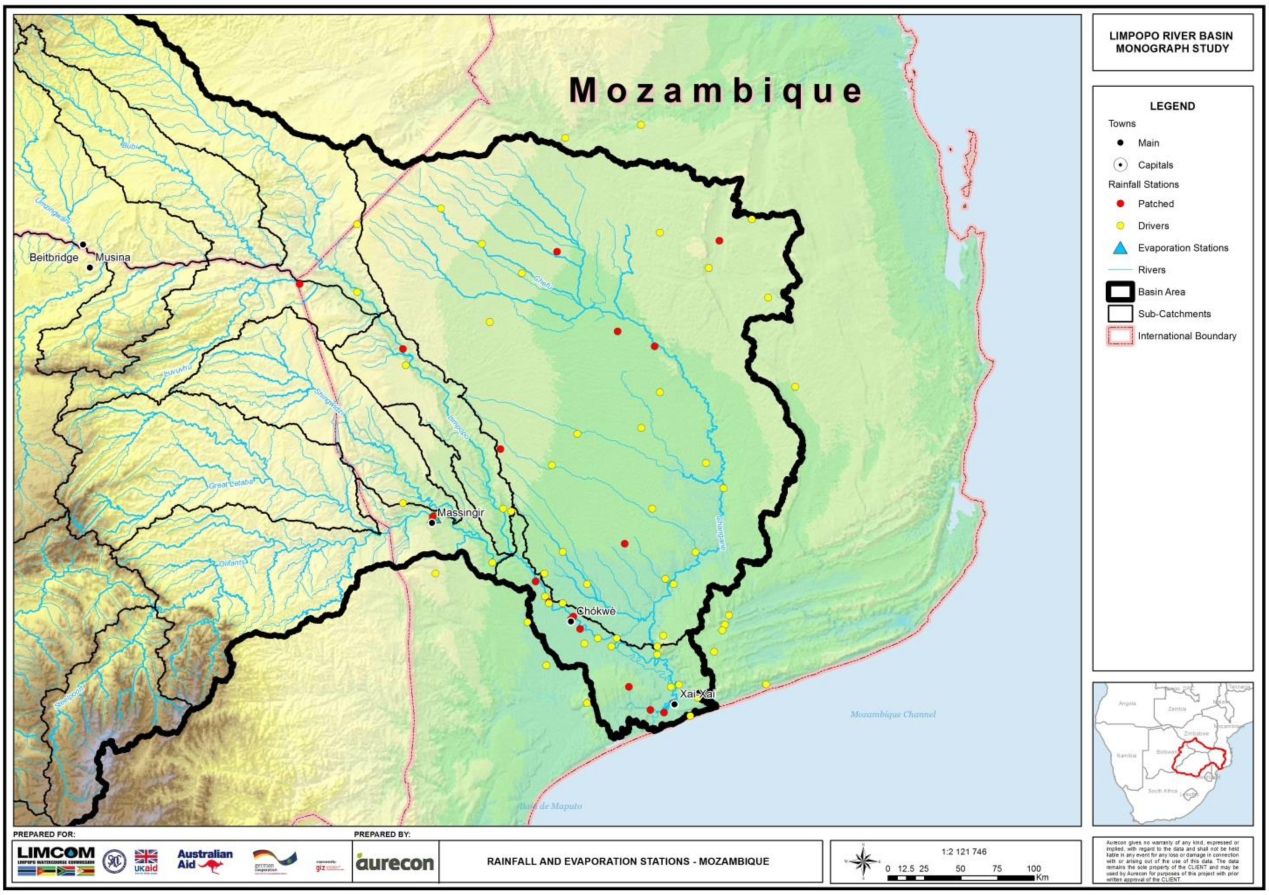



**Figure 5.2:** Rainfall and Evaporation Stations in the Moçambican portion of the LRB

### 5.2.2.3 *South Africa*

A total of 150 rainfall stations were still open by hydrological year 2010 and missing values in their records were patched up to that date. Monthly data was obtained from the latest database in the Water Resource Information Management System (WRIMS) (supplied by the South African Department of Water Affairs) as well as the DWA web site. The mean monthly evaporation data imbedded in the inherited WRSM2005 configurations is being used in this Study; therefore, obtaining evaporation station data was not necessary for this Study. The locations of rainfall and evaporation stations in the South African portion of the LRB are presented in **Figure 5.3**.

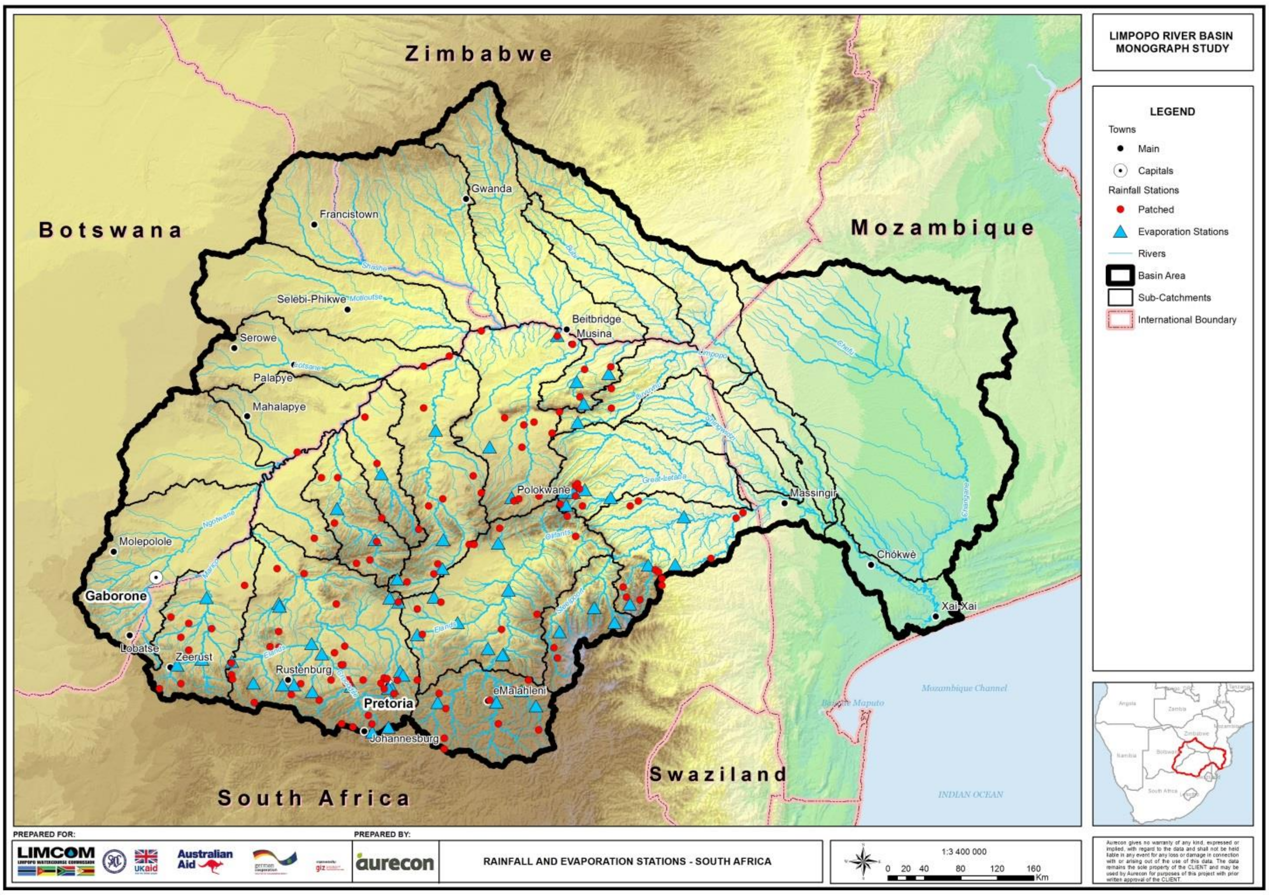



**Figure 5.3:** Rainfall and Evaporation Stations in the South African portion of the LRB

### 5.2.2.4 *Zimbabwe*

Monthly rainfall data was obtained from the Zimbabwe Meteorological Department as well as from an in-house archive at Aurecon, created during the 2001 project entitled “Hydrological Model of the Limpopo River Main-Stem”. In total, records for 54 rainfall stations were patched and, of these, 6 stations have long records up to the current-day and are utilised as “driver stations” in the patching process, as well as in the catchment modelling process.

Monthly data for 10 evaporation pan evaporation stations was received. These stations adequately represent the spatial distribution of evaporation across the Zimbabwe portion of the LRB. The locations of rainfall and evaporation stations in Zimbabwe portion of the LRB are presented in

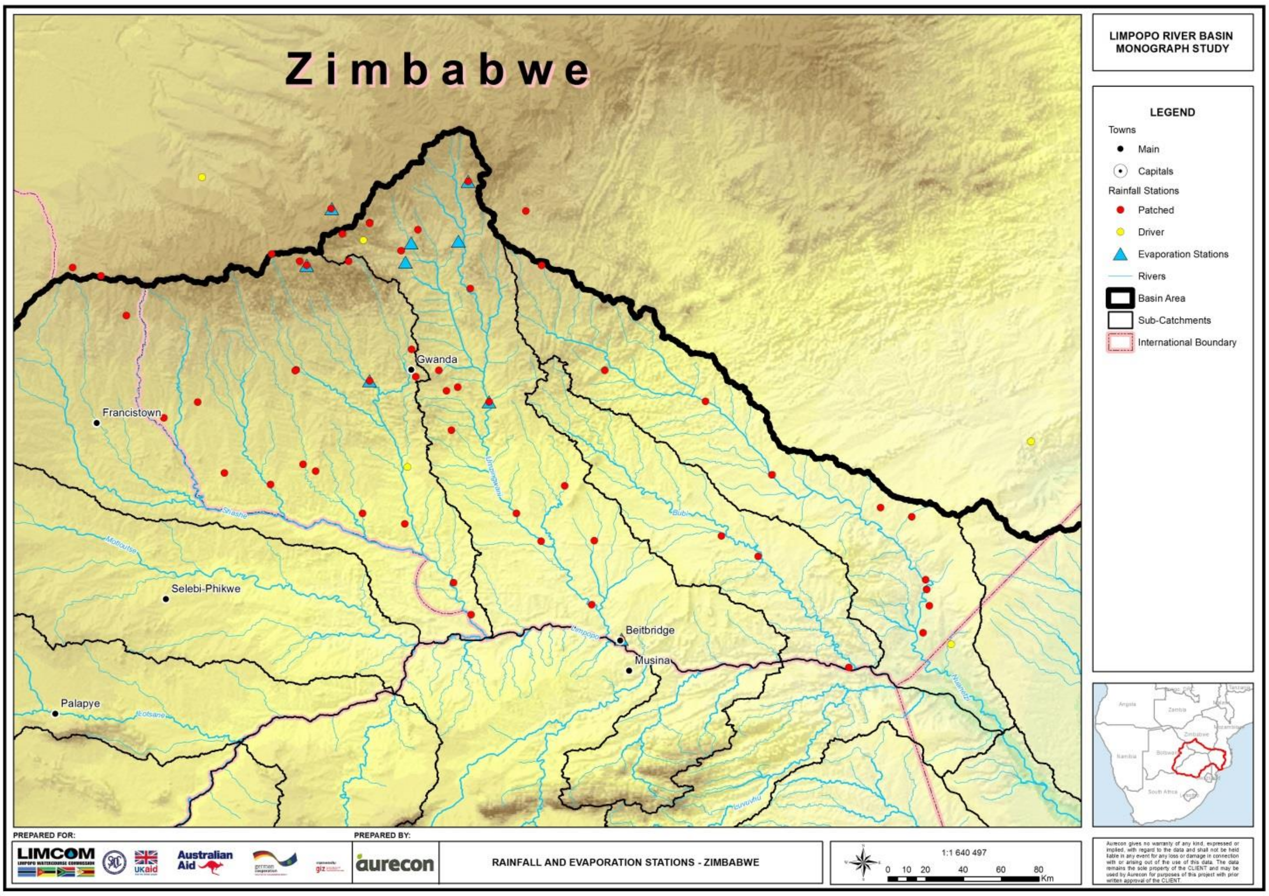



**Figure** 5.4.

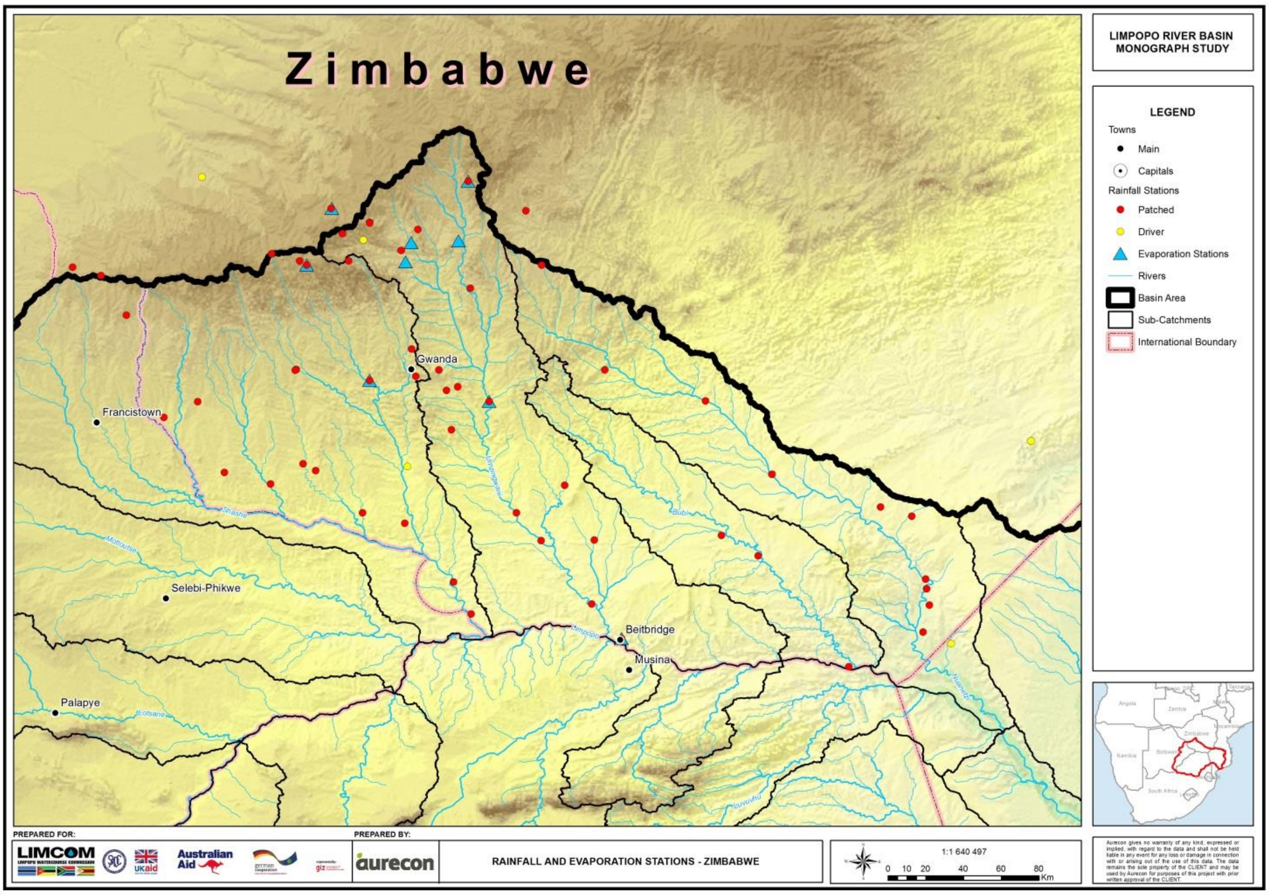



**Figure 5.4:** Rainfall and Evaporation Stations in the Zimbabwean portion of the LRB

### 5.2.3 Streamflow Data

#### 5.2.3.1 *Botswana*

Monthly streamflow data for 7 gauging stations was supplied by the Botswana Department of Water Affairs. Missing data was provisionally patched using the PATCHS software imbedded in WRSM2005. Simulated values ultimately replaced these patched values at problem stations. The locations of all the streamflow gauging stations in the Botswana portion of the LRB used in this Study are presented in **Figure 5.5**.

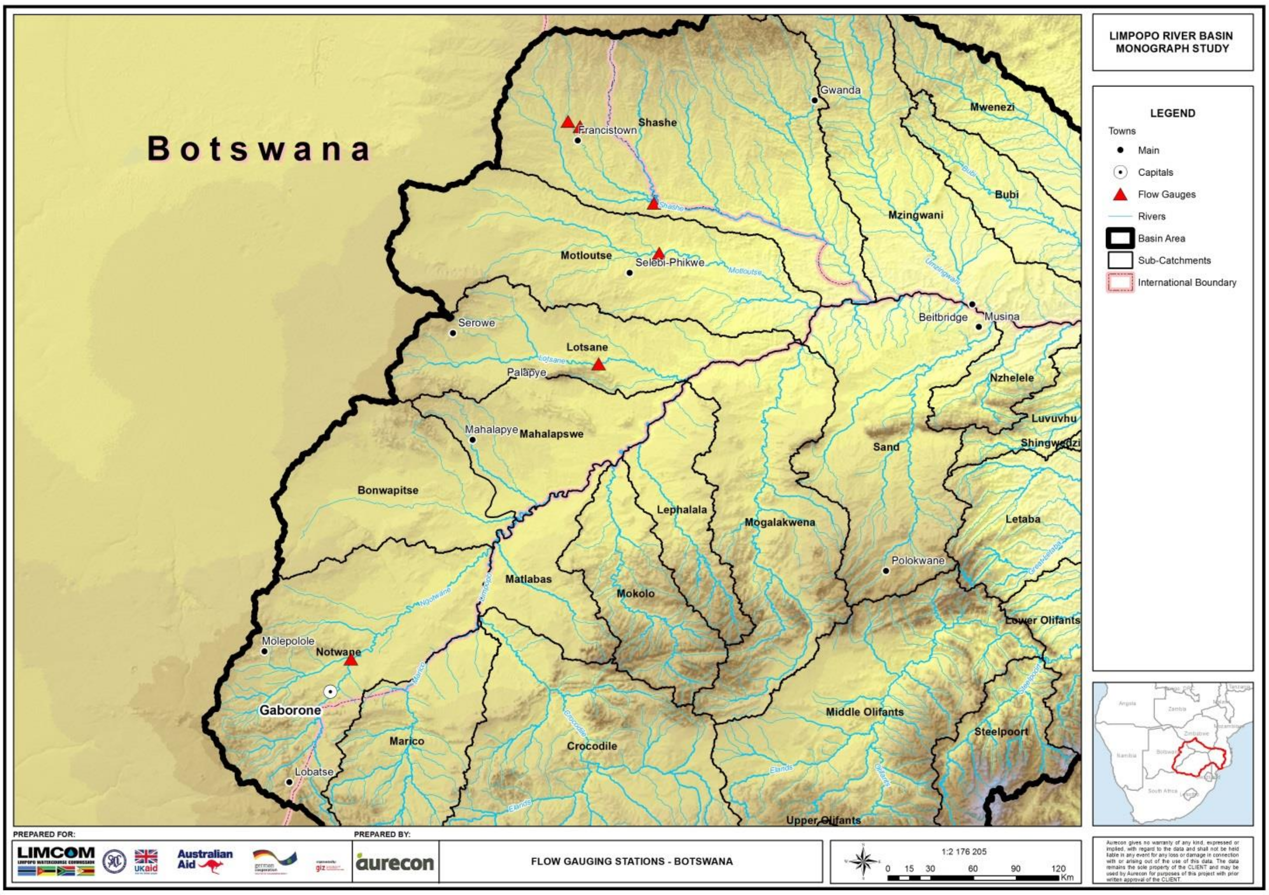



**Figure 5.5:** Flow gauging stations in the Botswana portion of the LRB

### 5.2.3.2 *Moçambique*

Early in the Study, daily water levels and rating curves for 33 streamflow gauges were supplied by ARA-Sul. Based on quality of record and location, three gauging stations were selected for model calibration purposes, using monthly streamflows for these four stations supplied by ARA-Sul. For WRSM2005 calibration purpose, missing data was provisionally patched with PATCHS where acceptable regression relationships were possible. Simulated values ultimately replaced these patched values at problem stations. The locations of all the streamflow stations in the Moçambique portion of the LRB are presented in **Figure 5.6**.

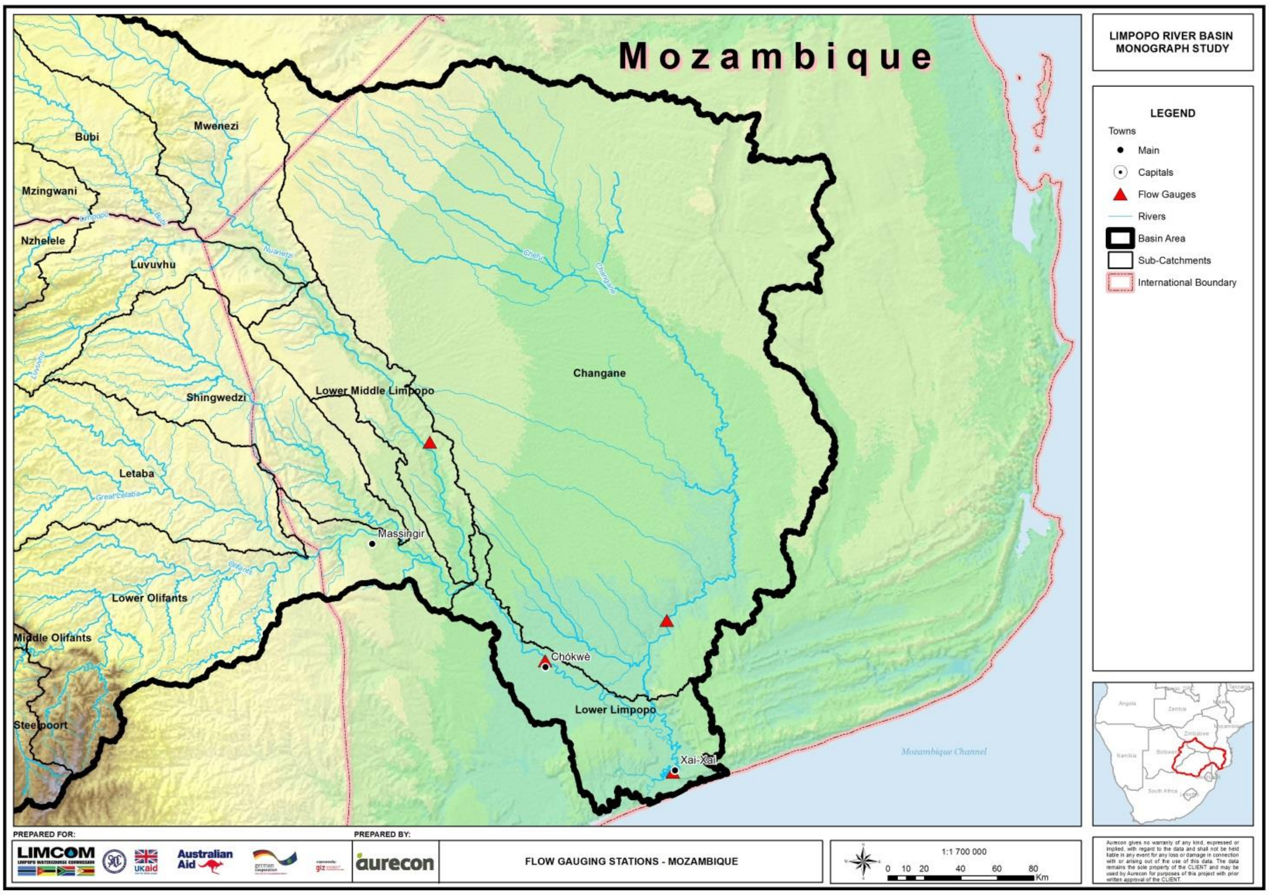
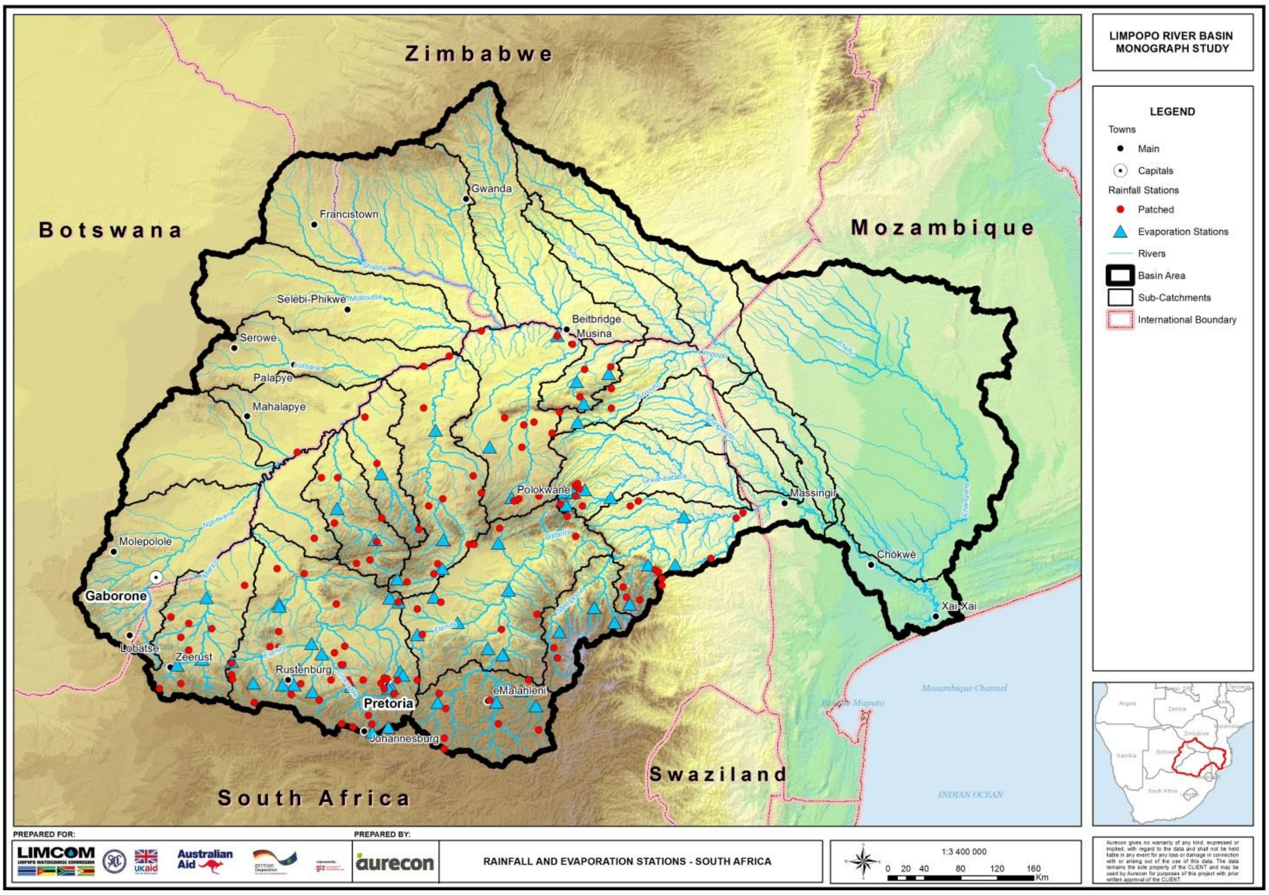



**Figure 5.6:** Flow gauging stations in the Moçambican portion of the LRB

### 5.2.3.3 *South Africa*

Streamflow data is available from the RSA DWA at 102 streamflow gauges in the RSA portion of the LRB. Of these, 12 gauges have been closed after 2004 and the rest have data up to at least 2011. All 102 of the WR2005 streamflow gauging stations have been used and the locations of these stations in the South African portion of the LRB are presented in



LIMPOPO RIVER BASIN MONOGRAPH STUDY
LEGEND
Towns
Main
Capitals
Rainfall Stations
Patched
Evaporation Stations
Rivers
Basin Area
Sub-Catchments
International Boundary
Zimbabwe
Botswana
Mozambique
South Africa
Swaziland
Gwanda
Francistown
Selebi-Phikwe
Serowe
Palapye
Mahalapye
Beitbridge
Musina
Polokwane
Massingir
Chókwè
Xai-Xai
Molepolole
Gaborone
Lobatse
Zeerust
Rustenburg
Pretoria
eMalahleni
Johannesburg
Mozambique Channel
INDIAN OCEAN
PREPARED FOR:
LIMCOM
Australian Aid
PREPARED BY:
aurecon
RAINFALL AND EVAPORATION STATIONS - SOUTH AFRICA
1:3 400 000
0 20 40 80 120 160 Km


**Figure** 5.7**.**

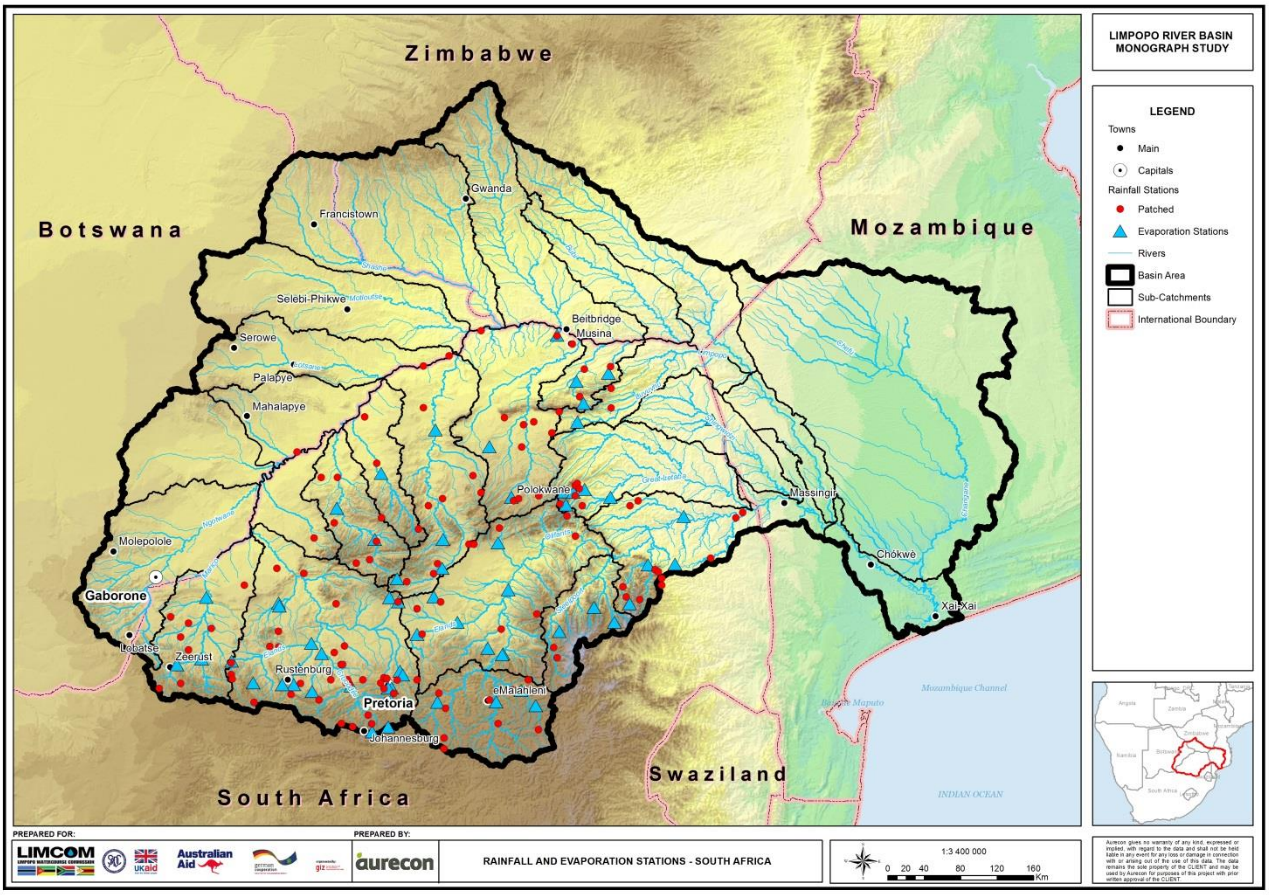



**Figure 5.7:** Streamflow gauging stations in the South African portion of the LRB

### 5.2.3.4 *Zimbabwe*

Data for 50 streamflow gauging stations was supplied by the Zimbabwe National Water Authority. A total of 20 of these streamflow records were selected for use in the model calibration process, based on quality of record and location of gauging stations. During the model calibration process, missing data were provisionally patched with PATCHS where acceptable regression relationships were possible. Simulated values ultimately replaced patched values at problem stations. The locations of the streamflow stations in the Zimbabwe portion of the LRB for which records were supplied to the Study are presented in **Figure 5.8.**

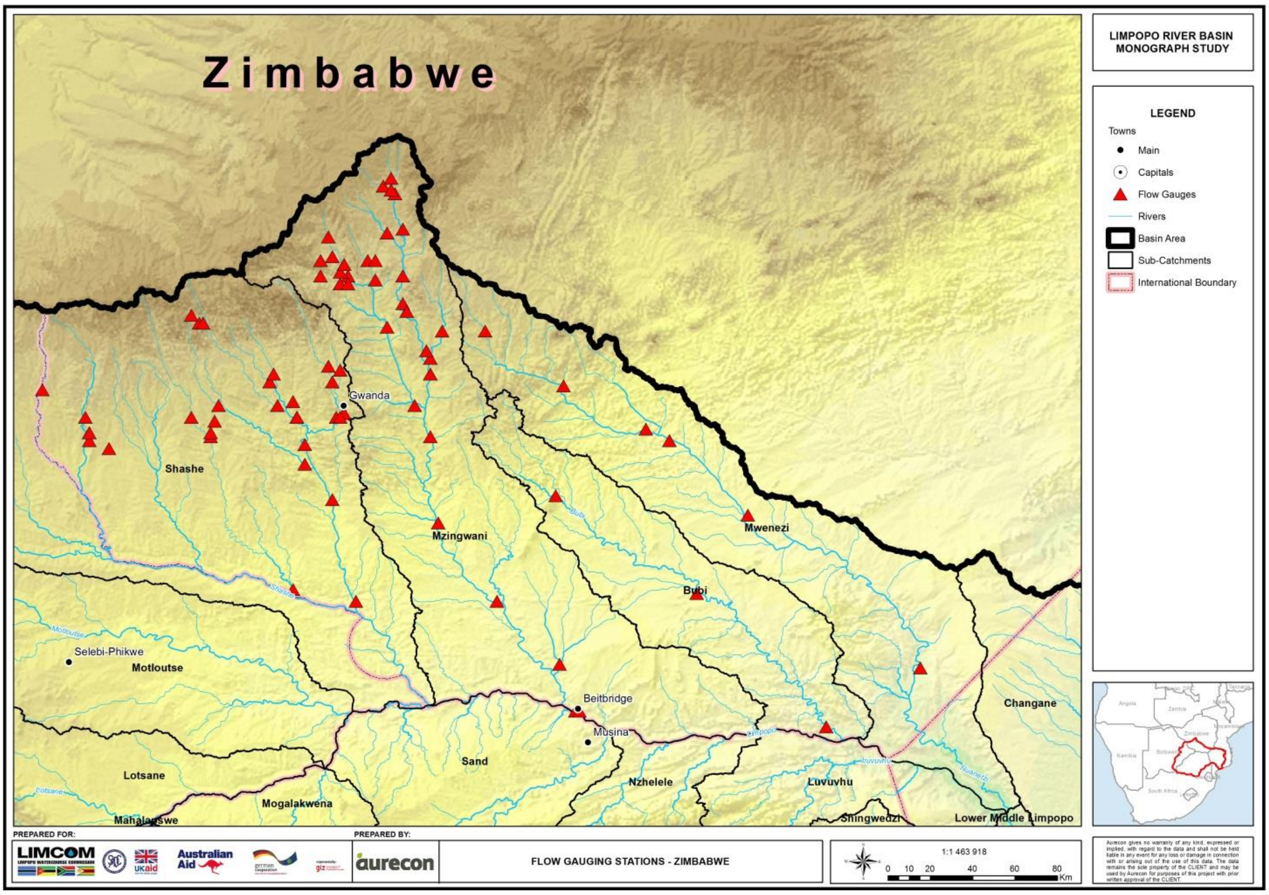



**Figure 5.8:** Flow gauging stations in the Zimbabwean portion of the LRB

### 5.2.4 Catchment Modelling

An example of a typical catchment model configuration is diagrammatically represented in **Figure 5.9**. Monthly runoff for a sub-basin is generated using the Pitman Model. A proportion of this runoff flows into a "dummy" farm dam (usually a cluster of small farm dams consolidated into one larger storage) and the rest of the runoff bypasses the dummy dam. A reservoir simulation is then performed for the dummy farm dam, with it supplying an irrigation demand. The spillage from the dummy farm dam as well as irrigation return flows are added to the runoff that bypasses the dummy dam, before accounting for any abstractions directly from the river. The resultant downstream flow becomes the inflow to a large on-channel dam (in this case Shashani Dam in Botswana) with the spillage cascading to the next modelling module.

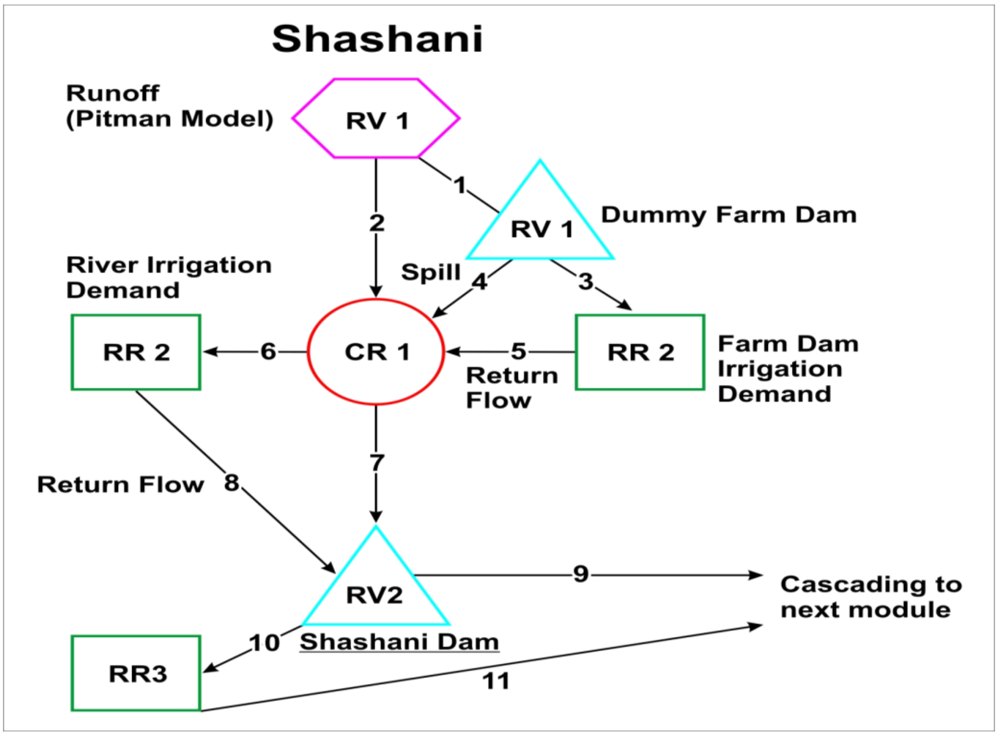



**Figure 5.9:** Modelling Sub-basin Discretisation

**Figure 5.10** presents the sub-basin discretisation that has been used for the application of the WRSM2005 modelling package and the calibration of the Pitman Model parameters, where relevant. Historical water-use estimates have been compiled for each of these sub-basins. Large dams or clusters of small dams (so-called “dummy dams”) have been included in the respective sub-basin model configurations.

The detailed sub-basin divisions in the upper reaches of the South African tributaries to the south and the upper reaches of the Zimbabwe tributaries to the north (especially the Mzingwane River) are necessary to capture their high degree of irrigation and water infrastructure development, as well as marked rainfall-runoff gradients. Modelling sub-basins to the west (in Botswana) and east (Moçambique) have been discretised at a much coarser scale, given their lower degree of surface water development, as well as their relatively lower rainfall-runoff gradients.

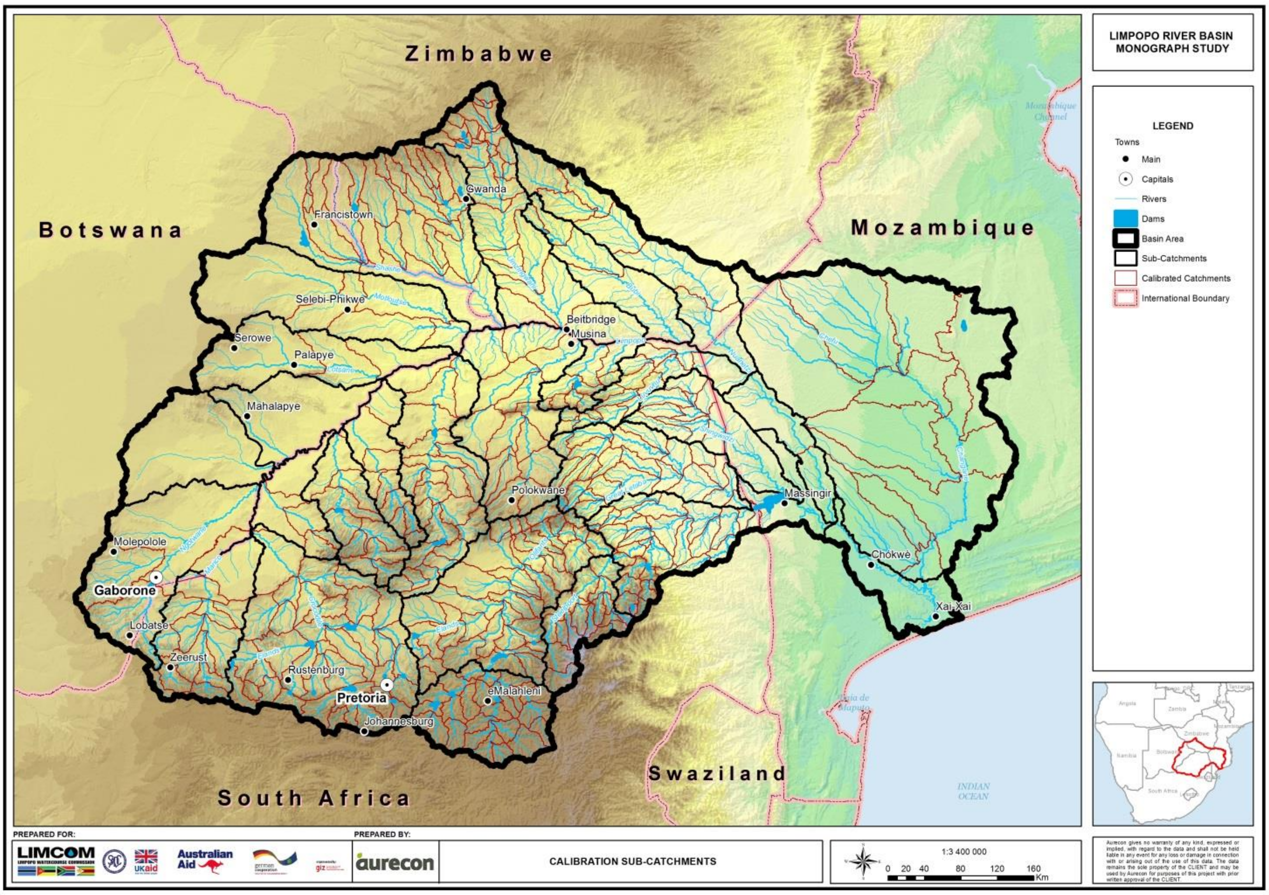



**Figure 5.10:** Model Calibration Sub-basins

#### 5.2.4.1 *Model Parameter Calibrations*

WRSM2005 Model configurations have been completed for all the Sub-Basins of the LRB. Pitman Model parameter calibrations for the gauged Botswana sub-basins are complete. Interim Pitman Model parameter calibrations of the gauged Zimbabwe and Moçambique sub-basins are also complete. However, extensive refinement of the historical and current-day water-use in the latter sub-basins is required before final Pitman Model parameter calibrations in the Zimbabwe and Moçambique sub-basins can be concluded.

The extension from 2004 to 2010 of the input data for the inherited WRSM2005 Model configurations for the South African Sub-Basins was completed. All the updated configurations arising from DWA studies that superseded the WR2005 Study have been included.

Interim naturalised and current-day monthly flow sequences have been prepared at all the EWR sites as inputs to the EWR process.

### 5.2.5 Mean Annual Runoff

Monthly streamflow sequences were simulated by means of the calibrated Pitman Model configurations per Sub-Basin for the 91-year period, 1920 – 2010. Two sets of streamflows were prepared for current-day (2010) and natural catchment conditions, respectively. For the natural scenario, the modelling was done with no human impacts present in the catchment configurations. For the current-day scenario, all existing land-use, water-use and bulk water resource infrastructure were super-imposed on the natural conditions at 2010 levels of demand and land-use, including transfers into and out of the Limpopo Basin.

A basin-wide comparison of Mean Annual Runoff (MAR) for current-day (2010) versus natural conditions is presented in **Figure 5.11**. The nett impacts of consumptive use on the surface water resources vary widely amongst the Sub-Basins and range from less than 1% in the Bonwapitse, Mahalapswe and Changane sub-basins to over 50% in the Upper and Middle Olifants sub-basins and nearly 70% in the Lower Olifants sub-basin. The total cumulative Basin MAR at the mouth of the Limpopo is 4072 million $m^3$/a for current-day condition which is 66% pf the 6197 million $m^3$/a for natural Basin conditions. This indicates that the accumulative nett human impacts on the surface water resources of the Basin currently constitute, on average, somewhat less than 35% of the natural surface water resources.

The MAR details and the current-day nett surface water impacts in the Sub-Basins in each country are displayed in more detail in **Tables 5.1 to 5.5**.

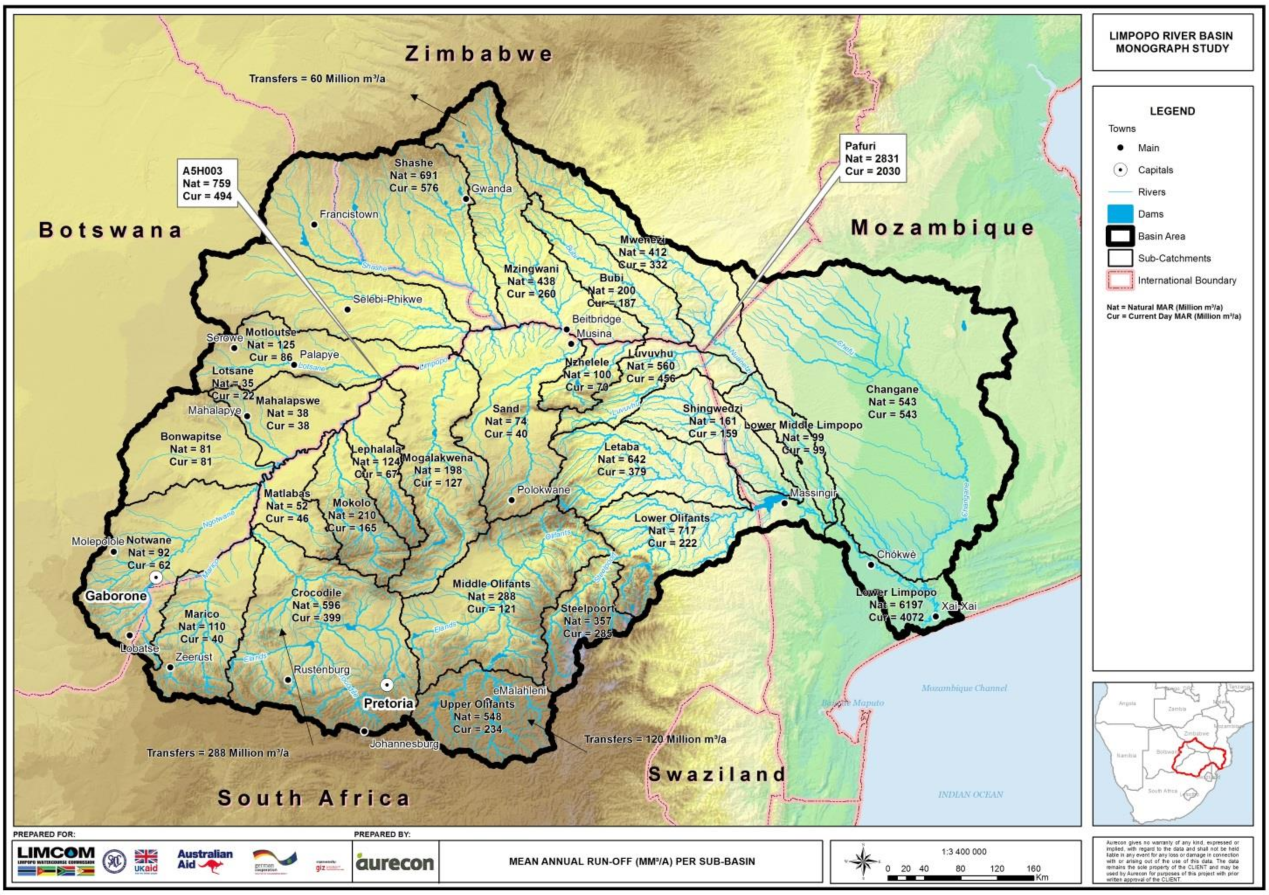



**Figure 5.11:** Comparison of Current Day (2010) MARs versus Natural MARs for Sub-Basins (million $m^3$/a)

***Botswana Sub-Basins***

**Table 5.1** presents the MARs and current-day nett surface water impacts for the Botswana Sub-Basins. These surface water impact figures include water transfers between certain Sub-Basins, as well as nett reservoir evaporation.

**Table 5.1:** MARs and Current-Day Nett Surface Water Impacts for Botswana Sub-Basins

| Sub-Basin | **Natural MAR** [Million $m^3$/a] | **2010 MAR** [Million $m^3$/a] | **2010 Nett Surface Water Impacts** [Million $m^3$/a] |
|---|---|---|---|
| **Shashe (to downstream of Dikgathlong Dam)** | 220 | 118 | 102 |
| **Bonwapitswe** | 81 | 81 | 0 |
| **Lotsane** | 35 | 22 | 13 |
| **Motloutse** | 125 | 86 | 39 |
| **Mahalapswe** | 38 | 38 | 0 |
| **Notwane** | 92 | 62 | 30 |
| **Total** | **591** | **407** | **184** |

***Zimbabwe Sub-Basins***

**Table 5.2** presents the MARs and current-day nett surface water impacts for the Zimbabwe Sub-Basins. These MARs include current-day water transfers of 60 million $m^3$/a from the Shashe and Mzingwane Sub-Basins to Bulawayo, as well as nett reservoir evaporation.

**Table 5.2:** MARs and Current-Day Nett Surface Water Impacts for Zimbabwe Sub-Basins

| Sub-Basin | **Natural MAR** [Million $m^3$/a] | **2010 MAR** [Million $m^3$/a] | **2010 Nett Surface Water Impacts** [Million $m^3$/a] |
|---|---|---|---|
| ***Ramokgwebana*** | *75* | *46* | *29* |
| ***Sansukwe*** | *23* | *22* | *1* |
| ***Simukwe*** | *81* | *70* | *11* |
| ***Shashani*** | *66* | *41* | *25* |
| ***Thuli*** | *215* | *190* | *25* |
| **Sashe (Zimbabwe Portion)** | 460 | 369 | 91 |
| **Mzingwane** | 438 | 260 | 178 |
| **Bubi** | 200 | 187 | 13 |
| **Mwenezi** | 412 | 332 | 80 |
| **Total** | **1 510** | **1 148** | **362** |

***South African Sub-Basins***

**Table 5.3** presents the incremental MARs and current-day nett surface water impacts for the Sub-Basins in South Africa. These MAR values include water transfers into the Crocodile (West) and Olifants Sub-Basins from the Vaal, Usuthu and Incomati River Basins, as well as nett reservoir evaporation.

**Table 5.3:** MARs and Current-Day Nett Surface Water Impacts for South African Sub-Basins

| Sub-Basin | **Natural MAR** [Million $m^3/a$] | **2010 MAR** [Million $m^3/a$] | **2010 Transfers In** [Million $m^3/a$] | **2010 Nett Surface Water Impacts** [Million $m^3/a$] |
|---|---|---|---|---|
| **Marico** | 110 | 40 | | 70 |
| **Crocodile (West)** | 596 | 399 | 288 | 485 |
| **Matlabas** | 52 | 46 | | 6 |
| **Mokolo** | 210 | 165 | | 45 |
| **Lephalale** | 124 | 67 | | 57 |
| **Mogalakwena** | 198 | 127 | | 71 |
| **Sand** | 74 | 40 | | 34 |
| **Nzhelele** | 100 | 70 | | 30 |
| **Luvuvhu** | 560 | 456 | | 104 |
| **Upper Olifants** | 548 | 234 | 120 | 434 |
| **Steelpoort** | 357 | 285 | | 72 |
| **Middle Olifants** | 288 | 121 | | 167 |
| **Letaba** | 642 | 379 | | 263 |
| **Lower Olifants (RSA Portion)** | 670 | 479 | | 191 |
| **Shingwedzi (RSA Portion)** | 82 | 80 | | 2 |
| **Total** | **4 611** | **2 988** | **408** | **2 031** |

***Moçambique Sub-Basins***

Given that Moçambique shares portions of the Shingwedzi and Lower Olifants Sub-Basins with South Africa and that both the Lower Middle Limpopo and the Lower Limpopo Sub-Basins in Moçambique receive streamflows from various upstream Sub-Basins, as well as from the Limpopo main-stem, the presentation of the relevant Sub-Basin mean annual water volumes in **Table 5.4** has had to be augmented with more detail than earlier shown in **Table 5.1, Table 5.2** and **Table 5.3**. In contrast, in **Table 5.5** the focus falls only on the Moçambique portion of the Limpopo Basin. In all cases the values include nett reservoir evaporation.

**Table 5.4:** MARs, Upstream Inflows and Current-Day Nett Surface Water Impacts for Total Sub-Basins Directly Relevant to Moçambique

| **Mean Annual Volume** [Million $m^3$/a] | **Full Shingwedzi** | **Lower Middle Limpopo** | **Full Lower Olifants** | **Changane** | **Lower Limpopo** |
|---|---|---|---|---|---|
| Natural Incremental MAR | 161 | 99 | 717 | 543 | - # |
| Current-Day Incremental MAR | 159 | 99 | 222 | 543 | - # |
| Current-Day Inflows: Limpopo Main-Stem & Mwenezi River | - | - | - | - | 2030 + 332 |
| Releases & Spills: Massingir Dam | - | - | - | - | 1243 |
| Current-Day Nett Incremental Surface Water Impacts | 2 | 0 | 495 | 0 | 126 ## |

# *Natural and current-day incremental MARs are both negative, because of significant Limpopo main-stem transmission losses.*

## *These current-day nett incremental surface water impacts include significant incremental transmission losses, as well as sizeable irrigation return flows.*

**Table 5.5:** Current-Day Nett Surface Water Impacts for Portions of Sub-Basins present in Moçambique

| **Mean Annual Volume** [Million $m^3$/a] | **Moçambique Portion of Shingwedzi** | **Lower Middle Limpopo** | **Moçambique Portion of Lower Olifants** | **Changane** | **Lower Limpopo** | **Total** |
|---|---|---|---|---|---|---|
| Current-Day Nett Incremental Surface Water Impacts | 0 | 0 | 314 | 0 | 126 | **430** |

The 314 million $m^3$/a current-day nett surface water impacts on the Moçambique portion of the Lower Olifants Sub-Basin include nett evaporation losses from Massingir Dam of 291 million $m^3$/a.

*Limpopo River Main-Stem*

**Figure 5.11** presents cumulative natural and current-day MARs, consecutively, for the Limpopo main-stem at RSA streamflow gauging station A5H003 on the RSA/Botswana border, at Pafuri on the RSA/Moçambique border and at the Limpopo River mouth. The consecutively increasing impacts of current-day upstream nett consumptive land-use and water-use activities are clearly evident in **Figure 5.11**.

Mean annual transmission losses along the Limpopo main-stem under current-day conditions are depicted in **Figure 5.12** – a cumulative total of 1 101 million m3/a over its total length. These transmission losses are additional to irrigation abstractions from main-stem streamflows and represent about 27% of the current day MAR at the Limpopo River mouth. It should be noted that under natural conditions these transmission losses would be larger in absolute terms, given the higher total availability of streamflow under natural conditions.

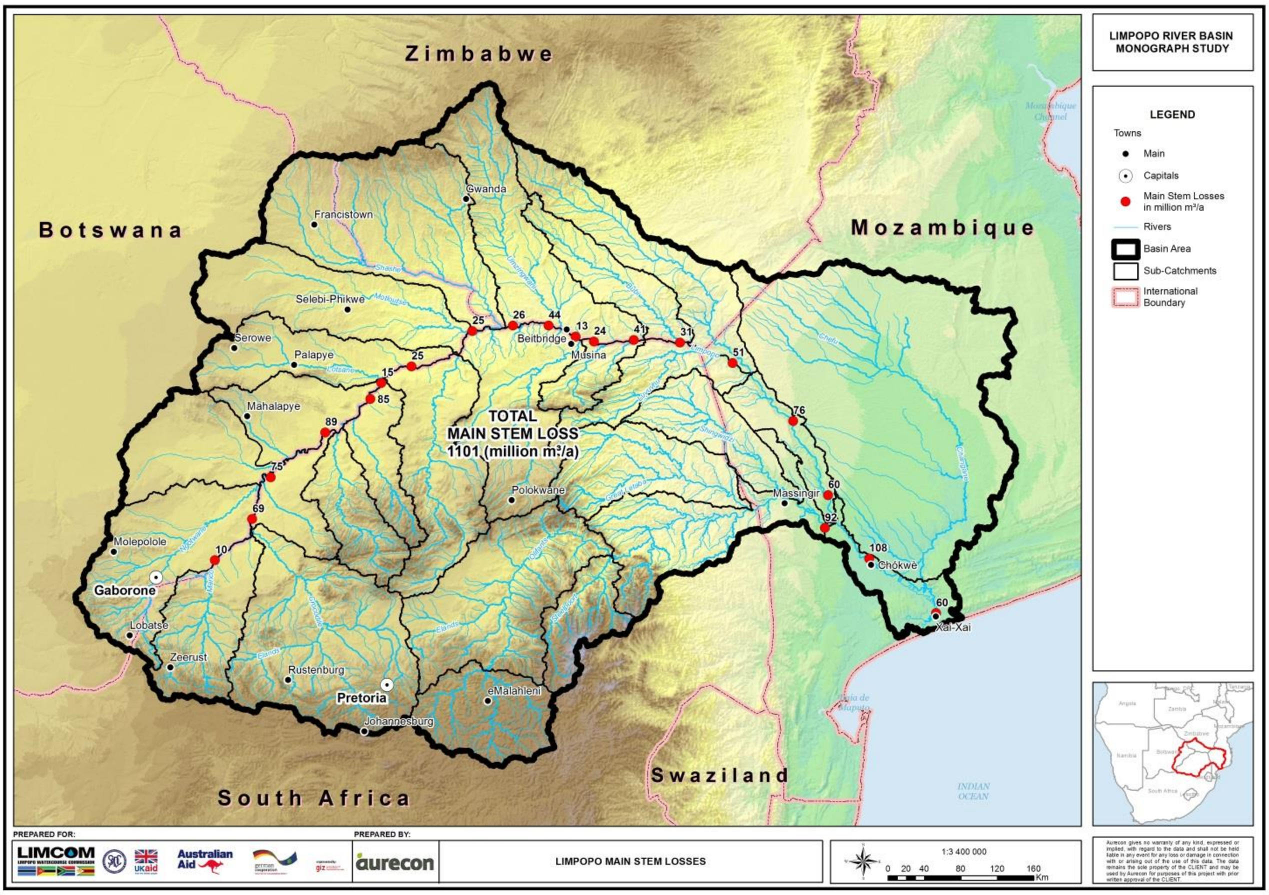



**Figure 5.12:** Distribution of Current-Day Transmission Losses along the Limpopo Main-Stem (million $m^3$/a)

### 5.2.6 Sub-Basin Yields

The 91-year simulated monthly streamflow sequences were used to determine current-day yields at 1:5 year recurrence interval (RI) of failure (80% assurance of supply on an annual basis) for all current-day storages and run-of-river abstraction points in each Sub-Basin, at the Sub-Basin rivers' confluences with the Limpopo main-stem and at a few critical Limpopo main-stem points. The yield modelling was done on a cascading basis, i.e. downstream yields already carry the impacts of upstream 1:5 year RI of failure drafts. The 1:5 year yield was approximated by the annual draft that caused 18 annual failures out of a 91 year sequence. At each yield point a monthly distribution of the annual draft appropriate to the relevant types of water use was employed.

The yields were summed up per Sub-Basin, the results of which are presented on a Sub-Basin basis in **Figure 5.13** and **Table 5.27.**

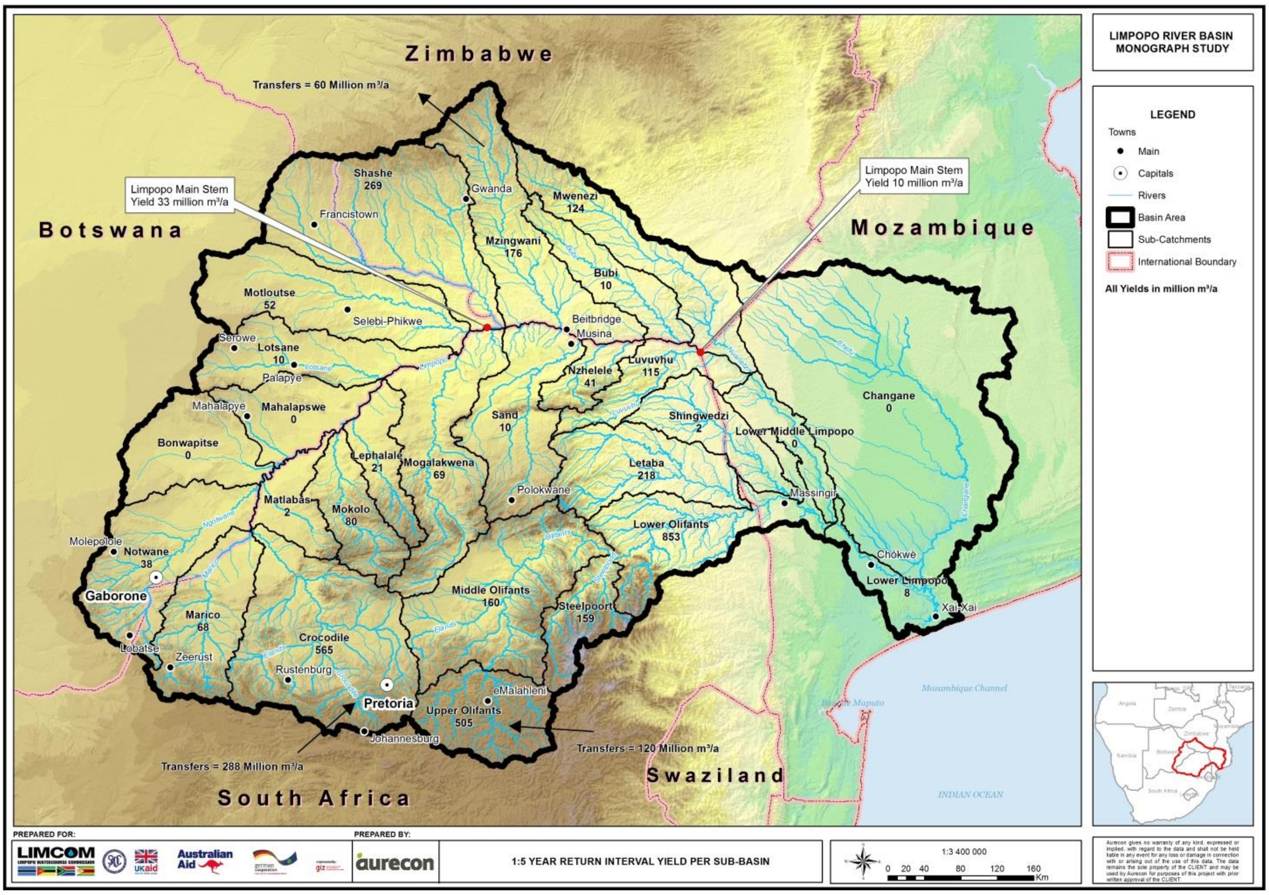



**Figure 5.13:** Current Day Yields at 1:5 Year RI of Failure (80% Assurance) at Sub-Basin Scale

It should be noted that the quantum of yield in a Sub-Basin is directly dependent on the quantum of storage in that Sub-Basin. For example, **Figure 5.13** shows that the Bonwapitse, Mahalapswe, Matlabas, Shingwedzi and Changane Sub-Basins have zero or near-zero yields despite sizeable MARs; this is because these Sub-Basins all lack significant storage, and the streamflow is too erratic to give a 1:5 year RI yield.

The 1:5 year RI yield values of the Limpopo main-stem in **Figure 5.13** appear quite low when compared with the relatively large MARs indicated in **Figure 5.11**. The cause of these low yield values is the fact that, in the absence of any structural storages on the main-stem Limpopo, the many occurrences of zero-flow months inevitably limit the magnitude of run-of-river abstractions at any given level of assurance.

### 5.2.7 Floods and Flood Peaks

#### 5.2.7.1 *Introduction*

The Limpopo River main-stem is subjected to periodic flooding caused by a range of large-scale weather systems that operate over different parts of the Basin (see sub-section 5.6.2). Recent examples of extreme main-stem flooding were the devastating events of January 2012 and February 2000.

In order to probabilistically quantify extreme floods in the Basin, annual maximum flood peak records were obtained from the co-basin countries and analysed in a sub-regional context. The following sub-sections describe the analysis approach and present the results of this sub-regional analysis.

#### 5.2.7.2 *Flood Peak Analysis Approach*

For the purposes of the Monograph the focus of the analysis had to be on more extreme, and therefore, less frequent flood peaks. The fact that most of the provided flood peak records were relatively short, posed a dilemma with the quantification of less frequent floods, such as those with a recurrence interval (RI) of 1:50 or 1:100 years. In statistical terms, estimates of high-RI flood peaks from short records are notoriously unreliable.

To resolve this dilemma, a sub-regional probabilistic analysis approach was followed, in which groups of flood peak records from hydrologically similar catchments were “pooled”, in order to achieve sample sizes large enough to allow statistically reliable estimates of high-RI flood peaks. Such pooling is a well-established approach, internationally, and is often referred to as the “flood index” approach.

In order to remove scale from the pooling process, the pooled flood peak values were standardised by dividing each value by the mean of its own flood peak record. The full sample of pooled dimensionless values was then used to fit alternative cumulative probability distributions. Next, the desired RI flood peaks, in dimensionless form, were quantified through the best-fitting distribution.
Finally, for each pooling sub-region, a relationship of mean annual maximum flood peak versus catchment area was developed to allow the re-dimensionalising of the dimensionless RI flood peaks for any site within the sub-region.

#### 5.2.7.3 *Pooling Sub-Regions and Gauging Stations Used*

Sub-regions and gauging stations were identified according to the following considerations:

- subjective assessment of hydrological similarity
- the creation of a statistically significant pooled flood peak sample (target: 100+ values)
- the need to include gauging stations with relatively large catchment areas
- no large dams immediately upstream
- catchment areas for sequential gauging stations on the same river must be of significantly different sizes.

**Table 5.6** presents the relevant pooling sub-region details. It should be noted that the attenuation effects of upstream dams were not removed and, in the case of rating table exceedences, the relevant flood peaks were estimated by power function extrapolation of the applicable rating curves.
It should furthermore be noted that the set of flood peak data available from Botswana was too sparse to consider for probabilistic flood analysis.

**Table 5.6:** Pooling Sub-Regions and Related Streamflow Gauges

| Pooling Sub-Region | Streamflow Gauges | Areas (km$^2$) | Number of Pooled Flood Peak Values |
|---|---|---|---|
| Zimbabwe Sub-Basin | B86 | 2 771 | 147 |
| | B85 | 7 670 | |
| | B37 | 13 000 | |
| | B91 | 11 100 | |
| | B94 | 3 397 | |
| | B31 | 4 140 | |
| Marico-Crocodile Sub-Basins | A3H007/A3R004 | 8 619 | 110 |
| | A2H060 | 20 627 | |
| | A2H128 | 28 781 | |
| | A2H025 | 21 349 | |
| Mokolo-Sand Sub-Basins | A4H005 | 3 786 | 165 |
| | A4H014 | 8 364 | |
| | A5H005 | 2 331 | |
| | A6H029 | 11 292 | |
| | A6H035 | 15 845 | |
| | A7H001/010 | 7 703 | |
| Nzhelele-Luvuvhu-Letaba-Shingwedzi Sub-Basins | A9H012 | 1 758 | 74 |
| | B8H018 | 12 938 | |
| | B9H003 | 4 540 | |
| Middle-Lower Olifants Sub-Region | B7H007 | 46 583 | 230 |
| | B5H002 | 23 566 | |
| | B8H018 | 12 938 | |
| | X2H036 | 21 481 | |
| | X1H003 | 8 614 | |
| | X2H016 | 10 365 | |
| | X3H015 | 5 713 | |
| Main-Stem Upstream of Beit Bridge | A7H004-08 | 202 985 | 97 |
| | A5H003-06 | 98 240 | |
| Main-Stem Between Beit Bridge and Olifants Confluence | A7H004-08 | 202 985 | 94 |
| | E33 | 256 077 | |
| Main-Stem Downstream of Olifants Confluence | E40 | 65 071 | 132 |
| | E35 | 341 077 | |
| | E33 | 256 077 | |

#### 5.2.7.4 *Dimensionless Recurrence Interval Flood Peaks per Pooling Sub-Region*

For each pooling sub-region, dimensionless values of the 1:20, 1:50 and 1:100 year recurrence interval flood peaks were derived from the probability distribution fitted to that sub-region's dimensionless flood peak data. **Figure 5.14** presents a typical example of such a flood peak probability diagram.

For each pooling sub-region, dimensionless flood peak values are presented in Table XX, along with the related mean annual maximum flood peak (MAMFP) relationship required to re-dimensionalise the dimensionless flood peaks at selected sites in each sub-region.

**NB:** It should be noted that each MAMFP relationship is only valid within its particular sub-region and at the scale of the main rivers in each sub-region. It should also be noted that for the Olifants downstream of Massingir Dam the attenuation effects of Massingir on incoming extreme floods have been ignored on the grounds that the 10806 km$^2$ Shingwedzi Sub-Basin joins the Olifants below Massingir and that the two rivers are likely to be in flood simultaneously. However, if so preferred by the Monograph user, the dimensionless flood peak values for the Middle-Lower Olifants sub-region in **Table 5.7** may be decreased by 5%, 10% and 15% for the 1:20, 1:50 and 1:100 year flood peaks, respectively, for the reach of the Olifants River downstream of Massingir Dam.

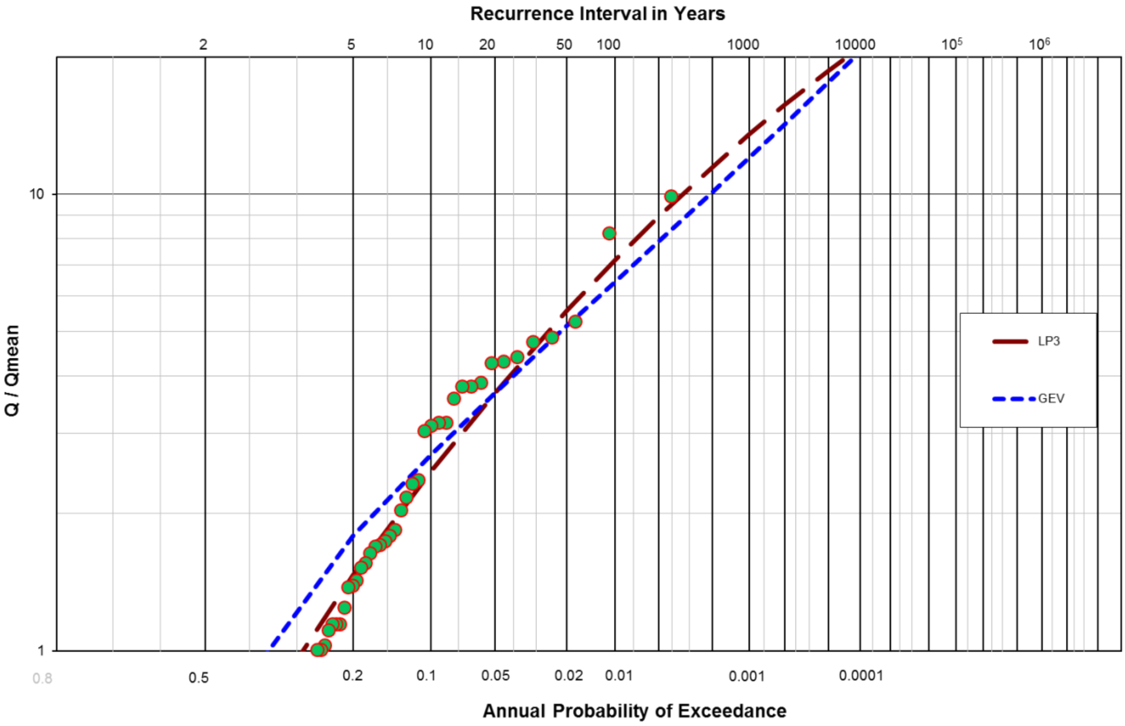



**Figure 5.14:** Flood Peak Probability Diagram for the Zimbabwe Pooling Sub-Region

**Table 5.7:** Dimensionless Recurrence Interval (RI) Flood Peaks and MAMFP Relationship per Pooling Sub-Region

| Pooling Sub-Region | Dimensionless RI Flood Peaks | | | Mean Annual Maximum Flood Peak (MAMFP) Relationship |
|---|---|---|---|---|
| | *1:20 Year* | *1:50 Year* | *1:100 Year* | |
| Zimbabwe Sub-Basins | 3.7 | 5.6 | 7.2 | MAMFP = 0.24*Area$^{0.83}$ |
| Marico-Crocodile Sub-Basins | 4.5 | 5.2 | 6.1 | MAMFP = 1467*Area$^{-0.21}$ |
| Mokolo-to-Sand Sub-Basins | 3.8 | 5.4 | 6.7 | MAMFP = 3096*Area$^{-0.33}$ |
| Nzhelele-Luvuvhu-Letaba-Shingwedzi Sub-Basins | 4.0 | 6.2 | 8.1 | MAMFP = 0.54*Area$^{0.80}$ |
| Middle-Lower Olifants Sub-Region | 3.6 | 6.7 | 10.3 | MAMFP = 1.20*Area$^{0.70}$ |
| Main-Stem Upstream of Beit Bridge | 3.0 | 4.5 | 6.1 | |
| | Upstream of Gauge A5H003/06 | | | MAMFP = 138*EXP$^{0.005*(Area/1000)}$ |
| | Between Gauge A5H003/06 & | | | MAMFP = 25.8 |

| Pooling Sub-Region | Dimensionless RI Flood Peaks | | | Mean Annual Maximum Flood Peak (MAMFP) Relationship |
|---|---|---|---|---|
| | *1:20 Year* | *1:50 Year* | *1:100 Year* | |
| | A7H004/08 | | | $*EXP^{0.02*(Area/1000)}$ |
| Main-Stem Between Beit Bridge and Olifants Confluence | 3.3 | 4.9 | 6.5 | $MAMFP = 12028* EXP^{-0.008*(Area/1000)}$ |
| Main-Stem Downstream of Olifants Confluence | 3.4 | 5.4 | 7.4 | $MAMFP = 24350*(Area/1000)^{-0.433}$ |

#### 5.2.7.5 *Recurrence Interval Flood Peaks for Sub-Basins and other Signigicant Locations*

The information in **Table 5.8** was used to derive recurrence interval flood peaks for Sub-Basins and selected tributaries at their confluences with the Main-Stem Limpopo. These results are presented in **Table 5.8.** It should be noted that results for the Botswana Sub-Basins are absent from **Table 5.8**, given that a probabilistic flood analysis for the latter Sub-Basins could not be undertaken due to the sparseness of the flood peak data available for Botswana. Results for the South African Sub-Basins, Upper Olifants, Middle Olifants and Steelpoort are also absent from **Table 5.8,** because their influence on the Limpopo Main-Stem flooding is embedded in the Lower Olifants results.

**Table 5.8:** Recurrence Interval Flood Peaks for Sub-Basins and Limpopo Main Stem

| Tributary / Sub-Basin / Main-Stem Gauging Station | Mean Annual Maximum Flood Peak (MAMFP) ($m^3/s$) | Recurrence Interval Flood Peak ($m^3/s$) | | |
|---|---|---|---|---|
| | | 1:20 Year | 1:50 Year | 1:100 Year |
| Shashani | 209 | 774 | 1 172 | 1 507 |
| Tuli | 413 | 1 527 | 2 311 | 2 972 |
| Mzingwane | 729 | 2 697 | 4 082 | 5 248 |
| Bubi | 423 | 1 564 | 2 367 | 3 043 |
| Mwenezi | 693 | 2 563 | 3 879 | 4 987 |
| Marico | 194 | 893 | 1 029 | 1 165 |
| Crocodile | 164 | 752 | 867 | 981 |
| Matlabas | 177 | 671 | 964 | 1 192 |
| Mokolo | 156 | 591 | 848 | 1 049 |
| Lephalale | 167 | 633 | 909 | 1 124 |
| Mogalakwena | 118 | 448 | 644 | 796 |
| Sand | 126 | 479 | 688 | 851 |
| Nzhelele | 440 | 1 773 | 2 723 | 3 550 |
| Luvuvhu | 578 | 2 331 | 3 580 | 4 668 |
| Letaba | 1 136 | 4 579 | 7 033 | 9 169 |
| Shingwedzi | 932 | 3 754 | 5 767 | 7 518 |
| Lower Olifants | 960 | 3 456 | 6 432 | 9 888 |
| Changane | 80 | 272 | 431 | 596 |
| 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 |
| E35 (Chokwe) | 1 952 | 6 637 | 10 521 | 14 542 |
| E38 (Xai-Xai) | 1 799 | 6 117 | 9 697 | 13 403 |

## 5.3 GROUNDWATER RESOURCES

***(Refer Technical Annexure Volume C2: Groundwater Assessment)***

The objective of this study is therefore to describe the groundwater status, potential and role in the sub-basins of the Limpopo River basin as a whole. All the available information was studied and evaluated. The key information sources include the following SADC Data and reports:

- The Southern African Development Community Hydrogeological Mapping Project, 2010, (SADC-HGM 2010)
- The SADC Borehole data base, 2010.
- CSIR and Environmentek on behalf of SADC, 2003. Protection and strategic uses of groundwater resources in drought prone areas of the SADC region: groundwater Situation analysis of the Limpopo River Basin. Report number: ENV -P-C-2003-026.
- Various national information sources were also consulted and they are included in the reference list at the end of this report.

The SADC borehole database consists of 75 480 borehole records within the Limpopo Basin. The distribution of boreholes across the basin is shown in **Figure 5.15**. Of these observations there are 22 790 or 30% recordings of borehole yields. During the compilation of the SADC borehole database, borehole yields were requested in ℓ/s. The data received however consisted of mixed units and in some cases unknown units. The data was sorted and converted and where no units were available judgment was made to determine the units used and records were converted accordingly.

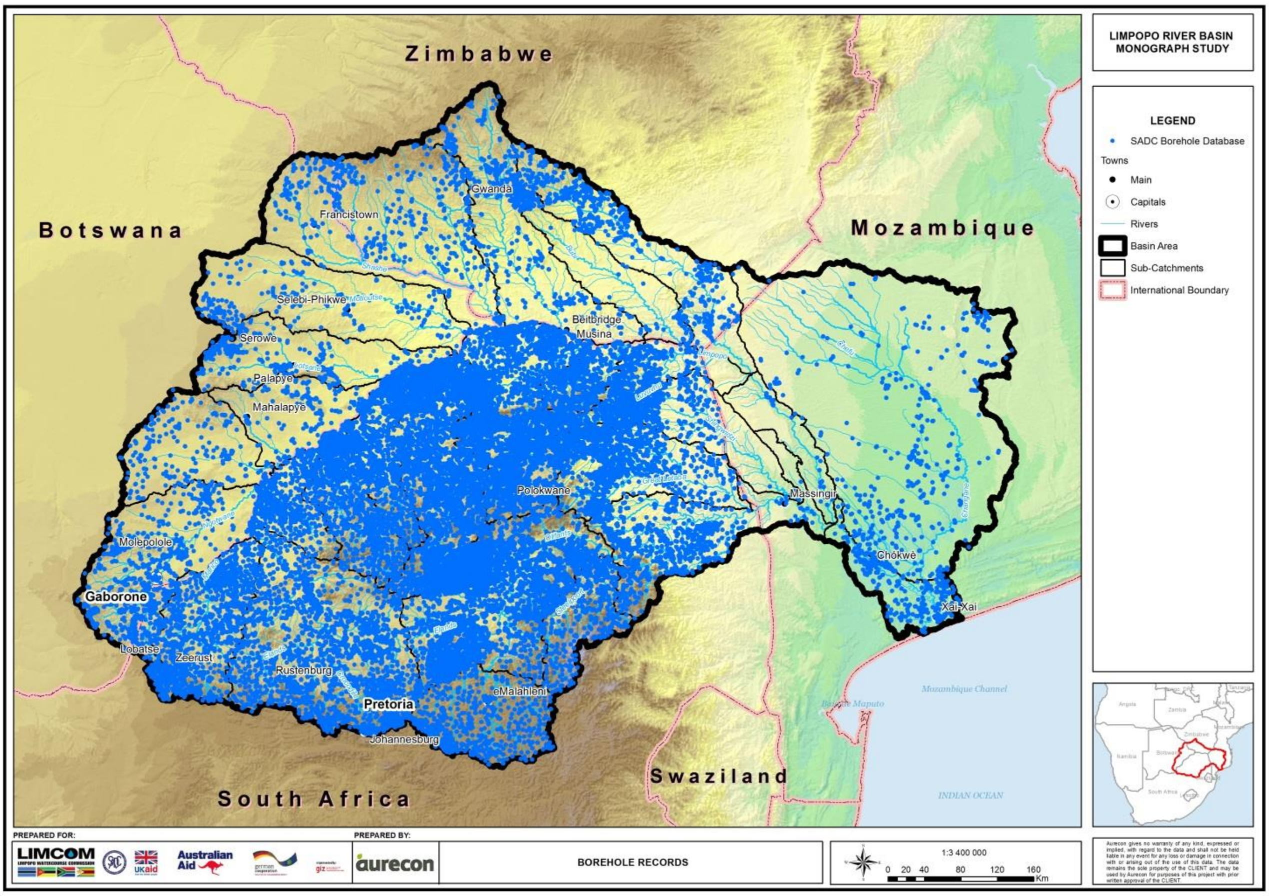



**Figure 5.15:** Borehole records in the Limpopo River Basin

The best data was obtained from the SADC borehole database and other data received were historical and did not have either water level or yield data. The Botswana data consisted of 2631 boreholes of which 88% contained water levels and 69% yield data. The Zimbabwe data consisted of 1758 boreholes of which 68% had water level data and only 25% yield data. Of the South African database of 70000 boreholes 50% showed water levels and 28% yield data. A total of 1077 boreholes are in the Moçambique database of which 93% showed water level data and 72% yield data.

### 5.3.1 Hydrogeological Setting

Substantial work has preceded this report in terms of defining and describing the various geohydrological units within the Limpopo River Basin. The primary focus is on the classification scheme adopted by the Southern African Development Community (SADC). Detailed geological and geohydrological mapping has been conducted in all four countries within the basin. Fundamental to the study of geohydrology is the manner in which water is stored and moves between geological units. The voids occurring in geological units, their origin, shape and interconnection are fundamental to groundwater flow. The characterisation of voids, the primary and secondary openings coupled with variations in lithological characteristics serves as the basis of the classification scheme adopted for the Limpopo River Basin.

The basin has been classified into four aquifer types namely fractured, intergranular, karst and low permeability. It is evident that 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. Karst aquifers (moderate to high yielding) constitute approximately 4% of the basin while (moderate to high yielding) Intergranular aquifers make up the remaining 14%.

A more detailed description of the hydrogeological setting is presented in the specialist report in the Technical Annexure, Volume C2: Groundwater Assessment. **Figure 5.16** represents a Geological map showing the various geological formations in the basin. The following section outlines the hydrogeological setting in each country and thereafter the identified geo-hydrological units of the basin are described.

**Botswana**

Four major geological units occur within the Botswana portion of the Limpopo River Basin. These include Archaean basements and gneisses, Proterozoic sedimentary units and sedimentary formations of the Karoo Supergroup and dykes of the same age. Alike to the South African and Zimbabwean portions of the basin, Botswana is underlain for a large part by archaen basements and gneisses. These units as expressed in the previous sub-section give rise to secondary aquifers with generally poor yielding aquifers. Fractured, porous aquifers including units within the Karoo sequence and the Waterberg group provide high yielding aquifers. Alluvial aquifers along the reaches of the Limpopo River and associated tributaries provide high yielding primary aquifers in the region.

**Moçambique**

The geology and hence the hydrogeology of the Moçambique portion of the Limpopo basin varies somewhat from the hydrogeological characteristics of the other three riparian states of the basin. While crystalline, secondary aquifers are predominant within the other countries, Moçambique is dominated by young tertiary and quaternary sediments. The extensive unconsolidated units host primary aquifers in this region and the groundwater yield tend to be high

**South Africa**

The groundwater in South Africa largely occurs in the secondary aquifers developed in the Archaean basement rocks of the Kaapvaal craton (CSIR, 2003). Through metamorphism, these rocks typically have poor groundwater potential thus the fractures and structures occurring within these units are of significance for groundwater storage. The groundwater yields within this unit are typically low. Sedimentary formations are the Karoo Supergroup and and dolomite formations. The presence of fractured zones along faults and dykes also plays a role in high yielding aquifers.

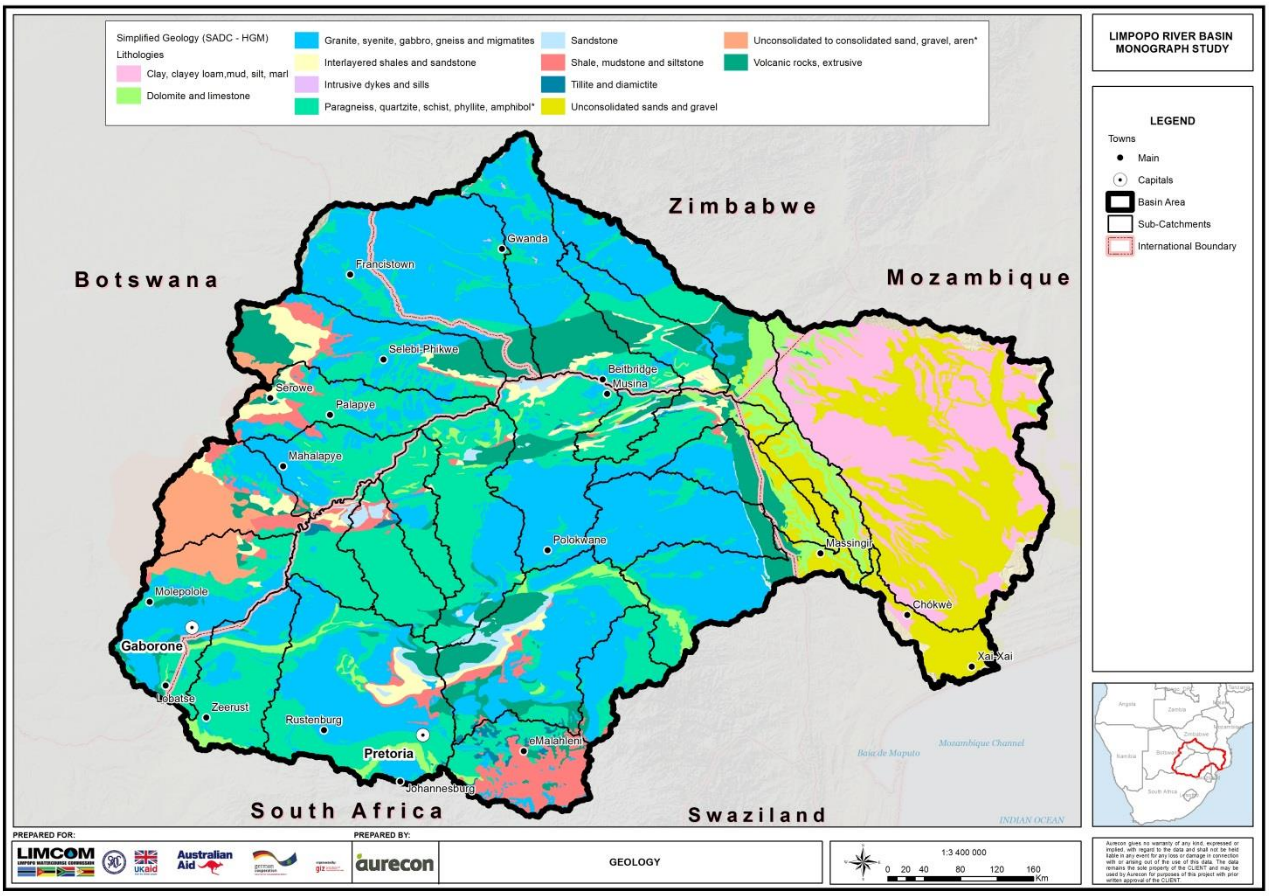



**Figure 5.16:** Geological Map

**Zimbabwe**

The geology of the Zimbabwean portion of the basin is much the same as that of South Africa. The hydrogeological units were identified during the compilation of the hydrogeological map of Zimbabwe. Approximately 80% of the Zimbabwean portion of the Limpopo basin is underlain by hard, crystalline basement rocks. The primary porosity and permeability of these rocks tend be low and groundwater occurrences are limited to structures such as dykes and fault zones. Thus the predominant aquifers in Zimbabwe tend to be low yielding (Owen and Madari, 2009).

### 5.3.2 Regional and Transboundary Aquifers

Apart from local aquifers, both regional and transboundary aquifers occur within the Limpopo river basin. A transboundary aquifer refers to a body of groundwater that intersects political boundaries. The implication of such a body of water is that there are at least two sets of governance over the single resource. Careful management through an international water management institution such LIMCOM is required in scenarios such as this to prevent exploitation of the resource by one state which in turn would negatively impact the availability of the resource to other states.

In 2008, the United Nations international law commission adopted a set of draft articles pertaining to the law of transboundary aquifers. The articles although not binding have moral authority and encourage states to make appropriate bilateral or regional arrangements for the proper management of their transboundary aquifers (International Groundwater Resource Assessment Centre, (2012)).

According to the SADC hydrogeological map (2010), shown in **Figure 5.17**, two transboundary aquifers have been identified in the Limpopo river basin, the Tuli Karoo Basin and the Ramotswa dolomite basin. The Tuli Karoo Basin is the most extensive of the two and encompasses portions of South Africa, Zimbabwe and Botswana. Although the largest portion of this aquifer occurs within the Zimbabwean portion of the basin, the majority of groundwater exploitation occurs in the South African portion of the basin.

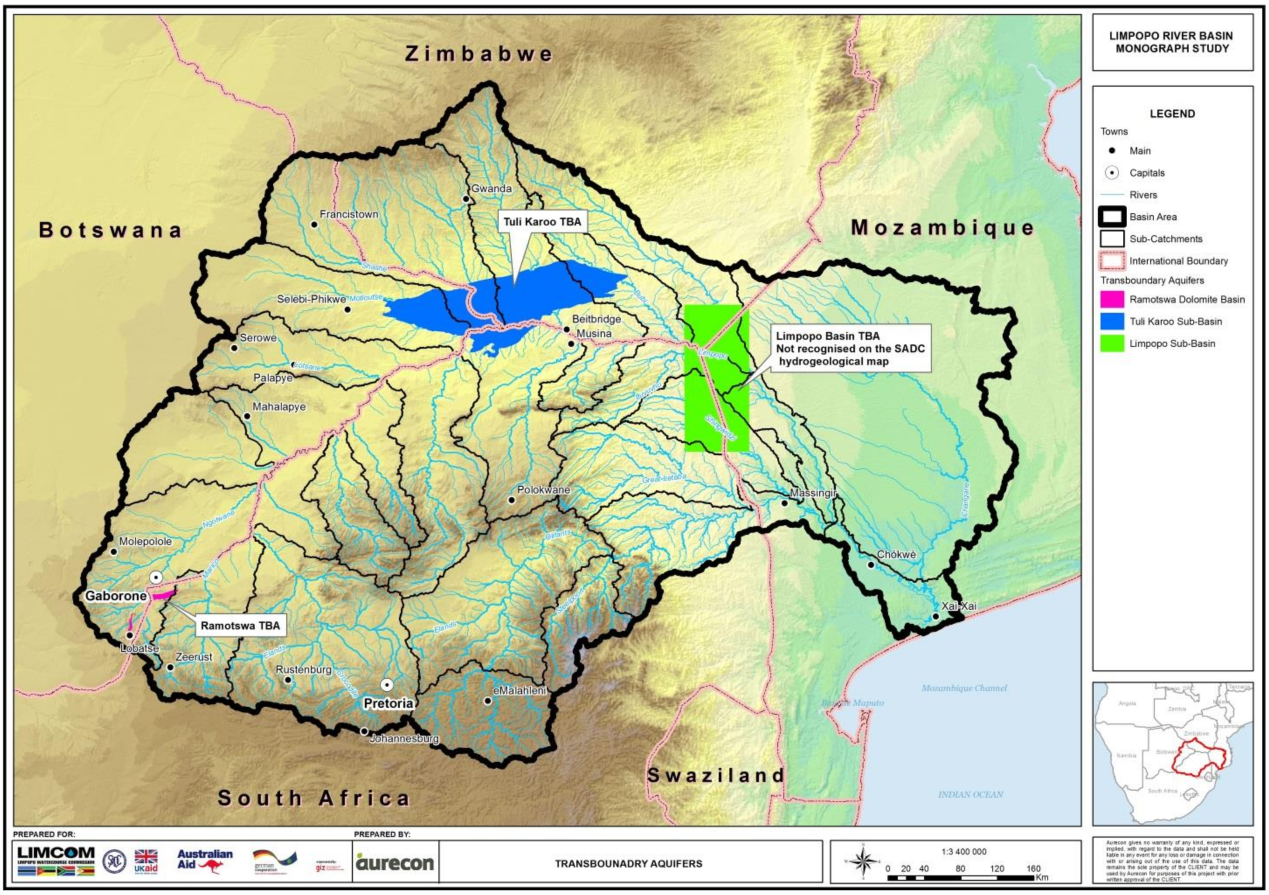



**Figure 5.17:** Transboundary Aquifers

The Ramotswa dolomite basin is a karstic aquifer and is shared between South Africa and Botswana. In comparison to the Tuli Karoo Basin, the Ramotswa dolomite basin has a much smaller surface extent. However in terms of water supply potential, this aquifer is significant. Due to the karstic nature of the dolomites the transmissivity values of the rocks are high and as such borehole yields are generally higher compared with fractured rock aquifers.

Also shown in **Figure 5.17** is the Limpopo Basin Transboundary Aquifer shared between South Africa, Moçambique and Zimbabwe. The aquifer is a fractured secondary aquifer in the sedimentary formations of the Karoo Sequence. This transboundary aquifer is not recognised on the SADC hydrogeological map.

### 5.3.3 Groundwater Recharge

Generally groundwater is a renewable resource, in that it may be utilised sustainably so long as abstraction is balanced by groundwater recharge. Recharge is defined as the downward flow of water reaching the water table and replenishing a groundwater resource. The volume of precipitation on an area essentially governs the potential recharge and hence the available groundwater in storage (DWAF, 2006).

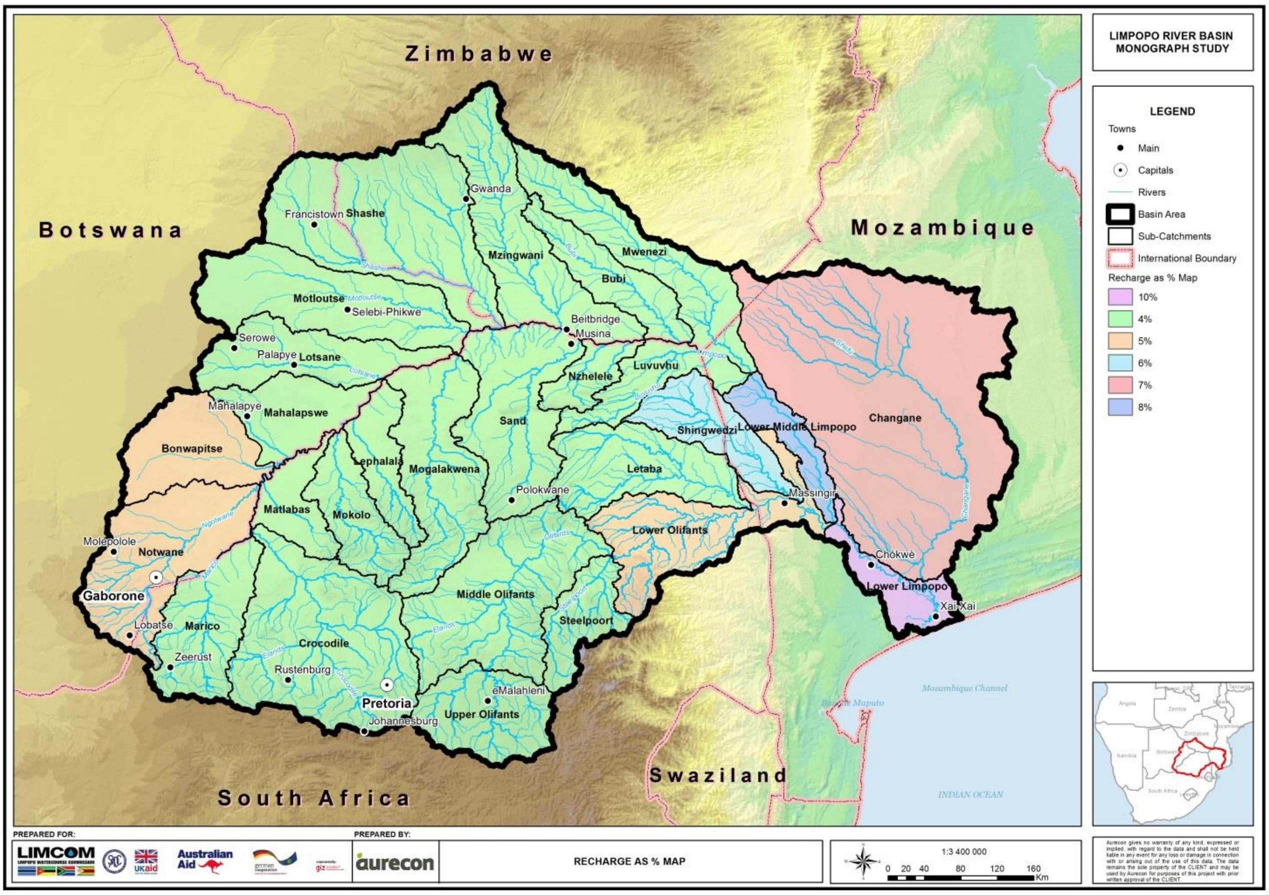



**Figure 5.18:** Recharge potential as % of MAP in the basin

As the volume of recharge on an aquifer is dependent on rainfall, an analysis of 100 rainfall station was conducted. The stations were selected to best represent the spatial extent of the basin. The data sets of each station were evaluated and where data gaps existed, expected values were substituted. The data sets of Moçambique are missing considerable amounts of data and as such the confidence of estimates of mean annual precipitation is low level in these catchments. While the confidence levels of Zimbabwe, Botswana and South Africa are comparatively higher.

Thus based on the data limitations, it was accepted that the supply potential of the basin does not include the groundwater in storage. The recharge potential in the basin is shown in **Figure 5.18.** The values presented in **Table 5.9** thus represent only the volume of water entering the aquifers. These values are thus an indication of the maximum groundwater values available for abstraction without resulting in the drawdown of hydraulic heads.

**Table 5.9:** Recharge volumes per annum under mean annual precipitation and drought conditions

| | Area (km$^2$) | Recharge per catchments calculated from MAP | | Recharge per catchment calculated under drought conditions (Lower 95th percentile) | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| | | million m$^3$/a | m$^3$/d | mm/a | million m$^3$/a | m$^3$/d | mm/a |
| Bonwapitse | 18503 | 425 | 1164390 | 23 | 214 | 586289 | 12 |
| Bubi | 8743 | 158 | 431948 | 18 | 80 | 218359 | 9 |
| Changane | 74412 | 2532 | 6936306 | 34 | Incomplete data | | |
| Crocodile | 30500 | 683 | 1870087 | 22 | 433 | 1185742 | 14 |
| Lephalale | 7036 | 128 | 351262 | 18 | 68 | 187356 | 10 |
| Letaba | 14549 | 423 | 1157844 | 29 | 239 | 653719 | 16 |
| Levuvhu | 6334 | 187 | 512550 | 30 | 116 | 317190 | 18 |
| Lotsane | 13299 | 212 | 582037 | 16 | 103 | 282693 | 8 |
| Lower Limpopo | 6739 | 429 | 1175265 | 64 | Incomplete data | | |
| Lower Olifants | 16486 | 485 | 1328531 | 29 | Incomplete data | | |
| Lower-Middle Limpopo | 13469 | 497 | 1362025 | 37 | Incomplete data | | |
| Mahalapswe | 9355 | 156 | 427063 | 17 | 76 | 208813 | 8 |
| Marico | 12430 | 256 | 702575 | 21 | 143 | 392253 | 12 |
| Matlabas | 6251 | 124 | 339669 | 20 | 70 | 192449 | 11 |
| Middle Olifants | 24587 | 549 | 1504846 | 22 | 324 | 888949 | 13 |
| Mogalakwena | 18177 | 326 | 891822 | 18 | 177 | 484935 | 10 |
| Mokolo | 8753 | 180 | 492155 | 21 | 101 | 277944 | 12 |
| Motloutse | 21091 | 331 | 905839 | 16 | 162 | 442716 | 8 |
| Mwenezi | 14121 | 263 | 721604 | 19 | 167 | 456369 | 12 |
| Mzingwani | 21412 | 367 | 1005102 | 17 | 169 | 463412 | 8 |
| Notwane | 21603 | 519 | 1421106 | 24 | 257 | 704075 | 12 |
| Nzhelele | 4465 | 117 | 319870 | 26 | 55 | 150102 | 12 |
| Sand | 18759 | 332 | 909949 | 18 | 181 | 495252 | 10 |
| Shashe | 30568 | 566 | 1549884 | 19 | 295 | 807836 | 10 |
| Shingwedzi | 10142 | 341 | 933212 | 34 | Incomplete data | | |
| Steelpoort | 7554 | 179 | 490404 | 24 | 115 | 315867 | 15 |
| Upper Olifants | 12042 | 299 | 820000 | 25 | 196 | 537046 | 16 |
| **Total** | **451 380** | **11 062** | **30 307 343** | | | | |

### 5.3.4 Groundwater Supply Potential

Groundwater supply potential refers to the volume of groundwater that may be abstracted from an aquifer. For sustainable groundwater abstraction withdrawal should not cause an unacceptable decline in the hydraulic head or deterioration in water quality in the aquifer. An understanding of the supply potential of an aquifer is crucial to the successful management of groundwater resources.

The aquifer supply potential is essentially dependent on the coefficient of recharge and rainfall. A catchment scale investigation such as this may have variable rainfall conditions. To account for this variability, a GIS based algorithm was developed to calculate recharge. The data processing methodology is discussed in the specialist report in Technical Annexure Volume C2: Groundwater Assessment and the results for the basin are shown in **Figure 5.19**.

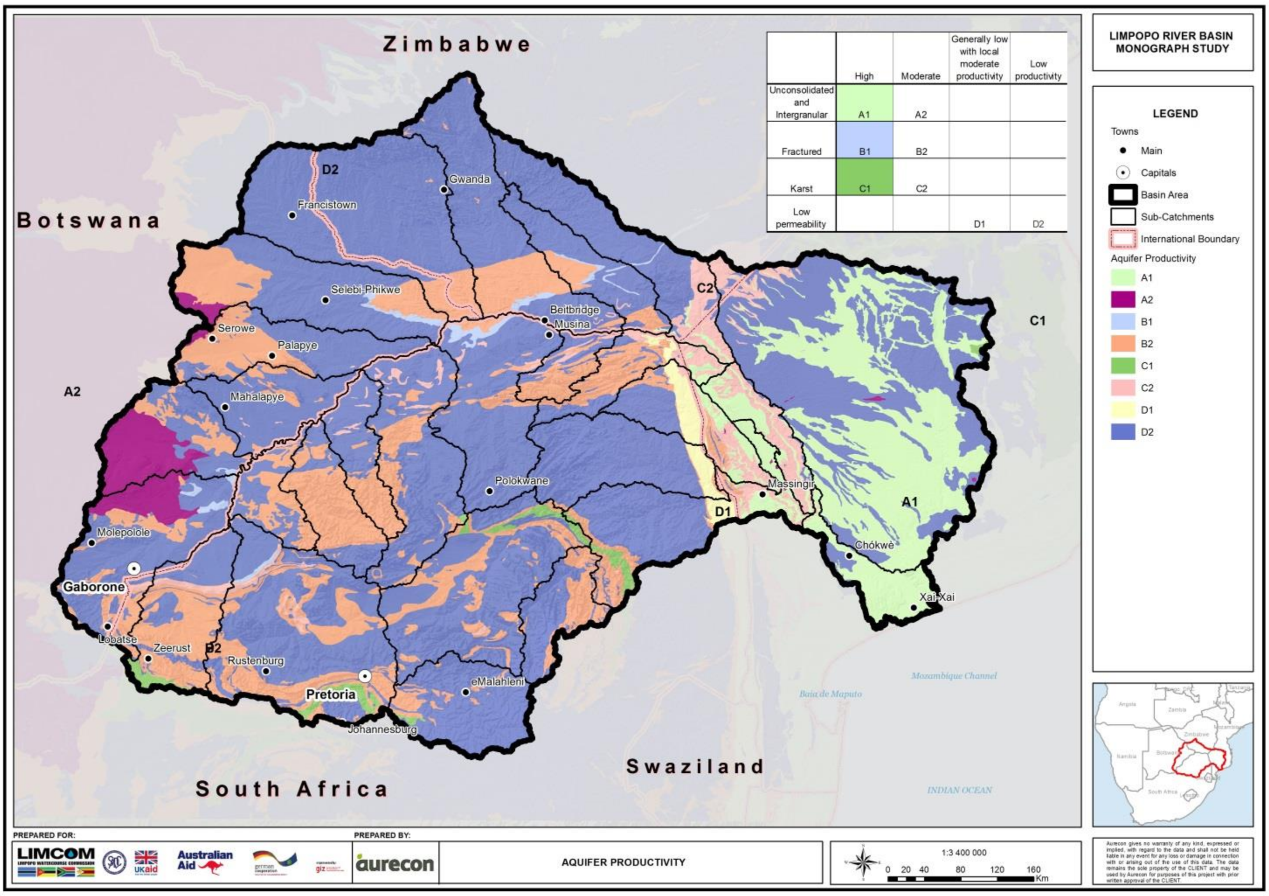



**Figure 5.19:** Groundwater supply potential

Under mean annual rainfall conditions, the sub-catchments with the highest potential yield (above 80th percentile), are the Lower Limpopo, Lower –Middle Limpopo, Changane, Levuvhu and Shingwedzi. These catchments have comparatively higher recharge values and thus potential yields of between 30 and 60 mm/a are expected. These catchments occur within Moçambique and South Africa and along the border of these two countries and are probably good targets for groundwater exploration.

Conversely, the catchments with the lowest potential yields (mm/a) (below 20th percentile) are located along the border of South Africa and Zimbabwe and include Lotsane, Motloutse, Mzingwani, Mahalapswe and the Sand river catchment. Re-charge values within these catchments ranges between 16 and 18 mm/a. These sub-catchments are largely underlain by low permeability geological formations and this area is typically drier than other parts of the basin.

### 5.3.5 Aquifer Productivity

The purpose of evaluating borehole yields within the river basin is to provide an indication of the yields per catchment and the possible supply that is expected from boreholes per catchment. The mean yield per borehole of all sub-catchments of the basin is 3 ℓ/s. The highest average yields are observed in the

Bonwapitse catchment of Botswana (~7 ℓ/s), while the lowest average yields were observed in the Mzingwani catchment in Zimbabwe (~0.9 ℓ/s). The yields of all catchments are generally high when compared with aquifer productivity map prepared by the SADC-HGM (2010).

This variation probably indicates the importance of groundwater supply from high yielding, primary aquifers associated with the alluvial channels within the sub-catchments. In addition, the presence of structures such as faults and dykes are also important in sourcing groundwater in low permeability aquifers such as those that predominates the Limpopo River Basin. Faults and weathered dykes act as conduits that enhance groundwater flow and thus greater groundwater yields can be expected when these features are observed.

The Aquifer Productivity is divided in 4 categories based on the expected yield and importance of supply. Aquifers with high productivity normally are used for regional bulk water supply. Aquifers with moderate productivity are normally for local supply to a village or user. The generally low productivity aquifers are for local use but can supplement other water supply locally. The low productivity is only for local supply but the sustainability cannot be ensured. The aquifer productivity is shown in **Table 5.10** and **Figure 5.19.**

**Table 5.10:** Aquifer productivity classification table, Refer to Figure 5.19

| **Aquifer Category** | **Specific Capacity** (ℓ/s/m) | **Transmissivity** ($m^2$/d) | **Hydraulic Conductivity** | **Very approximate expected yield** (ℓ/s) | **Groundwater productivity** |
|---|---|---|---|---|---|
| A1,B1,C1 | >1 | >75 | >3 | >10 | High: Withdrawals of regional importance |
| A2,B2,C2 | 0.1-1 | 5-75 | 0.2-3 | 1 -10 | Moderate: Withdrawals for local village supply |
| D1 | 0.001-1 | 0.05-5 | 0.002-0.2 | 0.01 -1 | Generally Low: May be utilised for local use |
| D2 | <0.001 | <0.05 | <0.002 | <0.01 | Low: productivity supply for local water supply difficult to ensure |

**Notes:** A = Unconsolidated and intergranular aquifer
B = Fractured aquifer
C = Karst aquifer
D = Low permeability aquifer
The numeric's (i.e A1, A2, B1, etc.) refer to the permeability with a decrease in permeability from 1 to 3

### 5.3.6 Borehole Supply and Groundwater Balance

Groundwater recharge from rainfall and the average ground water abstraction rates of boreholes identified in the sub catchments form the basis for calculating a groundwater balance. A simplistic groundwater balance indicates on the volume of water available in the groundwater resource taking into account current abstraction yields. However, due to the data confidence, the water balance calculation has a degree of uncertainty. Factors resulting in uncertainty associated with the water balance calculation that need further attention are the aquifer testing techniques, recording of yields and duty cycles of boreholes. The other uncertainty is whether the number of boreholes captured within the databases is reflective of the number of active boreholes within the catchment, i.e. have new boreholes been drilled but are not recorded? Or are historic boreholes included that are no longer in use? Field work is required to constrain the uncertainty.

Due to the scale and scope of the present study coefficients of recharge estimations were based upon the SADC hydrogeological map which in turn was based upon the SADC 1:2 500 000 geological map (SADC-HGM., 2011). Thus the scale of evaluation is large and it is possible that small areas with hydrogeological significance were overlooked. The following assumptions are used for evaluating the present groundwater balance:

1. The boreholes included within the borehole database reflect the only boreholes within the catchment. This is very likely untrue and it must be stressed that the margin of error on this assumption is unknown.
2. T he abstraction yields of these boreholes are assumed to be the average of the recorded yields per catchment.
3. The duty cycles were not generally available and thus it is assumed that the yields provided are for 12 hours per day.
4. The aquifer yield must be reduced by a factor of 25% to account for site accessibility and isolation.

Based on the above discussion it is evident that several assumptions are required for evaluating the groundwater balance of the Limpopo river Basin and its sub catchments. It is therefore stressed that the values provided within this sub section be considered only as an indication of the present groundwater status and may deviate from the values provided when additional information becomes available through further field work.

**Table 5.11** presents the simplistic groundwater balance for the Limpopo river basin under present day conditions. The table provides:

1. The number of boreholes identified within the various databases per catchment
2. The average yield per borehole per catchment presented in ℓ/s
3. The estimated total abstraction per catchment based on the number of boreholes and the average yields assuming an 12 hour duty cycle per borehole, presented in $m^3/d$.
4. The total abstraction of groundwater presented in million $m^3/a$.
5. The groundwater resource based on recharge to the aquifer and assuming 50% of the resource is either not associable or isolated presented as million $m^3/a$.
6. The simplistic groundwater balance calculated by subtracting groundwater abstraction from the conservative resource. A positive value denotes a surplus and a negative symbol infers a deficit. The balance is presented in million m3/a.

Taking cognisance of the assumptions made, it seems that the groundwater resources within the catchment are largely underutilised. Exceptions, where over utilisation is occurring, includes the Crocodile, Lephalale, Levuvhu, Marico, Sand, Mogalakwena and the Middle Olifants sub catchments. These catchments show a deficit value which implies that abstraction within these catchments is likely impacting upon the water table and resulting in drawdown. Over abstraction have implications not only on water-users dependent on the resources but also on the riparian habitats dependent on base flow contributions. Based on the finding, it is well worth investigating the development of well fields to augment the surface water supplies in the Limpopo River Basin. Note must be taken of limitations such as accessibility, well field development cost and sustainability.

It is recommended that a more detail study be made of the stressed catchments to confirm which assumptions are acceptable or need updating. Such studies will become more important in future as surface water balance studies in these catchments also indicate deficit future resources and transfer schemes will be required.

**Table 5.11:** An indication of the present day water balance of the sub-catchments of the Limpopo River Basin

| Sub-Catchments | Indication of the present day groundwater status of the Limpopo River Basin | | | | | |
|---|---|---|---|---|---|---|
| | Total No. Boreholes | Ave borehole yield (ℓ/s) | Estimated total abstraction $m^3/d$ (Assuming 12 hour duty cycle) | Total abstraction million $m^3/a$ | Accessible groundwater resource (Assuming 50% unobtainable) | Groundwater Surplus/Deficit (million $m^3/a$) (a negative symbol denotes a deficit) |
| Bonwapitse | 296 | 7.1 | 90 278.90 | 32.95 | 212.50 | 179.55 |
| Bubi | 54 | 1.0 | 2 332.80 | 0.85 | 79.00 | 78.15 |
| Changane | 477 | 1.2 | 25 570.340 | 9.33 | 1 266.00 | 1 256.67 |
| Crocodile | 11 556 | 2.3 | 1 126 243.90 | 411.08 | 341.50 | -69.58 |
| Lephalale | 2 654 | 2.5 | 291 421.90 | 106.37 | 64.00 | -42.37 |
| Letaba | 3 927 | 2.7 | 459 873.80 | 167.85 | 211.50 | 43.65 |
| Levuvhu | 2 495 | 2.7 | 290 109.10 | 105.89 | 93.50 | -12.39 |
| Lotsane | 455 | 5.8 | 113 599.80 | 41.46 | 106.00 | 64.54 |
| Lower Limpopo | 461 | 2.3 | 46 256.00 | 16.88 | 214.50 | 197.62 |
| Lower Olifants | 142 | 1.6 | 10 064.1 | 3.67 | 242.50 | 238.83 |
| Lower-Middle Limpopo | 2 265 | 2.3 | 229 879.40 | 83.91 | 248.50 | 164.59 |
| Mahalapswe | 217 | 5.7 | 53 404.60 | 19.49 | 78.00 | 58.51 |
| Marico | 5 513 | 1.7 | 411 990.60 | 150.38 | 128.00 | -22.38 |
| Matlabas | 1 700 | 2.2 | 158 332.90 | 57.79 | 62.00 | 4.21 |
| Middle Olifants | 9 199 | 4.4 | 1 742 324.70 | 635.95 | 274.50 | -361.45 |
| Mogalakwena | 9 865 | 2.8 | 1 178 396.80 | 430.11 | 163.00 | -267.11 |
| Mokolo | 3 430 | 1.6 | 244 136.80 | 89.11 | 90.00 | 0.89 |
| Motloutse | 280 | 6.2 | 74 739.60 | 27.28 | 165.50 | 138.22 |
| Mwenezi | 594 | 1.4 | 35 178.30 | 12.84 | 131.50 | 118.66 |
| Mzingwani | 615 | 0.9 | 25 161.50 | 9.18 | 183.50 | 174.32 |
| Notwane | 1 783 | 4.9 | 379 800.90 | 138.63 | 259.50 | 120.87 |
| Nzhelele | 1 432 | 2.3 | 144 390.90 | 52.70 | 58.50 | 5.80 |
| Sand | 9 712 | 6.8 | 2 854 625.20 | 1 041.94 | 166.00 | -875.94 |
| Shashe | 675 | 4.4 | 127 232.20 | 46.44 | 283.00 | 236.56 |
| Shingwedzi | 826 | 1.9 | 66 771.70 | 24.37 | 170.50 | 146.13 |
| Steelpoort | 1 827 | 2.0 | 160 275.60 | 58.50 | 89.50 | 31.00 |
| Upper Olifants | 2 580 | 1.4 | 154 725.10 | 56.47 | 149.50 | 93.03 |

### 5.3.7 Groundwater Quality

Groundwater quality describes the chemical and physical parameters of groundwater water. Woodford et al., (Woodford, 2006) on the investigation of the groundwater resources of South Africa found groundwater quality to be one of the main factors restricting the development of available groundwater resources.

These authors indicate that of the problems associated with water quality, high concentration of total dissolved solids, nitrates and fluoride are considered to be the most common and serious problems on a regional scale. SADC-HGM (2010) focus on electrical conductivity (EC (mS/m)), Fluoride (F (mg/ℓ)), Nitrate ($NO_3$ (mg/ℓ)) and Total Dissolved (solids (TDS (mg/ℓ)).

In order to standardise the interpretation of water quality across the basin the World health organisation's (WHO) guidelines for domestic water quality have been adopted and are presented in **Table 5.12.** The guidelines state that fluoride due to the negative health implications of elevated concentrations should not exceed below 1.5 mg/ℓ in domestic water sources. Similarly, nitrate values should not exceed 50 mg/ℓ as $NO_3$- or alternatively <11 mg/l as N. The maximum allowable TDS of 1000 mg/l is not based upon negative health effects but rather the taste implication associated with high TDS values. EC (mS/m) can be approximated by dividing TDS (mg/ℓ) by 6.6 and vice versa TDS may be determined from EC by multiplying the conductivity by a factor of 6.6 ( TDS (mg/l) = Conductivity mS/m x 6.6).

**Table 5.12:** World Health Organisation (2008) Water Quality Guidelines

| **WHO water quality guidelines (WHO, 2008)** | | |
|---|---|---|
| Determinant | Unit | Maximum Limit |
| Fluoride | mg/ℓ | <1.5 |
| Nitrate (as NO3) | mg/ℓ | <50 |
| TDS | mg/ℓ | <1000 |

**Electrical Conductivity**

Electrical conductivity (EC) is the measure of waters ability to conduct an electrical current. EC (mS/m) can be approximated by dividing TDS (mg/ℓ) by 6.6 and vice versa TDS may be determined from EC by multiplying the conductivity by a factor of 6.6 ( TDS (mg/l) = Conductivity mS/m x 6.6).

Typically the higher the electrical conductivity the higher the salinity, The EC values gives an indication of the impact of the geology as well as human influences on the water resource quality.

Nevertheless, the results of the interpolation indicate that the water quality in terms of EC across the South African portion of the basin is generally within the WHO water quality parameters as shown in **Figure 5.20.** Botswana however shows various zones of poor water quality. The occurrences of these zones seem unrelated to the geology and perhaps are a result of human impact. The large zone of poor water quality across Moçambique has been attributed to the depositional history of the area (CSIR, 2003). As there were very few data points within the Zimbabwe portion of the basin, it is uncertain whether the interpolated EC values in this region are valid.

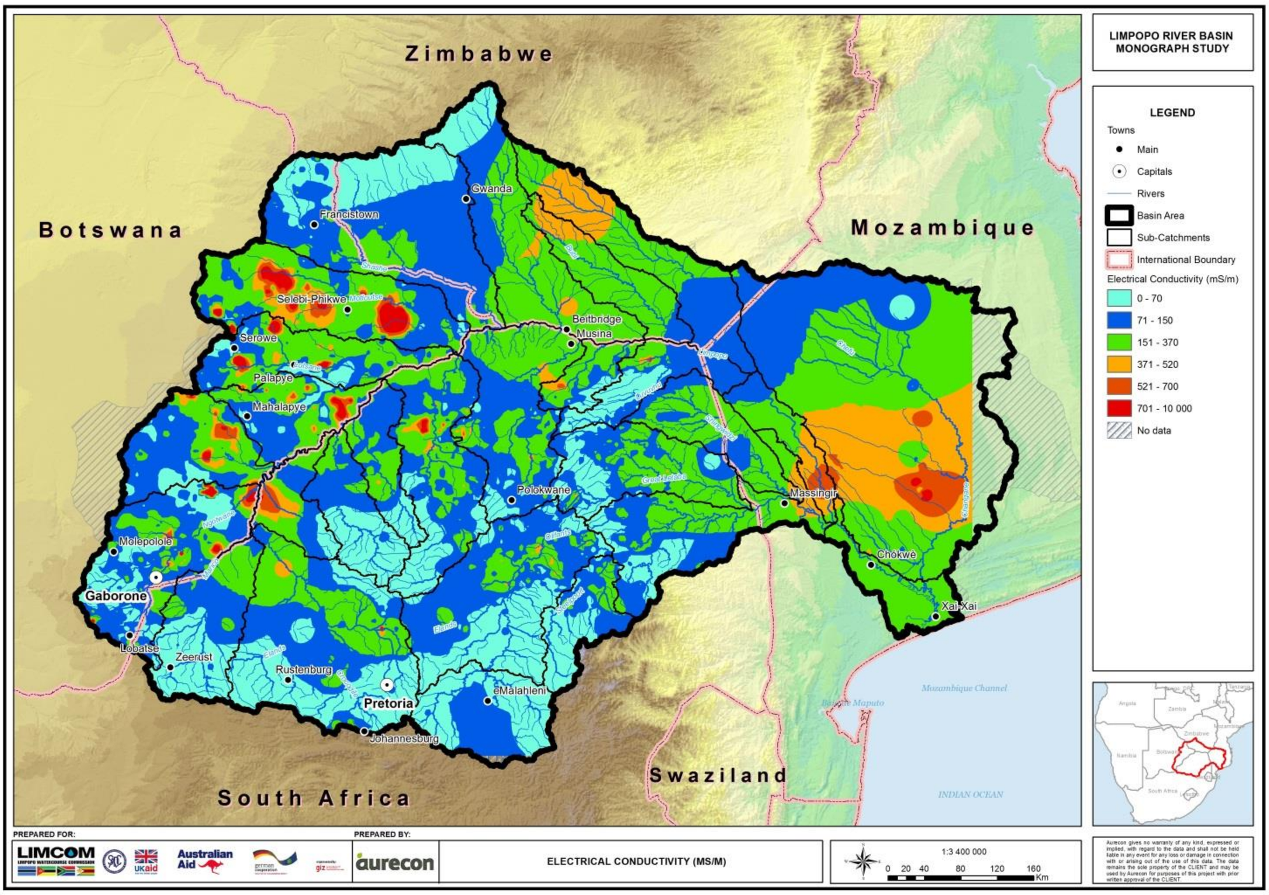



**Figure 5.20:** Electrical Conductivity of Groundwater in the Limpopo River Basin

**Fluoride**

Fluoride is a natural source of pollution and according to the WHO guidelines fluoride is one of very few chemicals that have been shown to cause significant effects to human health through its intake in water. 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 (Fawell et al., 2006).

Occurrences of elevated fluoride are present throughout the basin as shown in **Figure 5.21.** A large zone of high fluoride groundwater correlates with the position of the Bushveld igneous complex and Pilansberg complex, within the Crocodile and Middle Olifants catchments. It is well documented that groundwater associated with these complexes show high fluoride concentrations. The fluoride concentration map indicates that all five catchments within the Botswana portion of the basin show regions of impaired groundwater quality due to elevated fluoride. These occurrences are most likely due to the dissolution of fluoride bearing mineral within the granites of this area. In Moçambique high fluorides are reported by DNA (1987) in the Karoo formations.

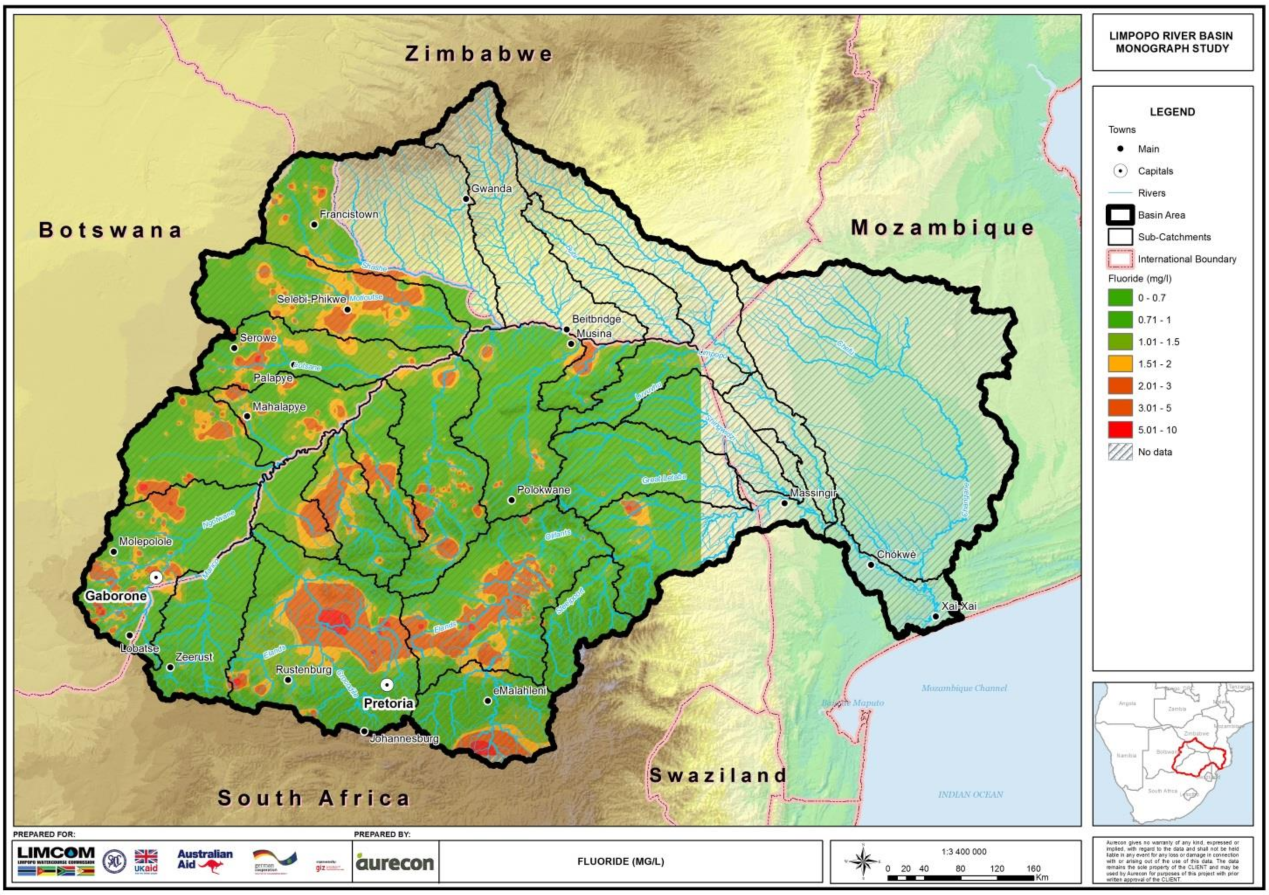



**Figure 5.21:** Concentrations of Fluoride in Groundwater in the Limpopo River Basin

**Nitrate**

Nitrate is a naturally occurring ion that forms part of the nitrogen cycle. The nitrate ion ($NO_3^-$) is the stable form of combined nitrogen for oxygenated systems. Although chemically unreactive, it can be reduced to nitrite which in turn may form other nitrogen compounds on reduction (WHO,2007).

The presence of nitrates in drinking water is typically associated with pollution from:

- Agricultural activities. This may include the excess application of inorganic nitrogenous fertilisers and manures
- Occurrence of pit latrines within settlements
- Waste water treatment
- Mine water polluted from the use of ammonium nitrate as explosive source.
- Oxidation of nitrogenous waste products in both human and animal excreta (pit latrines.)

In addition to the anthropogenic sources mentioned above, natural leaching of nitrate into groundwater may occur. Some factors influencing the natural leaching potential may include rainfall quantity and distribution, the depth to groundwater, the type and distribution of vegetation and the presence of nitrogen fixing vegetation (Tredoux et al., 2009).

Negative health implication related to the intake of excessive nitrates in drinking water most typically effects infants. In infants excess nitrates can cause Methemoglobinemia, a form of blue baby syndrome. Nitrates, on entering the body, reduce to nitrite and causes decreased oxygen carrying capacity of haemoglobin. The result is a lack of oxygen being transported through the body which ultimately can result in asphyxia (WHO, 2007).

There are local occurrences of high nitrate, poor groundwater quality, in all catchments occurring with the both South African and Botswana portions of the basin as shown in **Figure 5.22**. The northern, catchments of South Africa, tend to show poorer groundwater quality in terms of nitrate concentrations than those in the south. The catchments within Botswana typically show better water quality than those of South Africa, with a greater abundance of groundwater indicating nitrate concentrations of less than 20mg/l.

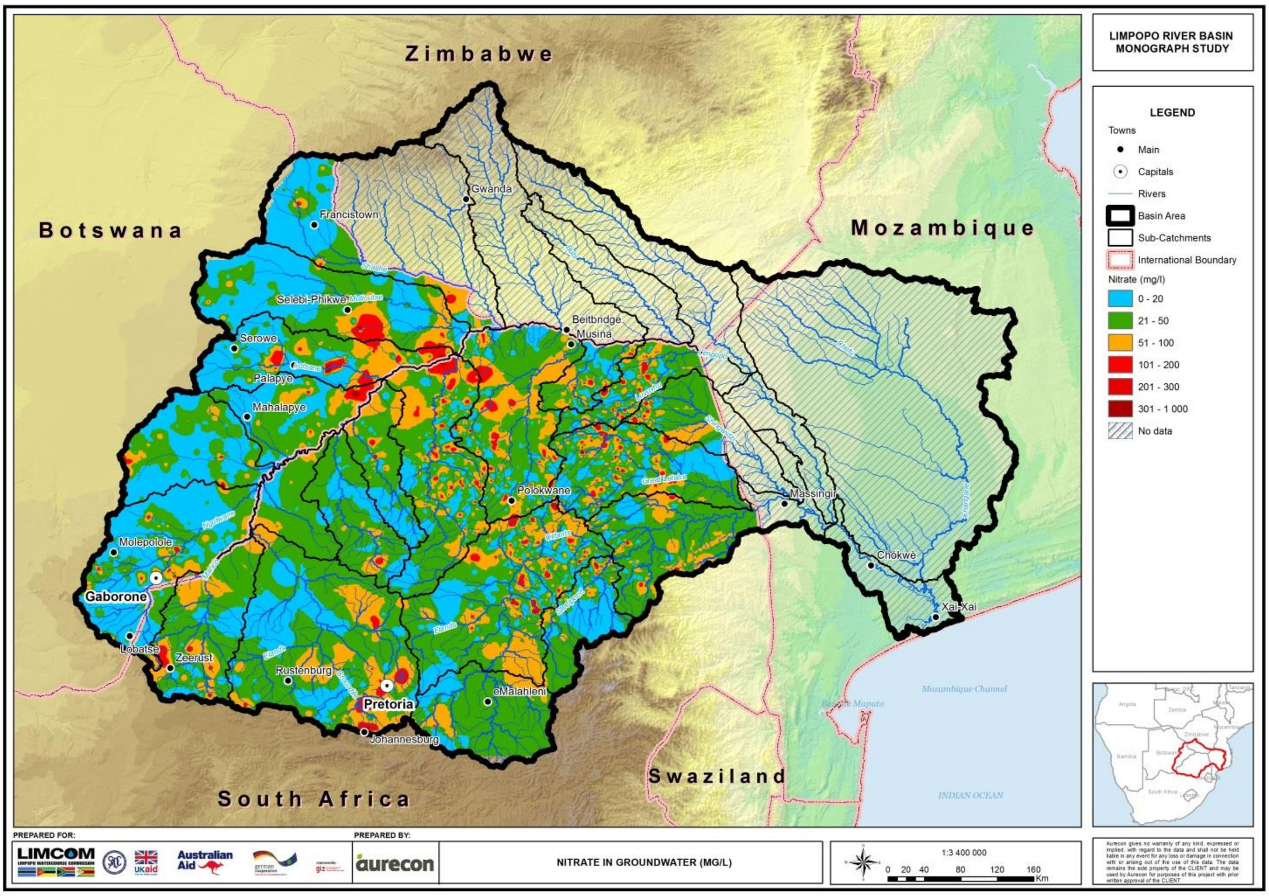



**Figure 5.22:** Nitrate Concentrations in Groundwater in the Limpopo River Basin

### 5.3.8 Ground Water Vulnerability

Groundwater vulnerability refers to the possibility of an aquifer system becoming compromised due to anthropogenic activities. Two predominant activities that negatively impact a groundwater resource are pollution and over-exploitation. Pollution typically initiates on land surface and through rainfall events contaminants may percolate through the soil zones and enter the saturated zone, compromising the groundwater resource below. Potential pollution sources within the Limpopo River Basin include agricultural activities, pit latrines in settlements, mining and to a lesser extent industry.

The use of fertilisers and manures particularly in the South African portion of the basin is extensive and as such the aquifers underlying the agricultural land are susceptible to nitrate contaminations. As discussed in previous sections, the health implications associated with the consuming high nitrate groundwater may be dire, particularly in infants.

Apart from agricultural impacts, mining is predominant in Southern Africa. According to Ashton (2001), there are an estimated 1800 mines in the basin of which approximately 318 are large scale mines that are currently or were previously active within the basin. The impact of mining on groundwater resources is extensive both in terms of groundwater contamination and aquifer exploitation. One of the major concerns in terms of groundwater contamination associated with mining is the generation of acid mine drainage (AMD). This is particularly prevalent in the South African portion of the basin where gold, platinum and coal mining has an extensive history.

Over exploitation is common in karst aquifer areas where high yielding boreholes are used for irrigation. An important karst aquifer within the basin is the Chuniespoort dolomites occurring in the Highveld of South Africa. Over exploitation is a result of poor aquifer management, whereby boreholes are pumped above their sustainable yield. Over exploitation results in severe drawdowns of the water table as abstraction is not balanced by recharge. The result of poor management in these settings is a decline in availability and quality of groundwater for other users.

### 5.3.9 Recommendations for further work

The following recommendations are made:

- Projects similar to the Groundwater Resources Information Project (GRIP) done on the South African part of the Limpopo Basin should be implemented in Botswana, Zimbabwe and Moçambique to increase the data sets in these countries for future evaluations.
- Once GRIP project information is done Groundwater Reserve Determination Studies done in South Africa to determine the available groundwater resources per catchment, can be implemented. The GRD establish the recharge per catchment and after ecological, human needs and base flow has been deducted the available groundwater resources is established.
- Sanitation involving pit latrines for village require that boreholes for groundwater supply must be located outside the urban and developed areas and protected by a protection zone to keep animals and pollution sources outside the zone.
- In areas where the groundwater is high in salinity or high in fluoride concentrations, conjunctive use with surface water must be considered to reduce the levels to acceptable standard, i.e. levels which won't pose a health threat.
- Artificial recharge must be considered in areas where suitable aquifers for recharge exist. This includes artificial recharge such as done in Botswana by building weirs to contain groundwater in a sandy aquifer.

## 5.4 WATER REQUIREMENTS

### 5.4.1 Introduction

This section deals with the water requirements of the Limpopo River Basin. Water use sectors covered are domestic, industry, mining, irrigation, forestry, livestock and power generation.

In the following paragraphs the methodology for calculation of the current water requirements for each sector listed above is described and the related water requirements are then provided. Projected water requirement estimates are only provided for the domestic water use sector and for known future developments for other sectors.

### 5.4.2 Methodology

#### 5.4.2.1 *Domestic*

The water requirements for each sub-basin were determined by the following three basic steps:

**Step 1:** In order to use the same raw data throughout this monograph, domestic water requirement calculations were based on the sub-basin and country level population data as presented in Chapter 3 on Socio-Economics.

**Step 2:** For each country the baseline year for population data was different. Based on these baseline years the annual population growth rate was used as in Chapter 3 on Socio-Economics to estimate the population in 2012 which was adopted as the base year for the Monograph.

**Step 3:** To calculate the respective water demand the population per sub-basin was split into urban and rural. Respectively the national world average unit consumption is 180 ℓ/c/d and the South African national average is 240 ℓ/c/d. Basic human needs have been legislated in South Africa as 25 ℓ/c/d, but most rural communities use in the order of 60 ℓ/c/d. Since 89% of domestic water in the Limpopo River basin is used in South Africa, the South African levels of service were adopted for the whole basin.

Levels of service of 60 ℓ/c/d and 240 ℓ/c/d were then applied for rural and urban population.

The urban/rural population split was only available on a fairly accurate level for South Africa and Botswana. For Moçambique and Zimbabwe a population split of 85% for rural and 15% for urban was assumed.

#### 5.4.2.2 *Industry*

Industrial water demand is based on water use licences for which information was received from the different departments/ministries. It does not include water used by industries which is supplied through the urban reticulation.

Only the current water use was obtained. Future water requirement projections were difficult to estimate as limited knowledge exist of new industries that are being established. In the next phase when an IWRM planning study will be undertaken, growth scenarios for industrial developments have to be developed.

An industry that was planned at some stage was the Sasol Mafutha Project in the Mokolo Sub-basin in South Africa which would require 37 million $m^3/a$. The planning however stopped and it is uncertain whether this industrial project will go ahead. Industrial development normally follows agricultural development and mining development and these types of development are applicable in all four countries in the Limpopo River Basin.

#### 5.4.2.3 *Mining*

The mining water demand in Botswana and Zimbabwe is based on the water use record of mines in these two countries. If water use information was available for more than one year, the year with the highest value was chosen.

There was no evidence of major mining activities in the Moçambique part of the Limpopo basin.

For South Africa the mining water demand is based on the water use licences.

#### 5.4.2.4 *Irrigation*

Different methodologies for determining irrigation water demand were followed for South Africa than for the other three countries. In South Africa water reconciliation strategies were recently completed for two water management areas, i.e. the Crocodile/Marico and the Olifants WMAs which include the delineated Marico, Crocodile, upper Olifants, Middel Olifants, Lower Olifants and Steelpoort Sub-basins.

The water requirement figures from the reports of the two water reconciliation strategies were used. For the other sub-basins in South Africa, the irrigated areas were obtained from current studies by DWA that have not as yet been completed such as the Levhuvhu Letaba Reconciliation Strategy Study and Validation and Verification exercises.

Information from the South African Department of Agriculture was also used. Since most of the irrigation is being managed by formal irrigation schemes with fixed annual quotas, the average water quota per hectare for each sub-basin was used to convert the irrigated areas into a water requirement.

For Botswana, Moçambique and Zimbabse satellite imagery (LANDSAT 7 imagery) was obtained from the United States Geological Survey (USGS). Imagery from 2006 to date for the months of June to September was used as they coincided with the dry season so that only the irrigation and not the rainfed dry land agriculture could be digitised. The irrigated areas in each Sub-basin were obtained by using special digitising techniques. This methodology has its limitations and the results must be regarded as indicative. Attention must be given to the recommendations in Technical Annexure Volume C3 for future improvement of the data.

The water requirements in each sub-basin were then determined by calculating the evapotranspiration for each sub-basin’s crop mix and subtracting the effective rainfall.

The information on irrigation areas and estimates for water requirements can be improved by confirmation of the on-field irrigation method, the crop mix and the conveyance efficiencies. Estimates provided should thus be regarded as lower bound estimates.

#### 5.4.2.5 *Forestry*

Commercial forestry is only practised in South Africa. These forests are not irrigated but depend solely on rainfall. The forests are normally planted in the upper reaches of a catchment where the rainfall is relatively higher and the water taken up by the trees reduce the streamflow of the rivers downstream of the plantations. The water requirements of the forest trees which are alien to South Africa are higher than the indigenous vegetation which was replaced by the forestry plantations. Forestry, which reduces the flow of streams, has in South Africa, been declared as a Streamflow Reduction Activity. The water requirement vary per quaternary catchment and per specie of tree and an improved methodology to determine such demands has been released by the South African Water Research Commission, (WRC 2002). This methodology was used to determine the water use of the forests in the LRB.

#### 5.4.2.6 *Livestock*

The livestock water demand comprises the water demand of grazing animals (cattle, sheep/goats, horses, donkeys, grazing game) and was calculated as follows:

**Step 1:** Calculate grazing area per sub-basin.

The area per sub-basin available for grazing by livestock and game is calculated by using the total catchment area, subtracting urban areas, cultivated land (irrigation, dryland) and other non-available land like roads, mining etc.

**Step 2:** Estimate "Grazing norm"

The grazing norm is the area estimated in hectares per "Animal Unit – AU" that is necessary to maintain one AU per annum. This figure changes per sub-basin as rivers tend to run through different climatic areas.

**Step 3:** Estimate number of Animal Units

Estimate number of Animal Units by dividing the grazing area per sub-basin with the estimated "grazing norm".

**Step 4:** Estimate daily water consumption

The daily consumption depends on:

- Daily maximum temperature
- Climate
- Daily walking distances
- Dairy cows and animals in feedlots on high energy feeding programs consume more water than free grazing animals.

**Step 5:** Calculate annual water consumption

Multiply Animal Units with the daily water consumption and with 365 days.

#### 5.4.2.7 *Power generation*

A questionnaire with a set of data which was needed was sent to country representatives and to the identified contact persons in the following institutions.

- South Africa: National Energy Regulator of South Africa (NERSA) and Eskom
- Moçambique: Ministry of Energy, Department of Energy
  National Directorate of Industry and the National Directorates of Geology, Mines and Water
- Botswana: Water Utilities Corporation, Department of Energy Affairs
  Ministry of Minerals, Energy and Water Resources
  Section of Water Rights in the Department of Water Affairs
- Zimbabwe: The relevant department/ministry dealing with energy.

### 5.4.3 Results

The water requirements for each water use sector are presented in this section. All the water requirements are expressed in million $m^3/a$.

#### 5.4.3.1 *Domestic*

The domestic water requirements for the 2012 base year are shown in **Table 5.13**.

**Table 5.13:** 2012 Domestic Water Requirements in the Limpopo River Basin

| | **Urban water requirements** million m$^3$/a | **Rural water requirements** million m$^3$/a | **Total water requirements** million m$^3$/a |
|---|---|---|---|
| Botswana | 36 | 17 | 53 |
| Moçambique | 13 | 19 | 32 |
| South Africa | 759 | 142 | 901 |
| Zimbabwe | 71* | 15 | 86 |
| **Total Domestic** | **879** | **193** | **1 072** |

**11 million m$^3$/a within the basin and 60 million m$^3$/a as a water transfer out of the basin to Bulawayo*

It can be seen in **Figure 5.23** that the largest water requirement (84%) for domestic purposes is in South Africa, which is due to the dense populated metropolitan areas in the upper reaches of the Crocodile (West) and Upper Olifants sub-basins and large towns such as Polokwane, Emalahleni and Middelburg and surrounding densely populated rural areas.

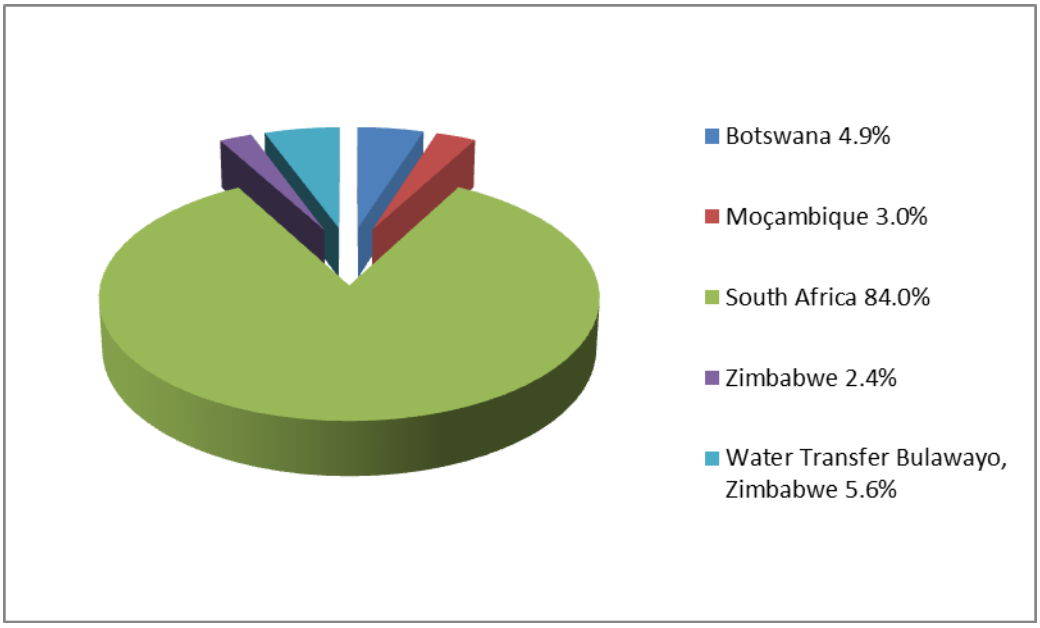



**Figure 5.23:** Percentage of Total Domestic Water Requirements in each country

In **Section 3.2.3**, **Table 3.3**, the Limpopo Basin population projections are shown from the 2012 base year up to 2040 in 5 yearly increments. These growth projections are based on the 2010 United Nations Secretariat World Population Prospects. It is assumed that the domestic water requirements will grow in relation to the population and the projected water requirement projections will be as shown in **Table 5.14.**

**Table 5.14:** Expected Growth in Water Requirements

| Country | Base Year 2012 (million $m^3$/a) | 2015 (million $m^3$/a) | 2020 (million $m^3$/a) | 2025 (million $m^3$/a) | 2030 (million $m^3$/a) | 2035 (million $m^3$/a) | 2040 (million $m^3$/a) |
|---|---|---|---|---|---|---|---|
| Botswana | 53 | 53 | 54 | 54 | 55 | 55 | 55 |
| Moçambique | 32 | 32 | 32 | 33 | 33 | 33 | 33 |
| South Africa | 901 | 921 | 941 | 961 | 980 | 999 | 1 016 |
| Zimbabwe | 86 | 88 | 90 | 91 | 92 | 93 | 94 |
| **Total** | **1 072** | **1 094** | **1 117** | **1 139** | **1 160** | **1 180** | **1 198** |

It is expected that the total water requirements for domestic purposes will grow from 1 072 million $m^3$/a in 2012 to 1 198 million $m^3$/a in 2040, i.e. by 126 million $m^3$/a.

When the scenario analysis is done in the next phase as part of the IWRM Strategy study, it is recommended that the population growth rates of the UN Secretariat are verified.

### 5.4.3.2 *Industry*

**Botswana**

No data was received that show an industrial water demand. For now industrial water demand is assumed to be zero. If data on industrial water requirements can be provided, it will be taken up in the Final version of the Monograph.

**Moçambique**

The only industrial water demand data received was for Xai-Xai. Therefore it was assumed that there is no significant industry in other Limpopo sub-basins in Moçambique. If more information on industrial water requirements can be provided, it will be taken up in the Final version of the Monograph.

Industrial water demand in Moçambique is only 10 000 $m^3$/a.

**South Africa**

South Africa's industrial water uses are based on the country's water use register. It is assumed that the registered volume as in the country's Water Authorisation and Regulation Management System (WARMS), is equivalent to the water demand.

Industrial water demand in South Africa: 327 million $m^3$/a.

**Zimbabwe**

Zimbabwe's industrial water uses are based on the country's water use licences.
Industrial water demand in Zimbabwe: 1.4 million $m^3$/a.

The total is thus 328.4 million $m^3$/a.

### 5.4.3.3 *Mining*

**Botswana**

- Copper/Nickel – 2 mines, Selibe-Phikwe in the Motloutsi sub-basin and Tati Nickel in the Shashe sub-basin.

- Coal – Morupele mine in the Lotsane sub-basin.
- Gold – Mupane mine in the Shashe sub-basin..

The total minig water use for the Botswana mines in the basin is approximately 0.15 million $m^3$/a.

**Moçambique**

According to current investigations heavy metal sand mines in Moçambique are not presently being operated and no indication could be found when they will be in the future. No other mining is recorded in the basin.

**South Africa**

- Platinum: Nine mines in the Crocodile (West) sub-basin
- Coal: 24 mines in Upper Olifants, two mines in Crocodile (West) and one mine in Mokolo Sub-basin
- Diamonds: Two mines in Crocodile (West) and one mine in Sand
- Iron Ore: One Mine in the Crocodile (West) sub-basin

Total mining water use in South Africa is approximately 285 million $m^3$/a.

**Zimbabwe**

There are approximately 17 mines in the Zimbabwean part of the Limpopo River basin. The minerals that are being mined are diamonds, gold and the platinum group metals.

The mines with the largest water demand are the Blanket mine and the HOWmines which are both gold mines.

The total water demand is 5.63 million $m^3$/a.

**Entire Basin**

The total mining water use in the 2012 base year are as per **Table 5.15.** For the four countries in the Limpopo River Basin.

**Table 5.15:** Mining Water Use in the 2012 Base Year

| Country | Water Use 2012 (million $m^3$/a) |
|---|---|
| Botswana | 7.8 |
| Moçambique | 0 |
| South Africa | 285 |
| Zimbabwe | 5.6 |
| **Total** | **298.4** |

***Future Mining***

A number of new mining projects are being planned and the planning is such that they should be implemented within the next five years. These projects are listed in **Table 5.16** showing their water requirements.

**Table 5.16:** Certain Future Mining Projects

| Country | New Mines | Water Requirement (million $m^3$/a) |
|---|---|---|
| Botswana | - | - |
| Moçambique | - | - |
| South Africa | Sekolo Coal mines in Mokolo Sub-basin. | 14.2 |
| | Ithabimetsi Exaro Coal mines in Mokolo Sub-basin. | 6 |
| | Makhado Coal mines in Nzhelele Sub-basin | 1.3 |
| | Sefateng Chrome Mine in Middle Olifants Sub-basin. | 4.1 |
| | Kusile Coal Supply Mines in Upper Olifants Sub-basin. | 14.2 |
| Zimbabwe | - | - |
| **Total** | | **39.8** |

There are also a few possible mining projects which are on the planning horizon but it is still uncertain whether or when these projects will be implemented. They are listed in **Table 5.17.**

**Table 5.17:** Possible Future, but uncertain Mining Projects

| Country | New Mines | Water Requirement (million $m^3$/a) |
|---|---|---|
| Botswana | New mines in Mahalapswe Sub-basin | ±40 |
| Moçambique | Metals from Sand Mining in the Lower Olifants Sub-basin | ±25 |
| South Africa | **Mokolo Sub-basin:**<br>• Resgin Boikara Bela Mines<br>• Anglo American Coal Mines<br>• Sasol Coal Mines | <br>5.8<br>6.0<br>10.0 |
| | **Sand Sub-basin:**<br>Greater Soutpansberg Project Mines | <br>4.1 |
| Zimbabwe | Proposed Platinum Mines<br>Proposed Uranium Mines | ±11<br>Unknown |
| **Total** | | **102** |

### 5.4.3.4 *Irrigation*

***(Refer Technical Annexure Volume C3: Determination of Irrigated Areas and Irrigated Crop Water Requirements in parts of the Limpopo River Basin)***

The irrigated areas and water requirements per sub-basin are provided in **Table 5.18**. Technical Annexure Volume C3 contains a specialist report on the digitising exercise for Botswana, Moçambique and Zimbabwe.

**Table 5.18:** Irrigation and water requirements per sub-basin

| Sub-basin | Irrigated Area (Ha) | Water Requirement |
|---|---|---|
| Notwane | 217 | 2.8 |
| Bonwapitse | 0 | 0 |
| Mahalapswe | 148 | 1.9 |
| Lotsane | 2 | ~0 |
| Motloutse | 140 | 1.8 |
| Shashe | 943 | 10.1 |

| Sub-basin | Irrigated Area (Ha) | Water Requirement |
|---|---|---|
| Mzingwane | 2 221 | 23.7 |
| Bubi | 104 | 1.2 |
| Mwenezi | 2 926 | 62.1 |
| Marico | 9 037 | 48.0 |
| Crocodile (West) | 55 974 | 447 |
| Matlabas | 0 | 0 |
| Mokolo | 15 353 | 95 |
| Lephalale | 7 337 | 45 |
| Mogalakwena | 13 977 | 87 |
| Sand | 17 175 | 124 |
| Nzhelele | 6 513 | 55 |
| Luvuvhu | 22 245 | 187 |
| Upper Olifants | 59 936 | 272 |
| Steelpoort<br>Middle Olifants | 17 891 | 88 |
| Lower Olifants | 23 197 | 169.9 |
| Letaba | 39 900 | 363 |
| Shingwedzi | 0 | 0 |
| Changane | 0 | 0 |
| Lower Limpopo (incl. Massingir Dam) | 12 800 | 266.2 |
| **TOTAL** | **308 036** | **2 351** |

The irrigated areas and water requirements per country are provided in **Table 5.19.**

**Table 5.19:** Irrigated areas and water requirements per country

| Country | Irrigated Area (Ha) | Water Requirement (mill $m^3/a$) |
|---|---|---|
| Botswana | 528 | 7 |
| Moçambique | 13 182 | 274 |
| South Africa | 288 153 | 1 974 |
| Zimbabwe | 6 173 | 96 |
| | **308 036** | **2 351** |

The only known future development in irrigation that has already been initiated is 7 000 ha of sugar cane downstream of Massingir Dam in Moçambique.

#### 5.4.3.5 *Forestry*

The water requirements for the eucalyptus and pine tree plantations are respectively shown in **Table 5.20.**

**Table 5.20:** Water Requirements of Forestry - 2012

| Sub-basin | Ha Eucalyptus | Water Requirements million $m^3/a$ | Ha Pine | Water Requirements million $m^3/a$ | Total Water Requirements |
|---|---|---|---|---|---|
| Luvuvhu | 5 877 | 3.7 | 11 753 | 5.6 | 9.3 |
| Letaba | 38 692 | 44.5 | 17 934 | 13.2 | 57.7 |
| Upper Olifants | 0 | 0.0 | 0 | 0.0 | 0.0 |
| Middle Olifants | 341 | 0.0 | 1 934 | 0.2 | 0.2 |
| Lower Olifants | 15 438 | 9.9 | 3 162 | 1.4 | 11.3 |
| Steelpoort | 1 024 | 0.9 | 5 801 | 3.3 | 4.2 |
| **Total** | **61 372** | **59.1** | **40 584** | **23.5** | **82.7** |

### 5.4.3.6 *Livestock*

The livestock water requirements of the four countries are shown in **Table 5.21.**

**Table 5.21:** Livestock Water Requirements - 2012

| Country | **Water Requirements** (million $m^3/a$) |
|---|---|
| Botswana | 20 |
| Moçambique | 21 |
| South Africa | 45 |
| Zimbabwe | 14 |
| **Total** | **100** |

### 5.4.3.7 *Power Generation*

*Thermal Power Stations:*

A total of 11 thermal electric power stations are operational in the South African portion of the Limpopo River Basin and one, the Morupele power station, in Botswana. Two power stations in South Africa are under construction. The water requirements of the current stations are listed in **Table 5.22**.

**Table 5.22:** Thermal Power Station Water Requirements

| Sub-basin | Number of Thermal Power Stations | Water Requirements million $m^3/a$ |
|---|---|---|
| Mahalapye | 1 | 3 |
| Mokolo | 1 | 7 |
| Crocodile (West) | 3 | 28 |
| Upper Olifants | 7 | 188 |
| **Total** | **12** | **226** |

Two power stations which are under construction, i.e. Kusile in the Upper Olifants and Medupe in the Mokolo Sub-basins will be completed within the next year and when they come into operation they will increase the water requirements by 30 million $m^3$. The water requirements of the new thermal electric power stations are listed in **Table 5.23.**

**Table 5.23:** Water Requirements of the new Thermal Electric Power Stations in South Africa

| Sub-basin | Power Stations | Water Requirements million $m^3/a$ |
|---|---|---|
| Mokolo | Medupi | 15 |
| Upper Olifants | Kusile | 15 |
| **Total** | | **30** |

Thermal electric power stations that are envisaged for the future are listed in **Table 5.24**. It is at this stage not certain if these projects will go ahead, but they can be taken into account for the next phase IWRM planning study.

**Table 5.24:** Thermal Electric Power Stations envisaged for the Future

| Country | Sub-basin | Project | Water Requirements million $m^3/a$ |
|---|---|---|---|
| Botswana | Mahalapye | Morupele | 18 |
| South Africa | Mokolo | Exaro private power station | 3 |
| South Africa | Mokolo | Second Medupi power station | 15 |
| **Total** | | | **18** |

*Hydro-electric Power Stations;*

The water use by hydro-electric power stations is normally non-consumptive in nature and the water can be used again after having passed through the plant. The water requirements of the hydro-electric power stations must therefore be interpreted with caution.

There are currently no significant hydro-electric power plants in the Limpopo River Basin in operation, only a small one for the town of Lydenburg in the Steelpoort Sub-basin. A number of hydro-electric power plants are however planned for the future. They are listed in **Table 5.25.**

**Table 5.25:** Possible future Hydro-electric Power Stations

| Country | Sub-basin | | Generation Capacity MW | Water Requirements million $m^3/a$ |
|---|---|---|---|---|
| Moçambique | Lower Olifants | Massingir Dam | 28 | 2 488 |
| Zimbabwe | Mwenezi | Manyuchi Dam | 5 | Unknown |

### 5.4.4 Summary of Water Requirements

In summary, the water requirements of the Limpopo River basin in the 2012 base year are as set out in **Table 5.26.**

**Table 5.26:** Summary of Water Requirements in the Limpopo River Basin

| Country | Water Requirements (million $m^3/a$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Domes-tic | Indus-trial | Mining | Irriga-tion | Forestry | Live-stock | Thermal Electric Power Generation | Total |
| Botswana | 53 | ~0 | 8 | 7 | - | 20 | 3 | 91 |
| Moçambique | 32 | | | 274 | - | 21 | - | 327 |
| South Africa | 901 | 327 | 285 | 1 974 | 83 | 45 | 223 | 3 838 |
| Zimbabwe | 86* | 1 | 6 | 96 | - | 14 | - | 203 |
| **Total** | **1 072** | **328** | **299** | **2 351** | **83** | **100** | **226** | **4 459** |

** Includes the 60 million $m^3/a$ water transfer out of the basin to Bulawayo*

## 5.5 SURFACE WATER BALANCES

The water balance evaluations in this Study had to be restricted to surface water resources, surface water requirements and environmental water requirements (EWRs) from surface resources, because of a general paucity of data on groundwater utilisation and related yields from existing groundwater infrastructure.

### 5.5.1 General Approach

The surface water balance in each Sub-Basin was calculated by subtracting its total 2010 (regarded as current-day) nett average annual human impacts on the surface water resources from the sum of its total annual surface water yields at 1:5 year assurance (see **Sub-Section 5.2.6** for explanation of the yield modelling). The current-day nett average annual human impacts were derived from the detailed catchment modelling described in **Section 5.2** and in the **Technical Annexure, Volume C1.** These simulated human impacts comprise any or all of the following effects, depending on local circumstances in each Sub-Basin:

- current-day abstractions for irrigation, urban, industrial and energy water requirements;
- nett reservoir evaporation;
- difuse upstream streamflow reductions due to commercial afforestation and alien plant invasions.

Return flows were embedded in the catchment model streamflow outputs.

To be internally consistent, a water balance exercise requires that the assurance level (RI) of the yield and that of the total water requirements be identical. For this Study, it was assumed that an assurance level of 1:5 years would be valid for irrigation requirements and an assurance level of 1:50 years for all other water requirements, bar the water requirements for energy, which were assumed to need an assurance level of 1:200 years. Given that the Sub-Basin yields had been derived for a 1:5 year assurance, a water balance exercise would dictate that the various water requirements for the respective Sub-Basins would need to be scaled to a similar level of assurance of supply by means of a factor larger or equal to 1.0, as the case might be. Average representative scaling factors were determined for the respective Sub-Basins by yield modelling at the various levels of assurance. These average Sub-Basin scaling factors vary between 1.0 and 1.35, depending on each Sub-Basin's mix of water users and flow regimes.

The surface water balances were calculated at the scale of the Sub-Basins, as well as at the much larger scale of eight distinct "Water Balance Regions" – shown in **Figure 5.24**. These Water Balance Regions were conceptualised as individual groups of Sub-Basins that make up logical spatial combinations for a large-scale surface water balance evaluation.

The surface water balances, as well as comparisons of EWRs with current-day streamflows, were examined for the following cases:

i. Per Sub-Basin: Current-day Sub-Basin development levels and water requirements, with no provision made for meeting EWRs.
ii. Per Water Balance Region: Current-Day development levels and water requirements, with no provision made for meeting EWRs.
iii. Per EWR site on the Limpopo main-stem: Comparison of EWRs with current-day streamflows. The locations of the EWR sites are presented in **Figure 4.7**.
iv. Per Water Balance Region: Future development levels and water requirements set at 2040 with no provision made for meeting EWRs.

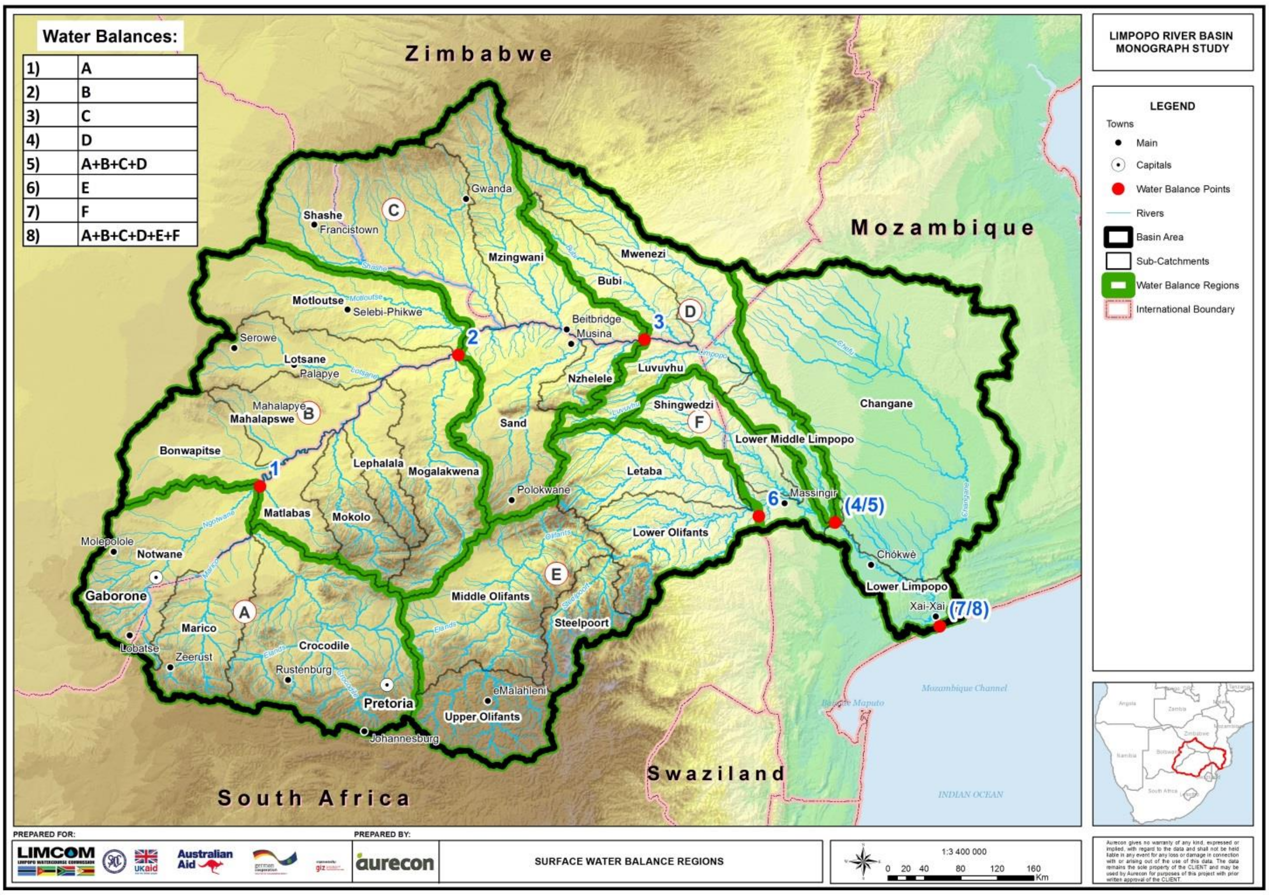



**Figure 5.24:** Surface Water Balance Regions and EWR Sites

### 5.5.2 Current-Day Surface Water Balances: Sub-Basins

**Table 5.27** presents the current-day surface water balances for the Sub-Basins. Sizeable deficits are evident in the Lephalale, Sand, Middle Olifants and Letaba Sub-Basins. Significant surpluses are indicated in the following Sub-Basins: Motloutse, Shashe, Mwenezi, Mokolo, Steelpoort, the Lower Olifants upstream of Massingir Dam and the Lower Limpopo including Massingir Dam. Each of the surpluses is the result of dams of which the yield is not yet fully utilised, namely Letsibogo and Thune Dams (Motloutse), Dikgatlhong Dam (Sashe), Mtshabezi Dam (Tuli), Manyuchi Dam (Mwenezi), Mokolo Dam (Mokolo), De Hoop Dam (Steelpoort), Flag Boshielo Dam (Lower Olifants) and Massingir Dam (Lower Limpopo). It should be noted that provision of EWRs in these Sub-Basins would reduce available yields and, hence, increase existing deficits and decrease existing surpluses.

### 5.5.3 Current-Day Surface Water Balances: Water Balance Regions

**Table 5.28** presents the current-day surface water balances for the Water Balance Regions. It is evident that only Water Balance Region B is currently in notable deficit, whereas Regions further downstream in the Limpopo Basin display sizeable current-day surpluses. It should be noted that provision of EWRs in these Water Balance Regions would reduce available yields and, hence, increase existing deficits and decrease existing surpluses.

### 5.5.4 EWR Comparisons with Current-Day Streamflows

Comparisons of EWRs with current-day streamflows are presented in the form of exceedence percentile curves (also known as flow duration curves) in **Figure 5.28** to **Figure 5.35** for the four EWR sites on the Limpopo River main-stem that is situated on or near to the outflow points of the Water Balance Regions. The comparisons focus on the three generally driest months in winter (July, August and September) and the three generally wettest months in summer (January, February and March) in terms of streamflows. The EWR sites on the main-stem Limpopo included in this evaluation are Spanwerk (just downstream of the Crocodile (West) River), Poachers Corner (just downstream of the Shashe River), Pafuri (at the joint border of Zimbabwe, Moçambique and South Africa) and Chokwe (in the Lower Limpopo). The following observations can be made:

- At all four main-stem EWR sites, current-day winter streamflows are notably lower than winter EWRs across most of the low-flow regime.
- At all four main-stem EWR sites, current-day summer streamflows comfortably exceed summer EWRs over most of the high-flow regime, but tend to be marginally lower than summer EWRs over the low-flow part of the summer flow regime.
- In order to meet the shortfalls of current-day Limpopo main-stem streamflows relative to both winter and summer EWRs, agreements would be required among the four co-basin states about which surface water storages in the various Sub-Basins would need to be employed to maintain each main-stem site's EWRs through customised operating rules.

**Table 5.27:** Surface Water Balances (million $m^3/a$) for Sub-Basins: Current-Day Conditions

| Sub-Basin | Urban Return Flows used in Catchment Modelling | Total Current-Day Nett Surface Water Impacts | Agriculture: Nett Surface Water Impacts at 1:5 Year Assurance | Urban / Industrial: Nett Surface Water Impacts at 1:50 Year Assurance | Urban / Industrial: Nett Surface Water Impacts at 1:5 Year Assurance | Total Current-Day Nett Surface Water Impacts at 1:5 Year Assurance | Cumulative 1:5 Year Yield# | Current-Day Surface Water Balance |
|---|---|---|---|---|---|---|---|---|
| **Notwane** | | 30 | 0 | 30 | 30 | 30 | 38 | 8 |
| **Bonwapitse** | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Mahalapswe** | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Lotsane** | | 13 | 0 | 13 | 18 | 18 | 10 | -8 |
| **Motloutse** | | 26 | 0 | 26 | 35 | 35 | 52 | 17 |
| **Shashe** | | 174 | 71 | 102 | 138 | 209 | 269 | 60 |
| **Mzingwane** | | 178 | 69 | 109 | 109 | 178 | 176 | -2 |
| **Bubi** | | 13 | 13 | 0 | 0 | 13 | 10 | -3 |
| **Mwenezi** | | 80 | 78 | 2 | 3 | 81 | 124 | 43 |
| **Marico** | | 70 | 59 | 11 | 14 | 74 | 68 | -6 |
| **Crocodile (West)** | 288 | 485 | 181 | 304 | 380 | 561 | 565 | 4 |
| **Matlabas** | | 6 | 5 | 2 | 2 | 6 | 2 | -4 |
| **Mokolo** | | 45 | 36 | 9 | 11 | 47 | 80 | 33 |
| **Lephalale** | | 57 | 53 | 4 | 5 | 58 | 21 | -37 |
| **Mogalakwena** | | 71 | 63 | 8 | 11 | 74 | 69 | -5 |
| **Sand** | | 34 | 13 | 21 | 28 | 41 | 10 | -31 |
| **Nzhelele** | | 30 | 26 | 4 | 6 | 32 | 41 | 9 |
| **Luvuvhu** | | 104 | 90 | 14 | 19 | 109 | 115 | 6 |
| **Upper Olifants** | 120 | 434 | 177 | 257 | 321 | 498 | 505 | 7 |
| **Steelpoort** | | 72 | 53 | 19 | 21 | 74 | 159 | 85 |
| **Middle Olifants** | | 167 | 71 | 96 | 120 | 191 | 160 | -31 |
| **Letaba** | | 263 | 227 | 36 | 45 | 272 | 218 | -54 |
| **Lower Olifants: U/s Massingir Dam** | | 192 | 136 | 56 | 70 | 206 | 295 | 89 |
| **Shingwedzi** | | 2 | 0 | 2 | 3 | 3 | 2 | -1 |
| **Lower Middle Limpopo** | | - | - | - | - | - | 0 | 0 |
| **Changane** | | - | - | - | - | - | 0 | 0 |
| **Lower Limpopo: Incl. Massingir Dam** | | 439 | 417 | 22 | 26 | 443 | 566 | 123 |

***Notes**: # Including yields from dams currently under construction or not yet fully operational*
*# Including contributions to yield from urban return flows and irrigation return flows, where relevant*

### 5.5.5 Surface Water Balances for 2040 Conditions: Water Balance Regions

*Rationale*

The following rationale guided the derivation of the future water balances for potential 2040 conditions of surface water developments in the respective Sub-basins that make up the Water Balance Regions.

i. For certain large dams that are currently under construction or not yet fully operational, as well as existing dams that are currently significantly under-utilised, drafts were increased in the Sub-basin modelling to their original design values as reported in related available documents. For certain currently under-utilised dams, reported design draft values were not available. For such dams, the current-day drafts in the Sub-basin modelling process were increased to their approximate 1:50 year assurance values to represent 2040 demands. For Massingir Dam the increase in draft was guided by currently advanced plans for irrigation expansion along the Lower Olifants River downstream of the Dam, as well as along the Lower Limpopo River in the vicinity of Chokwe. The increases in all these dam drafts are presented in **Table 5.30**.

ii. For Sub-basins which would benefit from the above two sets of increases (many through transfers between Sub-basins), it was assumed that these increases in dam drafts would meet all of their internal water requirement increases by 2040.

iii. Urban return flows in the Crocodile (West) and Upper Olifants currently form a significant part of the surface water resources in those Sub-basins. Increases to these return flows included in the modelling were based on projections contained in supporting reports to the respective Reconciliation Studies for those bulk water supply systems. Urban/industrial return flows in the Crocodile (West) were assumed to increase to 490 million $m^3$/a by 2040 and those in the Upper Olifants to 135 million $m^3$/a.

iv. For the Crocodile (West) Sub-basin it was assumed that these return flow increases by 2040 would meet all water requirement increases downstream of the metropolitan areas, given that the return flow increases would primarily be the end-products of imported treated water from the Vaal River System to meet rapidly increasing metropolitan domestic/industrial demands in the Crocodile (West).

v. For Sub-Basins which would not benefit from any of the above increases in dam drafts or return flows by 2040, it was assumed that the co-basin country percentage increases in water requirements by 2040, stated in **Table 5.14,** would apply. In these cases, no attempt was made to augment storages/transfer capacities to cover apparent deficits.

*Water Balances*

**Table 5.29** presents the water balances for the Water Balance Regions for potential 2040 conditions of surface water developments in the respective Sub-Basins that make up the Regions. In the absence of new storage schemes additional to those currently being implemented / more fully utilised, the majority of the Water Balance Regions could be expected be in deficit by 2040. It is emphasised that provision of EWRs in these Water Balance Regions would further increase the deficits and reduce available yields and probably turn them into deficits.

**Table 5.28:** Surface Water Balances (million $m^3/a$) for Water Balance Regions: Current-Day Conditions

| Water Balance Region | Total Current-Day Nett Surface Water Impacts | Agriculture: Nett Surface Water Impacts at 1:5 Year Assurance | Urban / Industrial: Nett Surface Water Impacts at 1:50 Year Assurance | Urban / Industrial: Nett Surface Water Impacts at 1:5 Year Assurance | Total Current-Day Nett Surface Water Impacts at 1:5 Year Assurance | Cumulative 1:5 Year Yield# | Current-Day Surface Water Balance |
|---|---|---|---|---|---|---|---|
| ***Region A*** | 603 | 258 | 345 | 424 | 683 | 681 | -2 |
| ***Region B*** | 281 | 219 | 62 | 82 | 301 | 257 | -44 |
| ***Region C*** | 457 | 220 | 237 | 282 | 502 | 496 | -6 |
| ***Region D*** | 197 | 182 | 16 | 21 | 202 | 249 | 47 |
| ***Region A+B+C+D*** | 1 538 | 879 | 659 | 808 | 1 688 | 1 683 | -5 |
| ***Region E*** | 1 128 | 664 | 464 | 577 | 1 241 | 1 337 | 96 |
| ***Region F*** | 443 | 419 | 24 | 29 | 448 | 568 | 120 |
| ***Region A+B+C+ D+E+F*** | 3 109 | 1 962 | 1 147 | 1 415 | 3 378 | 3 588 | 210 |

***Notes**: # Including yields from dams currently under construction or not yet fully operational*
*# Including contributions to yield from urban return flows and irrigation return flows, where relevant*

**Table 5.29:** Surface Water Balances (million $m^3/a$) for Water Balance Regions: 2040 Conditions

| Water Balance Region | Agriculture: Nett Surface Water Impacts at 1:5 Year Assurance | Urban / Industrial: Nett Surface Water Impacts at 1:50 Year Assurance | Total 2040 Nett Surface Water Impacts at 1:5 Year Assurance | Cumulative 1:5 Year Yield | 2040 Surface Water Balance |
|---|---|---|---|---|---|
| ***Region A*** | 326 | 583 | 909 | 883 | -26 |
| ***Region B*** | 197 | 125 | 322 | 257 | -65 |
| ***Region C*** | 188 | 339 | 527 | 496 | -31 |
| ***Region D*** | 217 | 24 | 241 | 249 | 8 |
| ***Region A+B+C+D*** | 927 | 1 072 | 2 000 | 1 885 | -115 |
| ***Region E*** | 692 | 720 | 1 412 | 1 352 | -60 |
| ***Region F*** | 451 | 32 | 483 | 568 | 85 |
| ***Region A+B+C+ D+E+F*** | 2 071 | 1 824 | 3 895 | 3 805 | -90 |

***Notes**: # Excluding yields from proposed dams that have not progressed to feasibility study stage*
*# Including contributions to yield from urban return flows and irrigation return flows, where relevant*

**Table 5.30:** Increased Drafts Imposed on Currently Under-/Unutilised Dams to Represent 2040 Development Conditions

| Dam | Sub-Basin | Current Draft (Million $m^3$) | Future Draft (Million $m^3$) | Increase (Million $m^3$) |
|---|---|---|---|---|
| Mokolo | Mokolo | 22 | 60 | 38 |
| Letsibogo | Mouloutse | 7 | 25 | 18 |
| Thune | Moutloutse | 0 | 5 | 5 |
| Ntimbale | Shashe | 2 | 6 | 4 |
| Shashe | Shashe | 14 | 25 | 11 |
| Dikgatlhong | Shashe | 10 | 77 | 67 |
| Mtshabezi | Shashe (Tuli) | 8 | 17 | 9 |
| Zhove | Mzingwane | 23 | 34 | 11 |
| Manyuchi | Mwenezi | 30 | 78 | 48 |
| De Hoop | Steelpoort | 0 | 70 | 70 |
| Flag Boshielo | Middle Olifants | 3 | 37 | 34 |
| Massingir | Lower Olifants | 164 | 221 | 57 |

The water balance per sub-basin for the current day water requirement is presented visually in **Figure 5.25.**

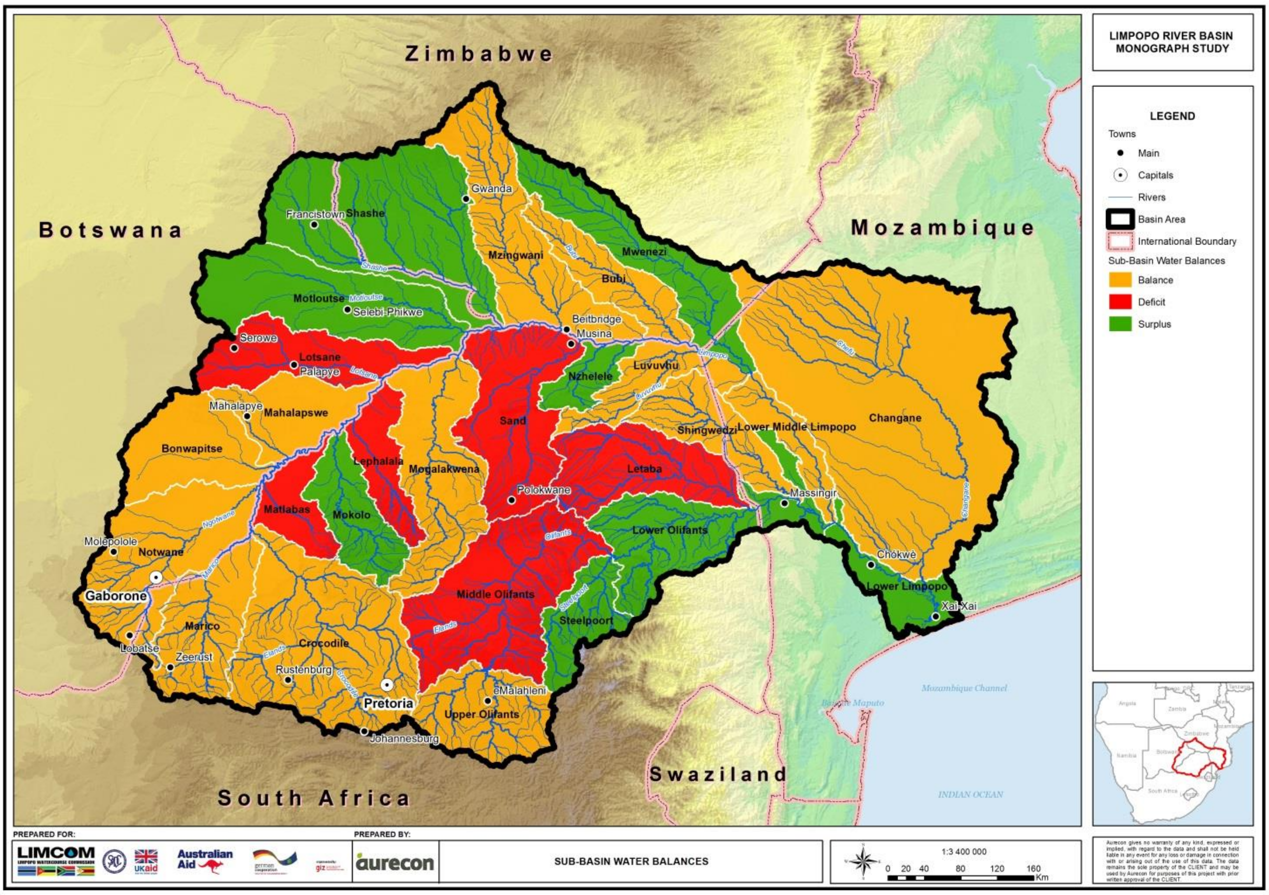



**Figure 5.25:** Water balance per sub-basin – no EWR

The Regional Water Balance for the current day and for 2040 is compared with each other in **Figure 5.26** and **Figure 5.27.**

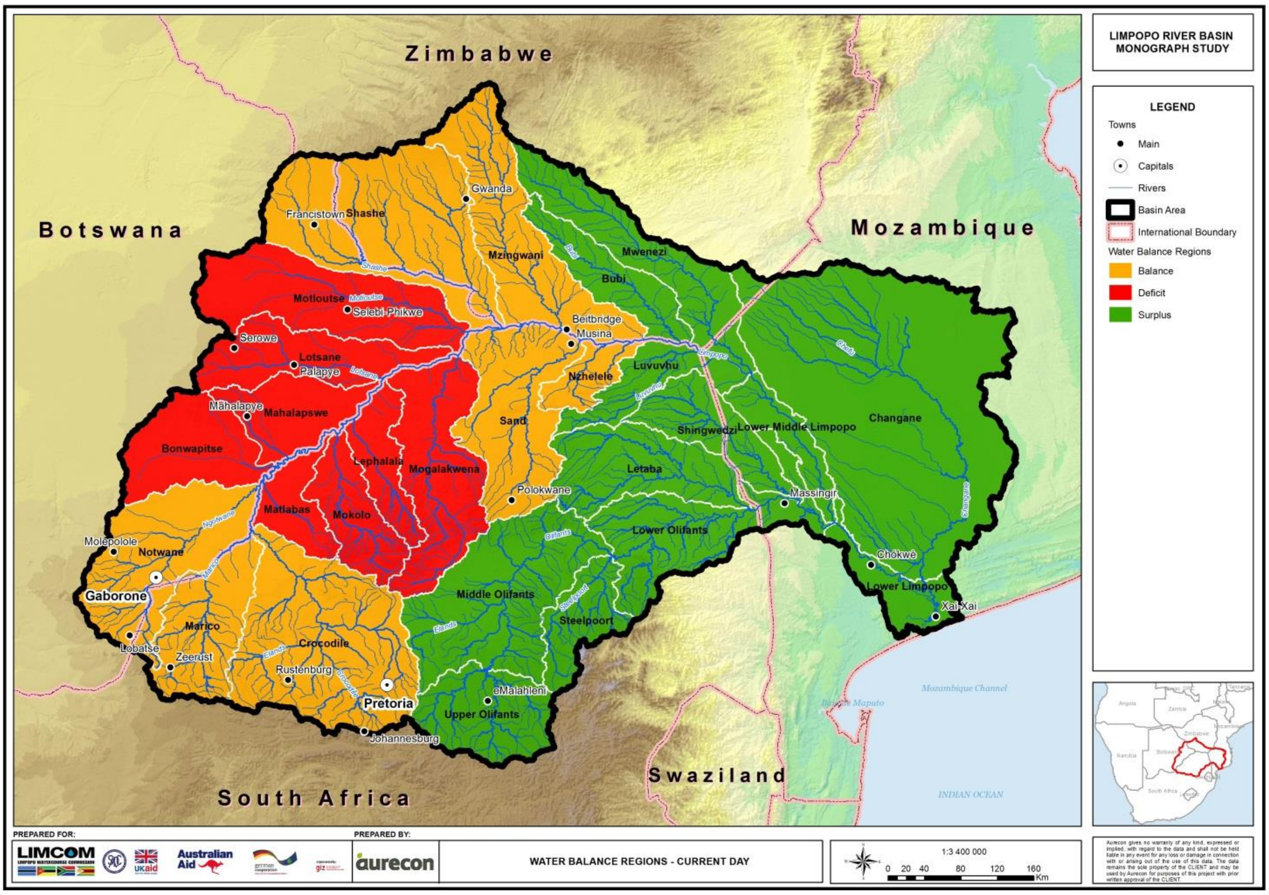



**Figure 5.26:** Regional Water Balances for current day – no EWR

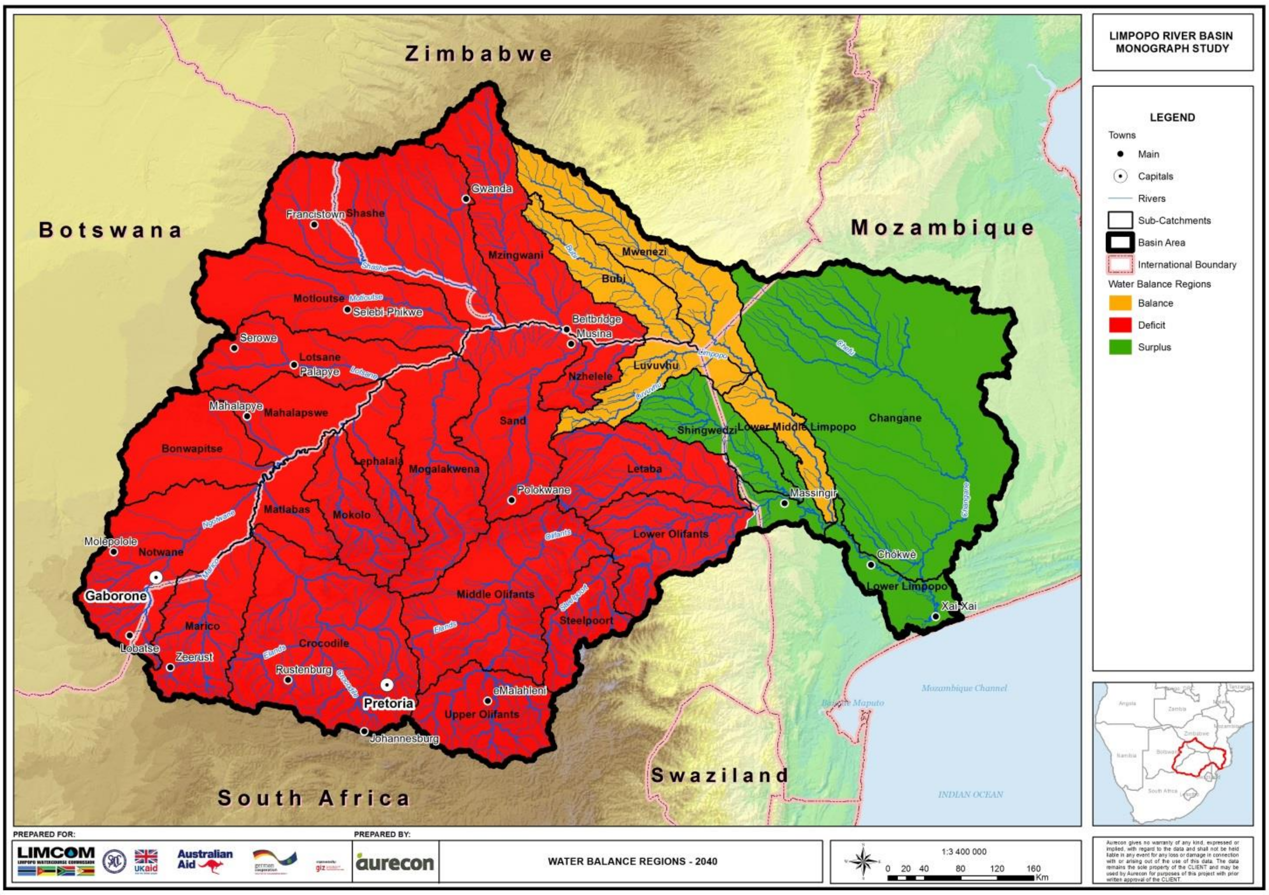



**Figure 5.27: Regional Water Balances** for 2040 – no EWR

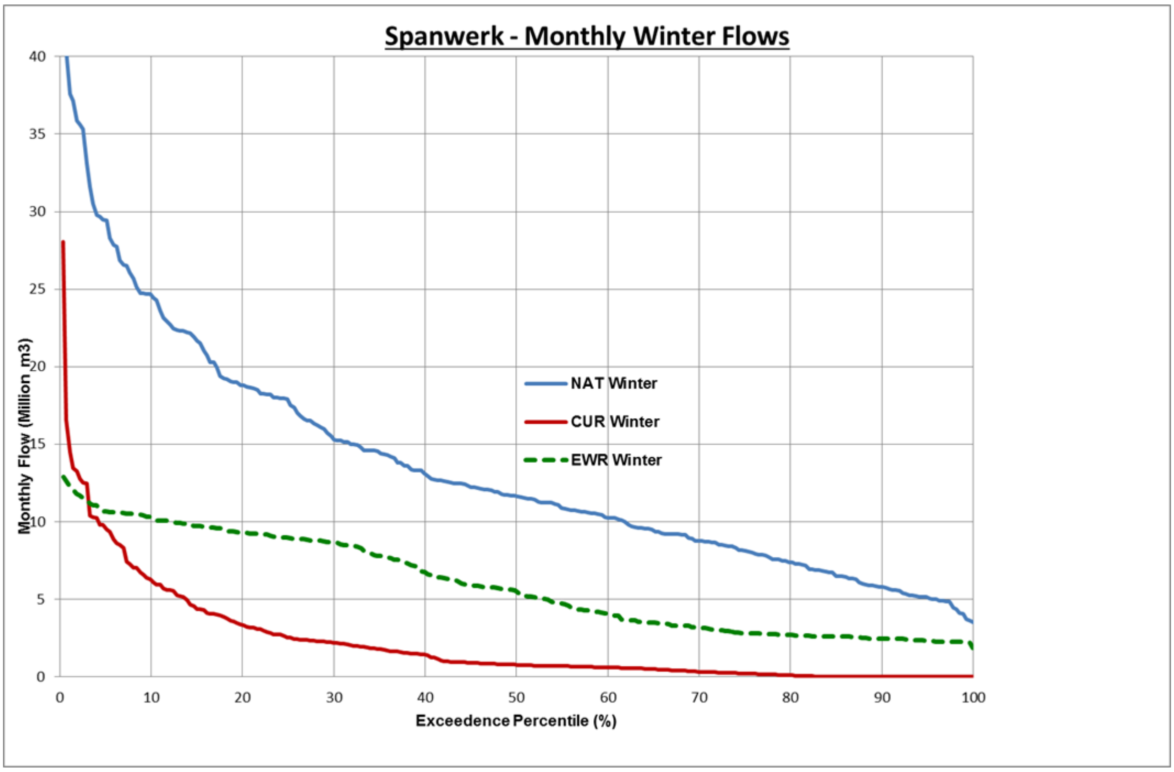



**Figure 5.28:** EWR Flow Duration Curves for the Limpopo Main-Stem for the Combined Months of July, August and September at Spanwerk (just Downstream of Crocodile (West) River)

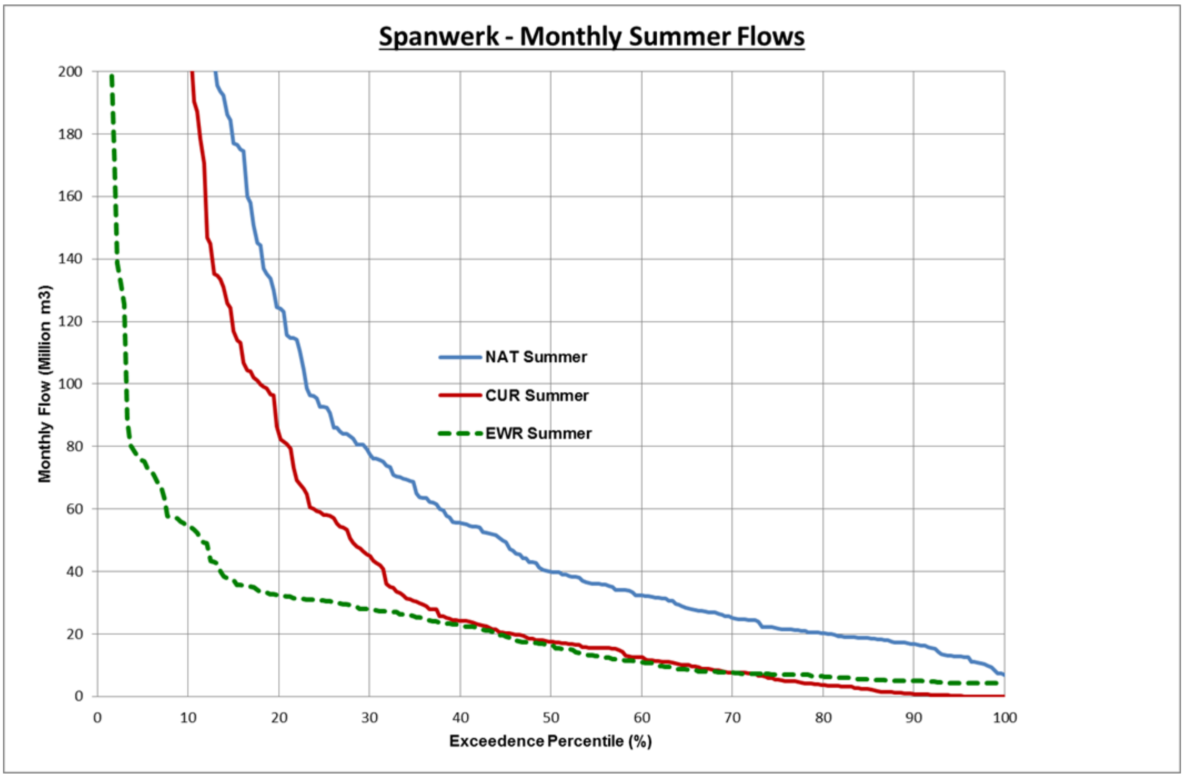



**Figure 5.29:** EWR Flow Duration Curves for the Limpopo Main-Stem for the Combined Months of January, February and March at Spanwerk (just Downstream of Crocodile (West) River)

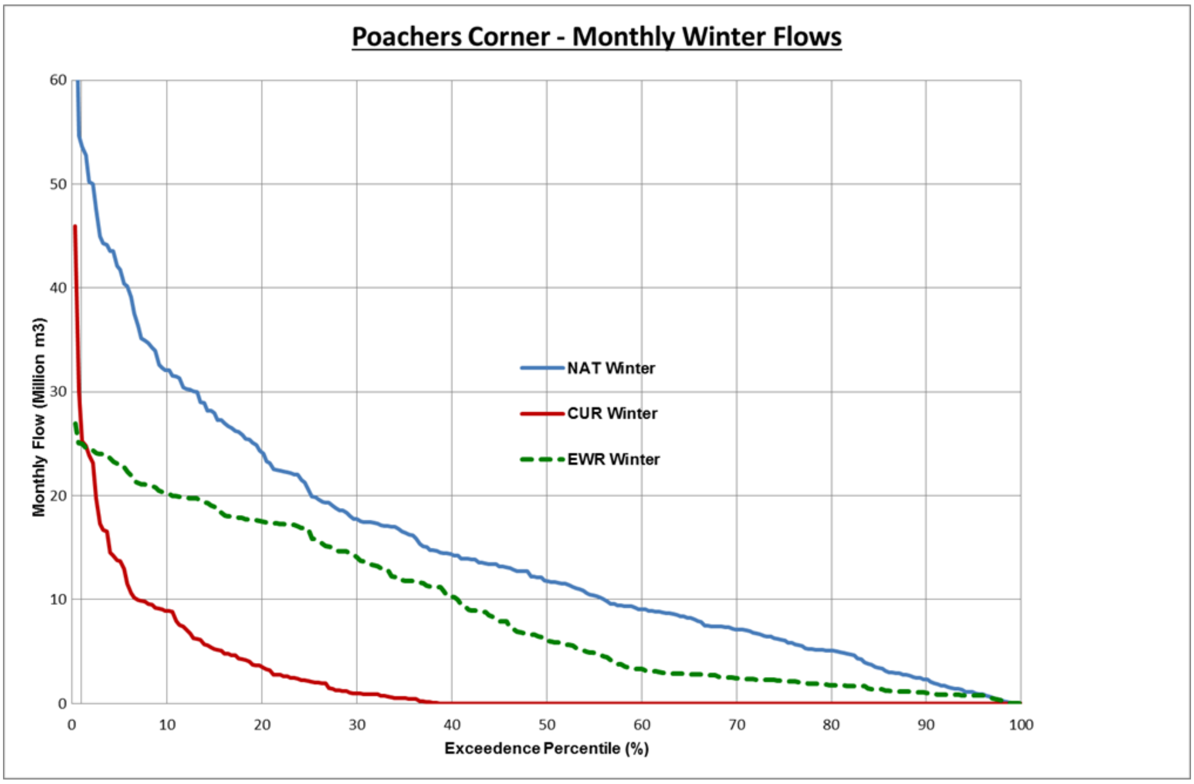



**Figure 5.30:** EWR Flow Duration Curves for the Limpopo Main-Stem for the Combined Months of July, August and September at Poachers Corner (just Downstream of Shashe River)

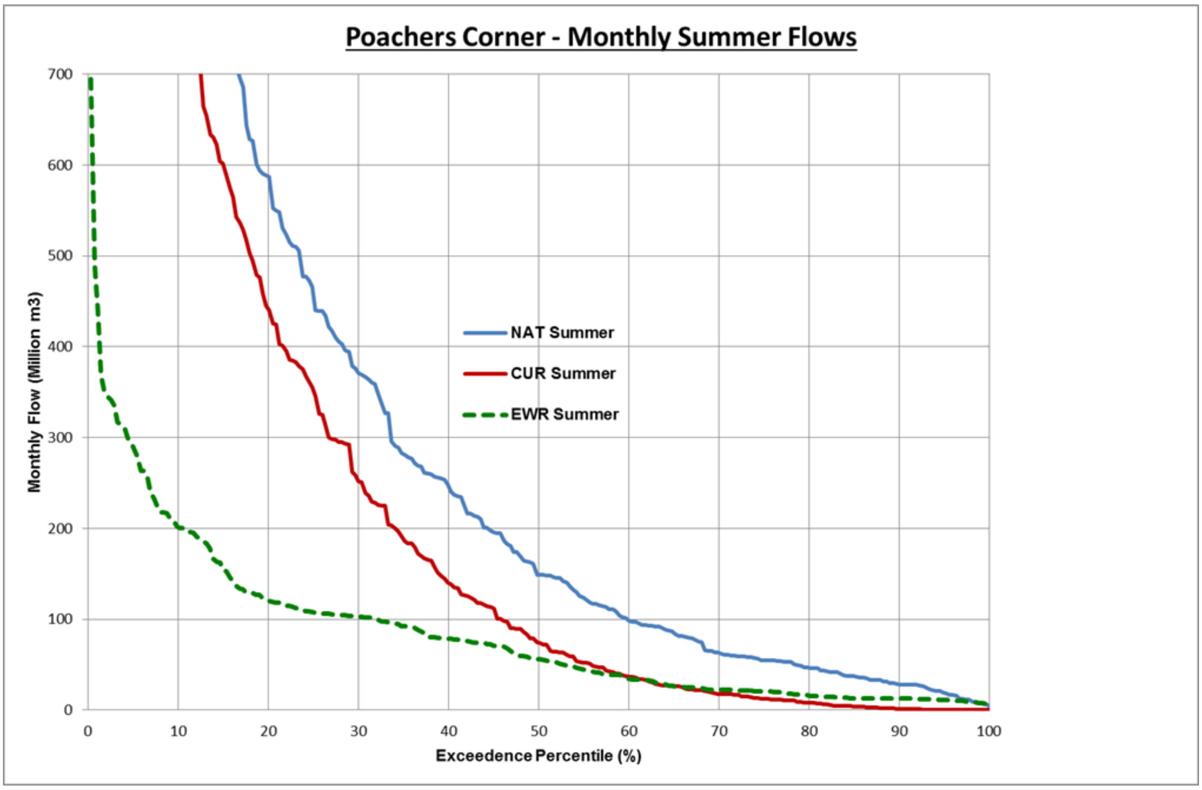



**Figure 5.31:** EWR Flow Duration Curves for the Limpopo Main-Stem for the Combined Months of January, February and March at Poachers Corner (just Downstream of Shashe River)

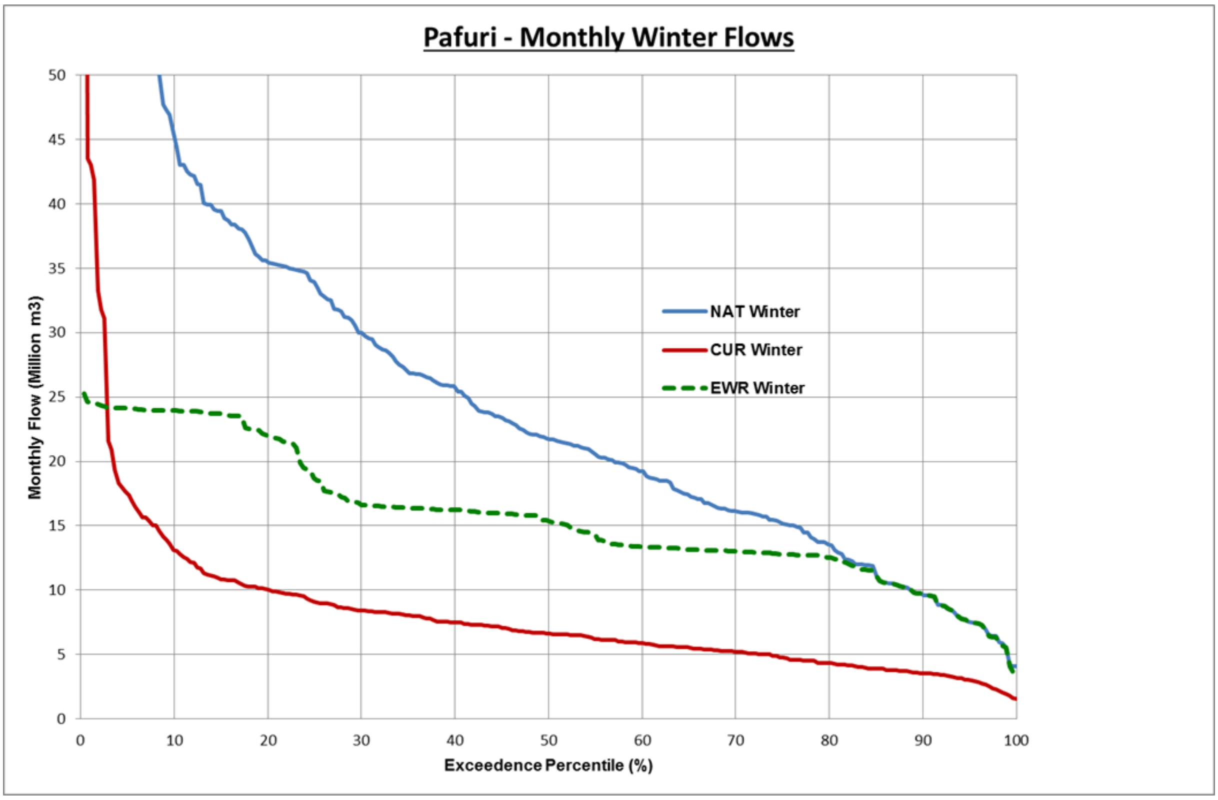



**Figure 5.32:** EWR Flow Duration Curves for the Limpopo Main-Stem for the Combined Months of July, August and September at Pafuri (at Joint Border of Zimbabwe, Moçambique and South Africa)

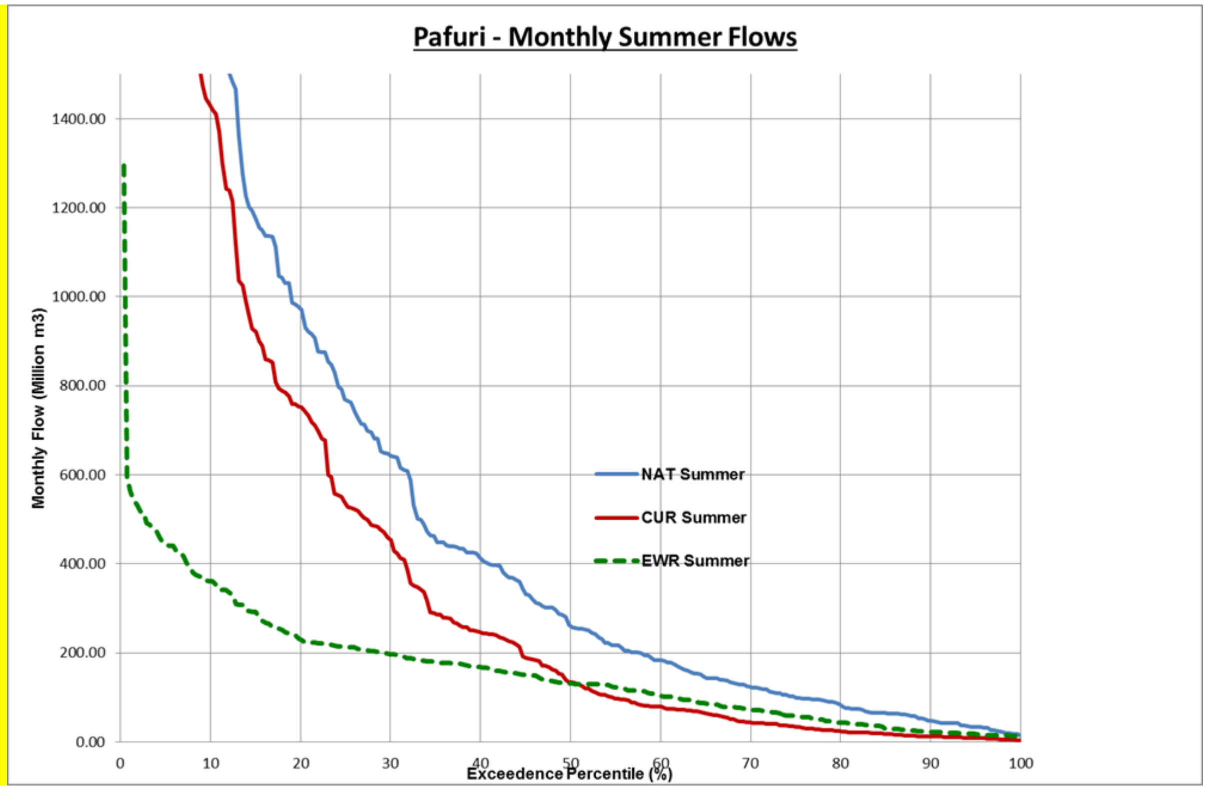



**Figure 5.33:** EWR Flow Duration Curves for the Limpopo Main-Stem for the Combined Months of January, February and March at Pafuri (at Joint Border of Zimbabwe, Moçambique and South Africa)

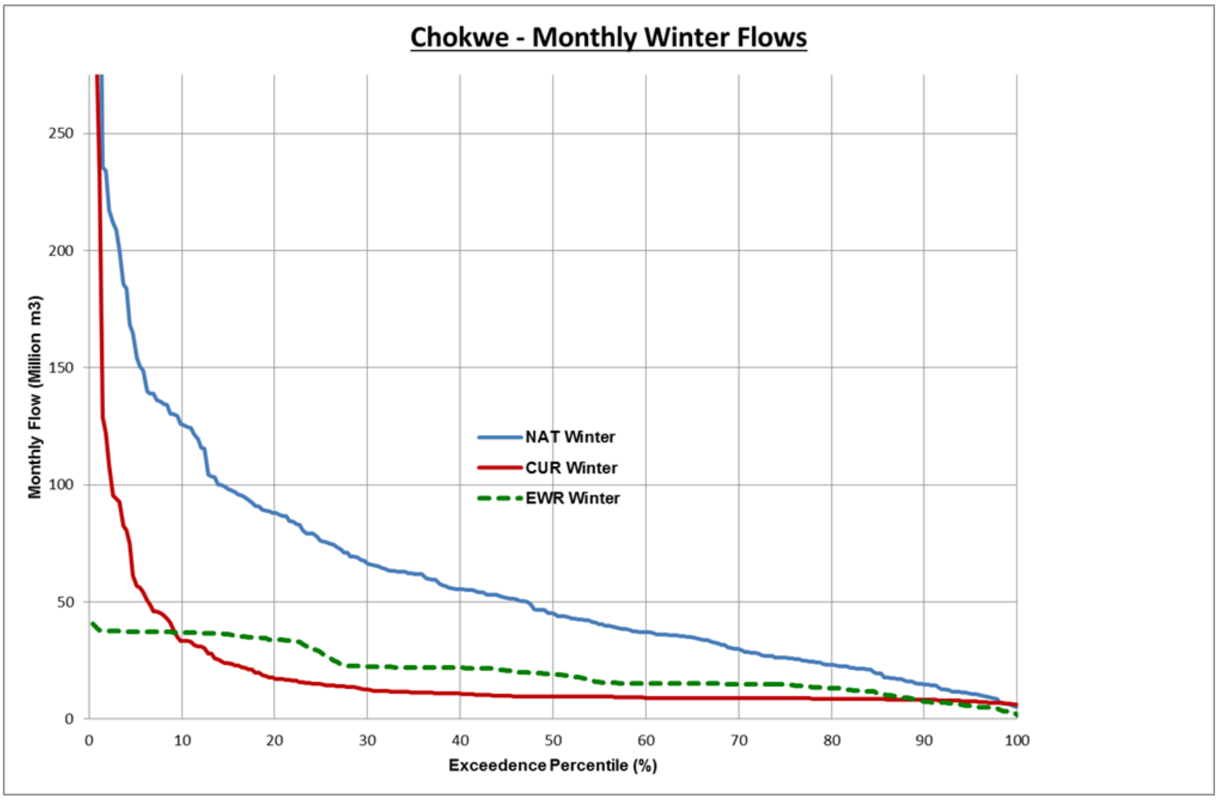



**Figure 5.34:** EWR Flow Duration Curves for the Limpopo Main-Stem at Chokwe for the Combined Months of July, August and September

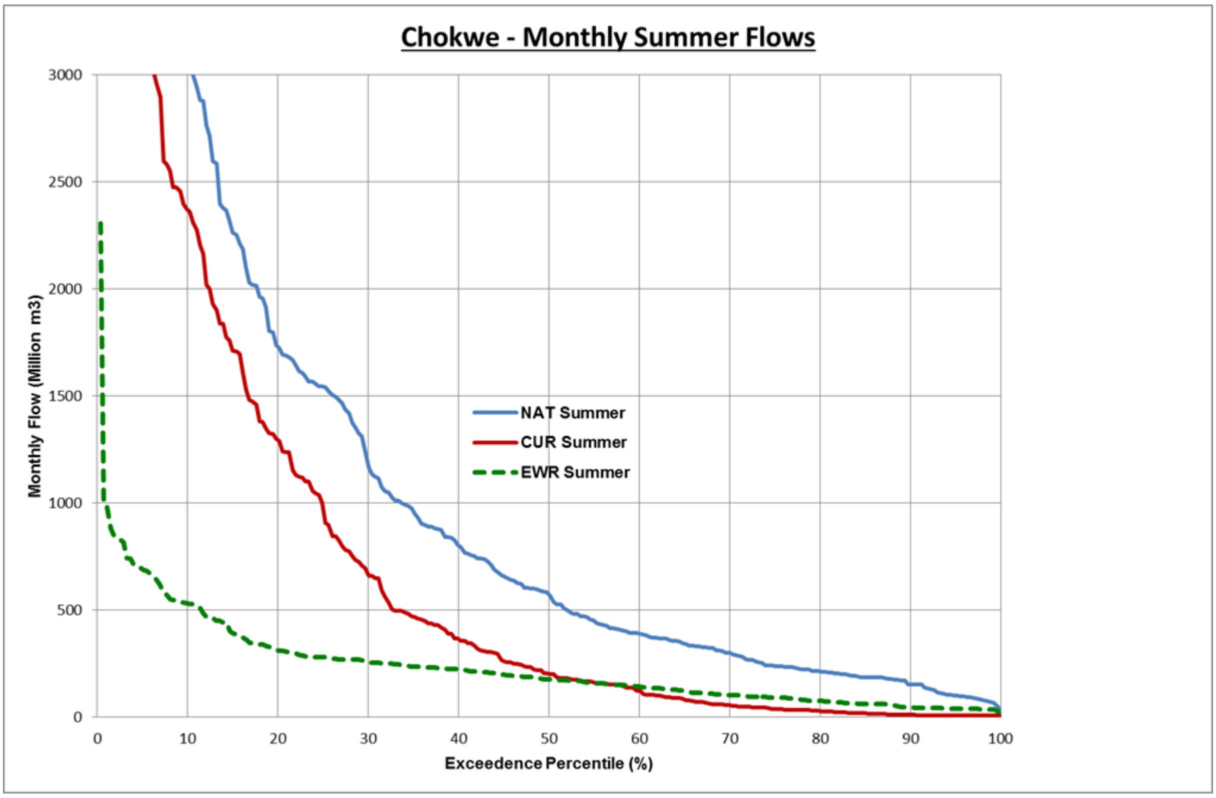



**Figure 5.35:** EWR Flow Duration Curves for the Limpopo Main-Stem at Chokwe for the Combined Months of December, January and February

## 5.6 CLIMATE CHANGE

***(Refer Technical Annexure Volume C4: Climate Change)***

### 5.6.1 Introduction

Climate change is projected to have major impacts in the Limpopo River Basin with consequences for the economies of the four co-Basin countries. The semi-arid nature of large portions of the Basin is likely to exacerbate the impacts of climate change because the Basin is already water-constrained. The aim of this Section is to synthesize the current understanding of the potential impacts of climate change on the LRB, with a specific focus on projected impacts on temperature, rainfall, ecosystems and socio-economic dynamics of major sub-zones of the LRB.

Projections of climate change impacts on the LRB have been carried out by the South African CSIR, using an average ensemble of six individual GCM down-scalings (Engelbrecht et al, 2011). The projections were established, using the period 1961- 1990 as baseline, for the near-future period 2011- 2040 and far-future period 2071- 2100.

**Technical Annexure Volume C4** provides a detailed review of potential climate change impacts in the LRB.

### 5.6.2 Basin characteristics relevant to climate change

#### 5.6.2.1 *Climate systems*

The climate systems important to the LRB are depicted in **Figure 5.36**. The climate of the LRB varies widely from arid conditions in the west to temperate conditions in the central and semi-arid conditions in parts of the east. The rainfall in the Basin is influenced both by local-scale convective systems and large-scale weather systems.

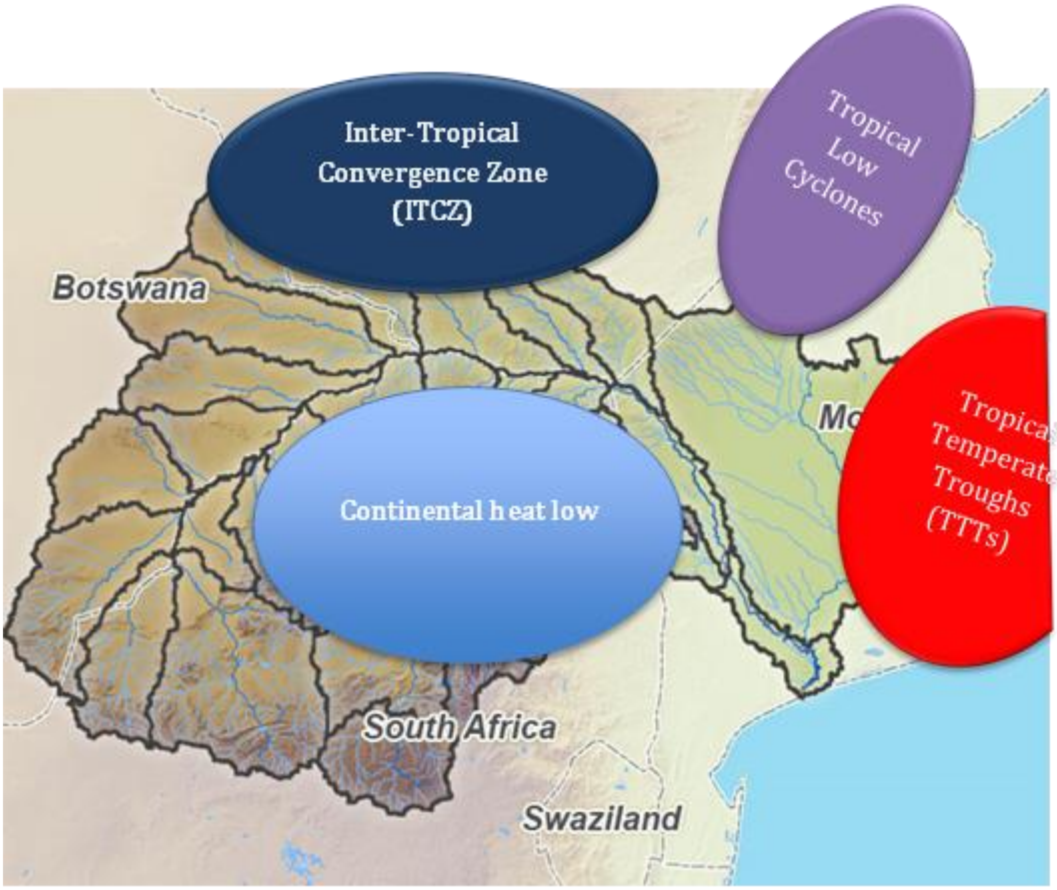



**Figure 5.36:** Major climate systems influencing the Limpopo River Basin

### 5.6.2.2 *Tropical Temperate Troughs (TTTS)*

These are a group of cloud bands occurring over the southern Africa region that are responsible for summer rainfall (40%) in large parts of the region. All TTTs are characterised by their linkage to temperate and tropical circulation regimes and contribute to the circulation of energy, moisture and momentum from the tropics to the mid-latitudes.

### 5.6.2.3 *Inter-Tropical Convergence Zone (ITCZ)*

The ITCZ is a band of cloud that circulates the globe and that bring showers and occasional thunderstorms around the equator. The position of ITCZ varies seasonally depending on the location of the sun. In summer it moves north during the northern summer and south in the northern winter. The ITCZ extends southwards during the southern hemisphere summer months, bringing tropical rainfall to the northern Sub-Basins of the LRB. This contributes significantly to the divergent weather patterns in the Limpopo Basin.

### 5.6.2.4 *Ridging high pressure systems*

The South Indian High and the Continental Low interact with the Tropical Temperate Troughs (TTTs) to bring rainfall to the LRB. The ridging anticyclone brings warm air from the Indian Ocean inland, causing orographic uplift that causes rainfall in mountainous areas.

#### 5.6.2.5 *Tropical low cyclones*

Tropical systems from the southwest Indian Ocean contribute more than 50% of multi-day rainfalls occurring in the LRB. In general, the types of rain-bearing systems occurring over southern Africa differ in frequency of occurrence and tracks followed between wet and dry phases.

#### 5.6.2.6 *El - Nino*

El Nino events are a major driving force behind long-term natural climate variability, and anthropogenic climate change will exacerbate these El Nino events, because warming increases their intensity, resulting in increased sea surface temperatures that are responsible for El Nino events. In southern Africa some of the major disasters associated with El Nino and El Nina events include flooding and droughts.

In trying to understand the impact of climate change in the Basin, it is important to consider the changes in temperature and rainfall and the intensity of El Nino in the Basin.

### 5.6.3 Temperature changes in the Limpopo River Basin

Air temperatures in the Basin reflect seasonal variability patterns with the hottest temperatures occurring in the early summer months and the lowest temperatures during the cool, dry winters. In the last century temperatures have increased by about 1.6oC in the central interior regions of southern Africa. The largest increase in temperature of 2oC per century has been recorded in the central interior of South Africa, during the winter and autumn seasons. Maximum temperatures in the LRB have increased by a rate of between 1oC and 1.4oC in summer months, with the southern and western regions recording the highest increases.

#### 5.6.3.1 *Projected changes in maximum temperature in the Limpopo River Basin*

The down-scaled GCM-based projections indicate that in the short term (2011- 2040), maximum temperature is projected to increase by between 1oC and 2oC warmer than the baseline.

### 5.6.4 Rainfall

#### 5.6.4.1 *Projected changes in rainfall*

Reported climate change-related projections of mean annual rainfall are depicted in **Figure 5.39**. These show that there may be limited, but spatially coherent, decreases in rainfall in the near future in the Basin. In the long term the rainfall is projected to decrease by up to -15%. More frequent high–intensity rainfall events are generally projected, with a consequent increase in local and large-scale flooding.

The decrease seasonal rainfall is most significant during the summer and autumn months, as these are the rainy season in the Basin. In some areas, especially the north-eastern side of the Basin, the reduction in rainfall may be by as much as -20% in summer (**Figure 5.37**).

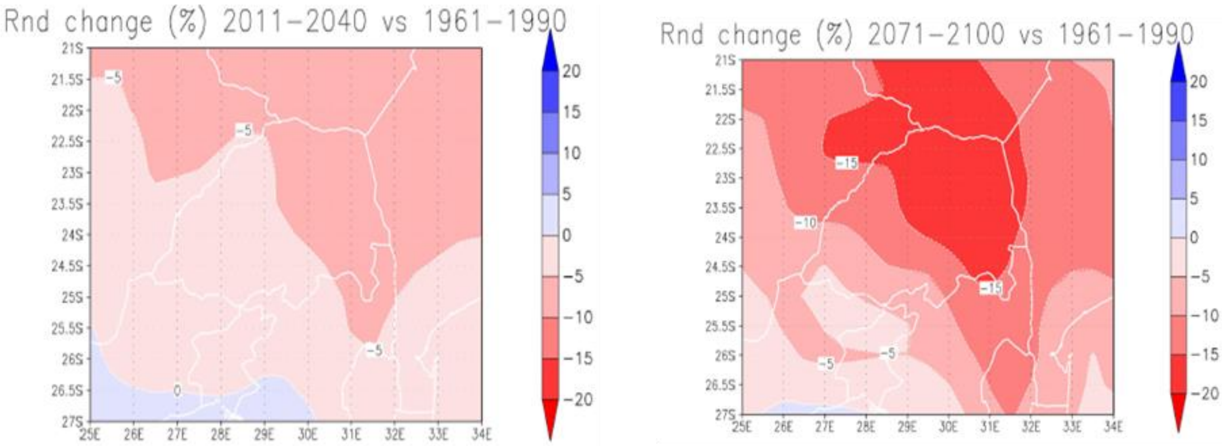



**Figure 5.37:** Projected change in mean annual rainfall over the LRB in the medium and long term

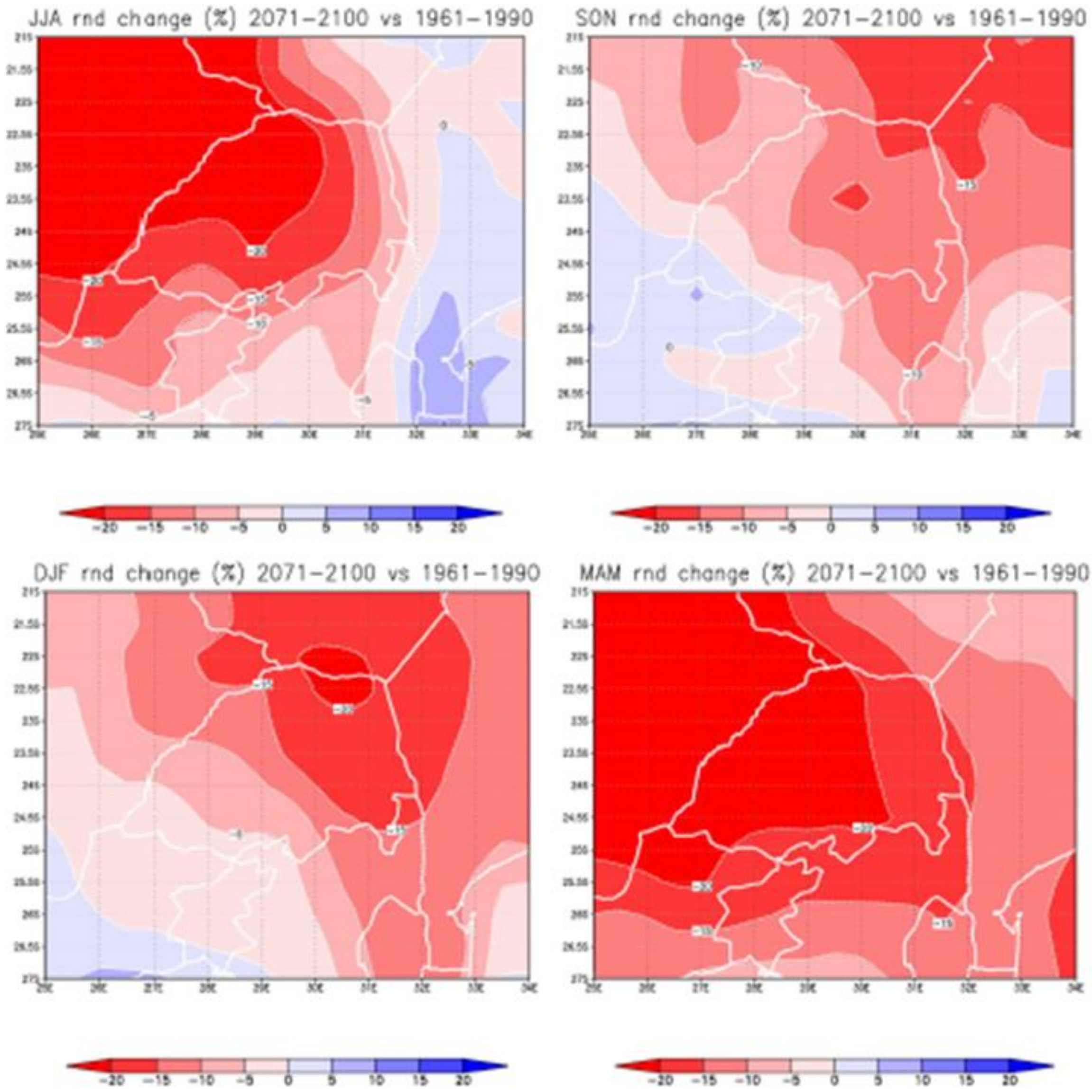



**Figure 5.38:** Projected change in seasonal rainfall totals over the LRB

### 5.6.5 Vulnerability to climate change

Vulnerability to climate change is defined as the degree to which a system is susceptible to or unable to cope with the adverse effects of climate change, including increased variability. Particular characteristics of the LRB such as the arid conditions, high dependence on rain-fed agriculture and relatively poor communities, make the Basin highly vulnerable to climate change. Understanding the key drivers of climate change vulnerability in the Basin and the key sectors of the economy that will be impacted by climate change is critical for adaptation. Vulnerability of the Basin to climate change is driven mainly by water availability (rainfall, streamflow, groundwater, infrastructure, water quality) and water requirements (sectoral demands, hydropower, in-stream environment).

The adaptive capacity across the Basin varies depending on the location, for example regions dependent on rain-fed agriculture are generally more vulnerable than those that use irrigation or have formal water infrastructure. Exposure to climate risk may not necessarily be an issue of major concern if the affected community or region has the adaptive capacity to respond. In the absence of such capacity, vulnerability becomes a major threat to the system, as is the case in a number of locations in the Limpopo Basin.

#### 5.6.5.1 *Impact of climate change on development in the Basin*

To effectively adapt to climate change it is important to understand from a development perspective how climate change will impact, the socio-economic, environmental and human security in the Basin.

#### 5.6.5.2 *Socio-economic dynamics*

The LRB has a large rural population who depend on rain-fed agriculture to produce their crops. Therefore, decreases in precipitation would have an adverse impact on the livelihood of the rural population in the Basin. (Of course, small-holder farming, commercial farming and commercial forestry would also be adversely affected.)

#### 5.6.5.3 *Environment*

The environment is an important element of the LRB development agenda. It is viewed as an important driver for poverty alleviation, as it provides important ecosystem services. Considering that a large part of the population of the LRB comprises rural communities, the environment plays an important role in providing services such as water provision and purification, raw materials and food. Climate change may significantly reduce the potential of the environment to provide these important ecosystem services. Such climate change impacts would, of course, be super-imposed on existing land-use practices in the LRB that impact negatively on the environment, through water quality degradation and loss of habitat and biodiversity.

#### 5.6.5.4 *Human security*

Climate change would threaten the physical security of many communities in the Basin, with rural communities in the Moçambican floodplains most at risk. The vulnerability in the Basin is exacerbated in many locations by a lack of capacity to cope with climate change shocks. Indeed the Basin has been prone to many extreme events with devastating impact on human security. High poverty-levels and scarcity of economic opportunities have reduced the adaptive capacity of local residents to respond to extreme events such as flooding and drought timeously to mitigate any negative consequences.

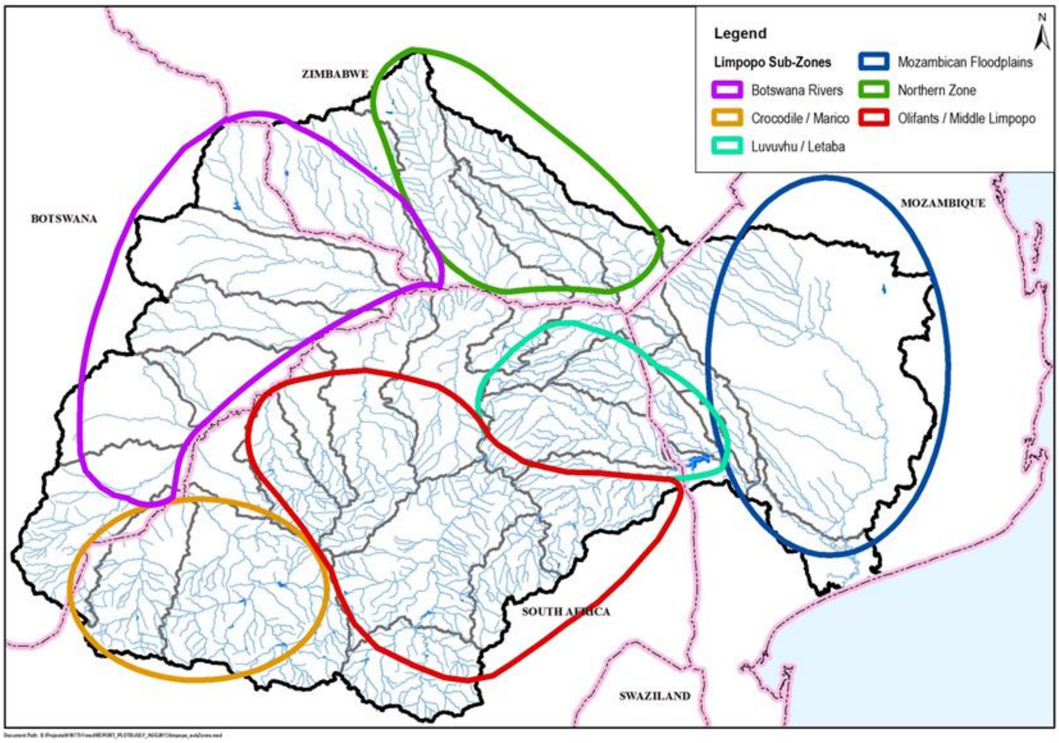



**Figure 5.39:** Zones for climate change impact evaluation

Given that the LRB is quite diverse; understanding the potential impact of climate change and its relation to development (socio-economic dynamics, environment and human security), a sub-basin scale analysis would be more useful. To develop this deeper understanding, the LRB was subdivided into the following five Zones according to the Sub-Basins, as shown in **Figure 5.39** (i) Olifants/Middle Limpopo Sub-Basins; (ii) Crocodile (West)/Marico Sub-Basins; (iii) Botswana Sub-Basins/Shashe Sub-Basin; (iv) Northern Zone Sub-Basins in Zimbabwe; (v) Luvuvhu/Letaba/Shingwedzi Sub-Basins and (vi) Moçambican Sub-Basins.

In **Technical Annexure Volume C4** each of the Zones in the LRB is reviewed separately and in detail to assess the potential water-related impacts of climate change.

### 5.6.6 Conclusions

#### 5.6.6.1 *Vulnerability of key zones in the LRB*

- **Middle Limpopo/Olifants Zone:** The vulnerability of this Zone is linked directly to its economic activities, which include commercial forestry and commercial agriculture. Monitoring rainfall patterns is critical for the forestry sector, as it is not dependent on irrigation. Increased temperatures on the other hand would impact on irrigation water requirements. The water resources of this Zone are more than fully utilised and decreases in yield due to decreased rainfall and related increased demands would have to be met by increases to the existing bulk imports from the Usuthu, Incomati and Vaal Basins. Rural populations that rely on rain-fed agriculture would become increasingly more vulnerable over the next century.
- **Crocodile (West)/Marico Zone**: This Zone would be relatively less impacted by climate change compared with the rest of the Basin. As it is part of the economic hub of South Africa, the security of its water supplies is critical and hence appropriate monitoring of climate change impacts to ensure that water security would be vital. As this Zone relies on extensive imports from Lesotho Highlands via the Vaal

Basin, climate change monitoring should also focus on the Senqu Basin in Lesotho and on the Upper Vaal.

- **Botswana Rivers/Shashe Zone**: Increases in extreme temperatures (extremely hot days are projected to increase by 40 to 60 days per year) and significant reductions in rainfall would have major negative impacts on agro-productivity, resulting in increased migration from rural to urban centres. Decreased availability of surface water would undermine economic development related to mining and energy production and make Botswana more dependent on water imports from the Marico Sub-Basin, as well as from the Zambezi.
- **Northern Zone**. The primary vulnerabilities of this Zone are threats to the water security of the second largest city in Zimbabwe, harm to a highly productive agricultural region of Zimbabwe, a weakening in the outlook for a growing tourism and conservation industry and threats to the subsistence livelihoods of many rural communities. A key challenge would be to build understanding of how to build resilience in the tourism and conservation sector and how reduced rainfall would impact biodiversity.
- **Luvuvhu/Letaba Zone**: The vulnerability of this Zone is linked directly to (i) its three thriving sets of economic activities, namely irrigated agriculture, commercial afforestation and eco-tourism, as well as the well-being of its many rural communities, and (ii) the existing high utilisation of its water resources. A sizeable decrease in rainfall would have a devastating impact on the economic profile of the whole Zone, as well as on the livelihoods of the rural population. More frequent local flooding due to increased numbers of extreme rainfall events would undermine the human security of already fragile rural communities.
- **Moçambican Floodplains Zone**: This Zone is probably one of the most vulnerable in the LRB in relation to socio-economic impacts of climate change. Changes in precipitation may result in both flooding and food insecurity for many rural communities. Unfortunately, the adaptive capacity of rural populations is also very low, because of high poverty rates and lack of infrastructure to cope with any adverse effects of climate change.

#### 5.6.6.2 *Vulnerability at Basin scale*

- As the LRB has a high population of rural poor who are the least resilient of all economic groupings, the projected adverse impacts of climate change would be a major threat to rural livelihoods in this Basin.
- The sustainability of all levels of agricultural practices across the LRB, including smallholder farmers, would be deleteriously affected by the projected adverse impacts of climate change. This would have major implications for the socio-economy of the Basin. Firstly, because small-holder farmers have a lower adaptive capacity, they might not have enough resilience to continue to be profitable. Secondly, commercial farmers might be forced to cut back on production, because bulk water availability for irrigation might be reduced.
- The high level of utilisation of water resources and, even, deficits in many Sub-Basins across the LRB would be pushed further into problem territory by the projected adverse impacts of climate change. Such a deleterious trend would threaten the development futures of a number of Zones. For example, development of major energy projects that are located in water-scarce Zones in South Africa and Botswana could potentially be negatively impacted as a result of projected decreases in rainfall.

# 6. WATER GOVERNANCE

## 6.1 INTRODUCTION

This review describes the inter-related framework of laws and policies applicable to the Limpopo River Basin (LRB) at national and international level, as well as the corresponding organisational management structures at basin and country levels. The review describes the constitutional order and organisation in the four Limpopo basin states, Botswana, Moçambique, South Africa and Zimbabwe. This is followed by an overview of overarching national economic development policies and sector development policies, focused on economic sectors most prevalent in the basin, e.g. mining, agriculture, energy and tourism. The review further provides an overview of the natural resource governance framework in the Basin with a focus on water, land and biodiversity management, as well as climate change adaptation. Key domestic legislation related to water and environmental management, as well as relevant legislation applicable to the main water use sectors in the basin is also discussed. In this context emphasis is placed on the water rights systems and mechanisms for water allocation, the framework for water quality management and control as well as disaster risk management frameworks.

## 6.2 ADMINISTRATIVE BOUNDARIES

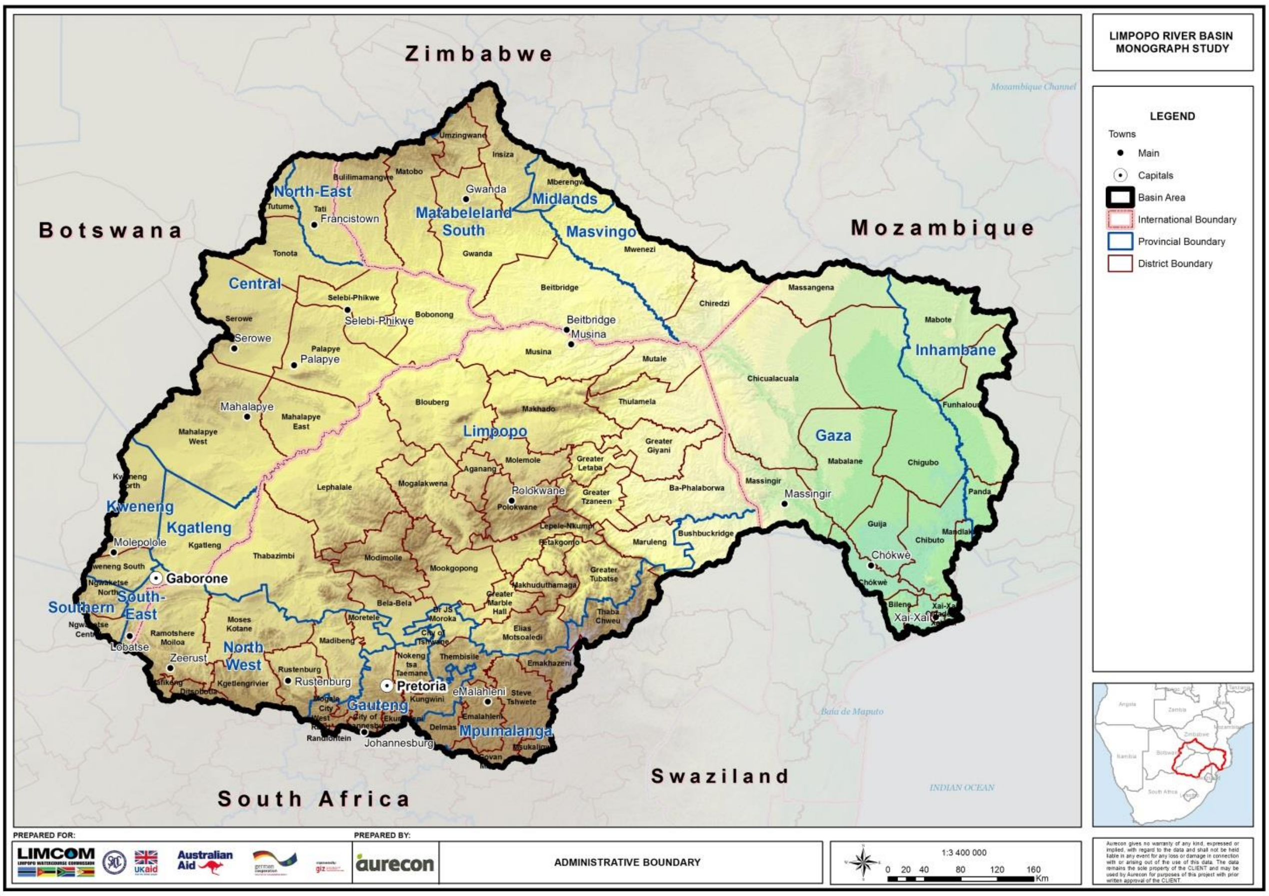



**Figure 6.1: Administrative Map of the Limpopo River Basin**

The Limpopo River Basin within Botswana covers most of the hardveldt and falls in the administrative districts of North East; Central; Kgatleng; South East and parts of Kweneng. The basin forms the eastern border between Botswana and South Africa. The main urban centres within the basin are Serowe, Selebi-Phikwe, Palapye, Mahalapye, Francistown, Mochudi and Gaborone, in addition to a small number of small and medium settlements. The Botswana part of the Limpopo River basin consists of the following sub-basins: Notwane, Bonwapitse and Mahalapswe, Lotsane and Motloutse and Shashe, which is also part of Zimbabwe.

In Moçambique there are two provinces that fall into the Limpopo River basin, namely; Gaza and Inhambane. The Gaza province lies in the basin of the Limpopo River, which runs from northwest to southeast, emptying into the Indian Ocean near Xai-Xai the capital of the province. The Changane River, a tributary of the Limpopo, forms part of the Gaza province's eastern boundary. The Rio dos Elefantes (Olifants River) flows into the district from the west through the Massingir Dam, to empty into the Limpopo. Inhambane province is located on the coast in the southern part of the country. The provinces are further divided into districts; there are ten districts in Gaza and four in Inhambane. The Limpopo River Basin falls almost entirely within the Gaza Province and also covers portions of three districts in Inhambane Province.

The South African part of the Limpopo basin cover parts of four provinces, namely; Limpopo, North West, Mpumalanga and Gauteng. The south-eastern Limpopo River Basin borders the Incomati River (with the upstream Komati and Sabie tributaries), whose basin covers the southern half of the Kruger National Park and the adjacent Nelspruit area. To the south and southwest, the boundary is shared with the watershed of the Orange River, which flows into the Atlantic Ocean, with the Vaal River as the nearest most northern main tributary. Main urban centres are Pretoria, parts of Johannesburg and Polokwane.

In Zimbabwe, the basin falls in the provinces of Matebeland South, Masvingo and Midlands. The following districts fall within the basin: Gwanda, Matobo, Mangwe, Beitbridge, Insiza, Mwenezi and Mberengwa, Umzingwane and Chiredzi. Major urban centres in the basin are Gwanda and Beitbridge.

## 6.3 LEGAL AND POLICY FRAMEWORK

***(Refer Technical Annexure Volume D1: Legal & Policy Review)***

### 6.3.1 Regional

At the regional level, the Revised SADC Protocol on Shared Watercourses is the key instrument for transboundary water management in the SADC. The Revised SADC Protocol (SADC, 2000) is a framework agreement, which contains the generic rules for the management of shared rivers within the SADC region, but does not contain basin-specific rules. The latter are to be included in (basin-wide) watercourse agreements. The link between the Revised SADC Protocol and the basin-specific rules is made in Article 6 (3) of the Revised SADC Protocol, which states that “watercourse states may enter into agreements, which apply the provisions of this Protocol to the characteristics and uses of a particular shared watercourse or part thereof”. The Revised SADC Protocol thus provides the general direction and principles for any future watercourse agreements concluded in the SADC region, while at the same time allowing for the consideration of certain characteristics that may be specific to the watercourse in question (Ashton et. al., 2006).

The Revised SADC Protocol contains the key rules of international water law, i.e. “equitable and reasonable utilisation” (Article 3 (7)) and the “duty to take reasonable measures to prevent significant harm” (Article 3 (8)). It furthermore, among others, contains provisions dealing with notification and consultation requirements regarding planned measures and rules on pollution prevention, reduction and control.

Equally important to setting out the above-mentioned general principles is that the Revised SADC Protocol establishes an institutional framework at the regional level for the implementation of the instrument. In Article 5 it establishes the SADC Water Sector Organs and mandates them as well as Shared Watercourse Institutions1 with the implementation of the Protocol.

In practice, the SADC institutions are currently mandated primarily with monitoring functions concerning the application of the Revised SADC Protocol as well as with facilitating the harmonisation of water law and policy between SADC member states. SADC institutions are not mandated with the implementation and enforcement of basin-wide agreements. Where those have been concluded this is done by Shared Watercourse Institutions as well as the domestic institutions in the countries that are party to the basin-wide agreement.

As described above, the Revised SADC Protocol mandates (in Art. 6 (3)) watercourse states to enter into basin-specific agreements in line with the legal principles of the Revised SADC Protocol. In 2003 the Limpopo River Basin states concluded an agreement on the establishment of the Limpopo Watercourse Commission (hereafter LIMCOM Agreement), which entered into force in 2011 after the ratification requirements were met. The LIMCOM Agreement is only the second (after the 1986 Agreement establishing the Limpopo Basin Permanent Technical Committee - LBPTC) basin-specific agreement to which all four basin states are Parties. While there is a long-standing history of cooperation on the Limpopo, all agreements except the LBPTC Agreement and the LIMCOM Agreement, are bilateral agreements. In terms of Art. 12 (3) of the LIMCOM Agreement, the LBPTC Agreement lapses with the entry into force of the former, with LIMCOM replacing the LBPTC as the basin-wide cooperative mechanism.

The purpose of the LIMCOM Agreement is to establish the LIMCOM and define the Commission’s objectives (Art. 3), functions (Art. 7) and powers (Art. 8) as well the institutional arrangements (Art. 4) and operational rules (Art. 6). It is worth noting in this context that the LIMCOM Agreement does not establish substantive legal obligations for the Parties for the development and management of the Limpopo water resources. The substantive (material) rules according to which the Parties need to manage the Limpopo watercourse are to be found in the Revised SADC Protocol as well as the existing bilateral agreements. In this context the LIMCOM Agreement stipulates (in Art. 2 (3)) that the rights and obligations of the Parties arising from other agreements regarding the Limpopo (that are in force prior to the entry into force of the LIMCOM Agreement), remain unaffected.

The LIMCOM Agreement establishes the LIMCOM as a technical advisor to the Parties (Art. 3 (1) & 7 (1)) on matters relating to the development, utilisation and conservation of the water resources of the Limpopo. Art. 7 (2) further elaborates the technical areas on which the Commission is to provide advice. Again, it needs to be pointed out that Art. 7 of the LIMCOM Agreement only specifies the functions of the Commission (Council), the international legal rules that determine water management in the Limpopo and within the framework of which the Commission needs to provide its advice, are contained in the Revised SADC Protocol and the bilateral agreements, not in the LIMCOM Agreement itself.

[1] Commonly referred to as River Basin Organisations (RBOs), but the Protocol uses the term Shared Watercourse Institutions.

### 6.3.2 National Legal and Policy Frameworks for Water Management

#### 6.3.2.1 *Botswana*

The Water Act (1968) controls the access to and use of water in the country and provides an institutional framework for water allocation and control. A draft Water Bill has been produced as part of the ongoing water sector reform in the country and will, once promulgated as an Act, replace the 1968 Water Act. The Water Act (1968) specifies conditions to water rights for industrial, mining, power generation, and forestry use. According to this Act, water rights are needed to abstract, store, dam and divert water and indicate the maximum amount and period of abstraction. The other relevant document for water allocation is the draft Botswana National Water Conservation (WC) Policy (2004). The Policy prioritises different water uses as follows: water for human consumption, urban and domestic use has top priority followed by water for production, environment, agriculture and livestock. The on-going water sector reform project will implement far reaching institutional reforms, and prepare new water legislation and tariffs. The Department of Water Affairs has developed a draft National Water and Wastewater Policy for the country in 2010, which is firmly based on IWRM principles. An Integrated Water Resources Management & Water Efficiency Plan has been concluded in May 2013.

The new draft Water Bill is based on the above-mentioned policy and will, once enacted, replace not only the 1968 Water Act, but also Borehole Act and the Water Works Act. The proposed new Act brings the country's legislation in line with IWRM principles. This Act also establishes a new Water Resources Board with key decision making functions in water resources management, allocation and development of policies related to water resources. National water planning will be supported by formal mechanisms for ensuring cross-sectoral consultation and inputs from all sectors whose interests must be taken into account and this function will be the responsibility of the proposed Water Resources Board. The technical functions of this body will be carried out by a division of the Department of Water Affairs (DWA), which will act as the executive arm of the WRB. Under the new legislative framework, the DWA will no longer have any water delivery functions, but will be responsible for assessing, national planning, developing and managing water resources for short, medium and long-term purposes, while the Water Utilities Corporation takes on the responsibility of a water supply authority (including waste water operations) for all cities, townships and villages.

Another piece of legislation that has been approved by cabinet is the establishment of the Botswana Energy and Water Regulator, which will be mandated to protect the rights and interest of the consumers. The proposed Water Regulator is tasked to ensure financial sustainability across the water sector, and reduce wastage by facilitating the streamlining of operations and determining revenue requirements to inform regular tariff adjustments.

The Botswana Water Act (1968) does not deal with water quality and the country has no designated legislation specifically for water quality management. Instead, water quality aspects are dealt with, directly and indirectly, in a number of Acts dealing with a variety of pollution aspects. The Botswana Bureau of Standards (BOBS) has produced unified potable drinking water standards, ending a situation where DWA Botswana and WUC used different standards. DWA Botswana has standards for effluent discharges in rivers and for re-use for irrigation.

In the absence of any specific legislation for disaster management, the declaration of disasters is currently backed by Chapter 22 of the Emergency Power Act. There exist other pieces of legislation relevant to disaster risk management in that they either directly address issues relating to disaster vulnerability or indirectly address risks of natural and/or man-made hazards. (NDMO, 2010). Botswana has also approved a

National Policy on Disaster Management in 1996. The National Disaster Risk Management Plan (NDRMP) provides a guideline to plan and implement responses against disasters in the country

#### 6.3.2.2 *Moçambique*

The most important legal document in what concerns water resources management in Moçambique is the Water Law (Law 16/91). The Law establishes water resources that are public domain, principles for water management, a general regime for water use and the rights and obligations of water users, with a distinction established between waters of free use and those which use is depending on a licence or concession. Regarding the water use and exploitation, the waters are classified into waters of common use and waters of private use with the provision of water for consumption and sanitation by the population being the main priority. The Law stipulates that Waters of common use are free – they do not require any licence or concession nor is any payment of tariffs involved while waters of private use need an authorisation by licence or concession.

Moçambique adopted the Water Policy in 2007. This Policy superseded the first policy from 1995 which introduced key reform elements such as reduced direct implementation by government, increased private sector roles, recognition of water and sanitation services as both social and economic goods, and the application of the demand-responsive approach to service provision, especially for rural areas.

The National Water Resources Management Strategy (ENGRH) 2007 is aimed at improving the implementation of the National Water Law. The ENGRH recognises that the country is vulnerable to the occurrence of extreme events such as floods and droughts and defines strategies that will help to mitigate and manage these events.

The Environment Law (Law no. 20/97) prohibits pollution as well as activities that accelerate erosion, desertification, deforestation or any other form of environmental degradation except as permitted by law. Regulations relating to standards for environmental quality and effluent emissions were published in the Government Bulletin in June 2004 (Decree No 18/2004). The purpose of these regulations is to establish the standards for environmental quality and for effluent emissions, aiming at the control and maintenance of the admissible levels of concentration of pollutants in the environment. Water quality is covered in Chapter III of the regulations.

The Master Plan for Disaster Prevention and Mitigation approved in May 2006 and Disaster Management Policy of 1999 are the main policy documents for disaster risk reduction in Moçambique. Moçambique has also developed a (National Action Plan for Adaptation (NAPA) as the main strategy document dealing with climate adaptation within the country.

#### 6.3.2.3 *South Africa*

Water Resources Management in South Africa is primarily governed by the National Water Act (36 of 1998). In the context of transboundary water management, 'meeting international obligations' is stipulated as one of the purposes of the Act.

Section 21 of the Act defines eleven types of water uses, including abstraction, storage, stream flow reductions, recreational use, discharge of waste, diverting and impeding flow, controlled activities and altering the bed, banks or characteristics of a water course. The NWA makes provision for only one right to water - the Reserve, which is the water required for basic human needs and for maintaining ecosystem functioning.

All other water use is subject to a four-tiered use authorisation/ licensing system defined in Section 22 of the Act.

The NWA is complemented by the National Water Resource Strategy, Edition 2 which provides the framework for the protection, use, development, conservation, management and control of water resources for the country as a whole. In addition, the supply of basic water and sanitation services is regulated in the Water Services Act (108 of 1997).

The South African National Water Policy (1996) and National Water Act (NWA) are explicit about the need to protect aquatic ecosystems in order to allow for sustainable achievement of social and economic benefits from these systems. In addition to the National Water Act, aspects of water quality management are regulated in the National Environmental Management: Waste Act No. 59 of 2008 (NEMWA). The Act contains a broad definition of “waste”, which includes substances that are “surplus, unwanted, rejected, discarded, abandoned or disposed of”. The National Framework Policy for Water Quality Management introduces the precautionary approach with a concomitant waste reduction and minimisation strategy.

The Disaster Management Act, (2002) provides for an integrated and coordinated policy of disaster risk reduction in which the main emphasis is on disaster risk reduction and aspects of post-disaster recovery. The White Paper on Disaster Management (1999) recognises that measures taken in South Africa have the potential to increase or reduce risk in neighbouring countries while threats in countries beyond South Africa’s borders have the potential to increase or reduce disaster risk in the country. In addition South Africa launched the National Climate Change Response Green Paper in 2010, which is part of a policy process that builds on the 2004 National Climate Change Strategy.

#### 6.3.2.4 *Zimbabwe*

The Water Act (1998) sets the parameters for access to and use of water as well as providing for the establishment of catchment and sub-catchment councils composed of elected representatives. Under this Act all water in Zimbabwe vests in the President and no water shall be capable of being privately owned with use rights being conferred through a permit.

In terms of the Water Act (1998), pollution of water is an offence and the Act operates through the “polluter pays" principle. Section 13 of the Act lays out the requirements to define the maximum permissible levels of pollution within the catchment area concerned, subject to prescribed quality standards. The Water Act is complemented the Water (Waste and Effluent Disposal) Regulations of 2000 based on the Water Act. Furthermore, the Public Health Act (Chapter 15:09), and the Environmental Management Act (Chapter 20:27) as well as by-laws passed by local authorities are applicable to water quality management.

The Civil Protection Act (1989) is the legal instrument for disaster management in Zimbabwe. Part IV of the Act focuses on prevention and recognises the linkages between disasters and development. Regarding the water related disasters, Sections 61 and 99 of the Water Act (1998) address the issues of water shortages due to droughts and safety of dams respectively and adopt a unified approach to the management of surface water and groundwater. Part IX of the Environmental Management Act deals with the environmental quality standards and has a bearing on disaster prevention.

### 6.3.3 National Development and Sector Policy Framework

#### 6.3.3.1 *Botswana*

The long-term development planning in Botswana is guided by the Vision 2016. The Vision emphasises that water resource management and development planning need to be fully integrated in the economic development of the country. Guided by the Vision 2016 Botswana develops National Development Plans (NDPs) as the main economic and development planning instruments. The current NDP 10 covers the years 2009 - 2016.

Botswana's first National Policy on Agricultural Development (1991) is currently undergoing a review. The key objectives of the policy are to improve food security at the household level; diversify the agricultural production base; increase employment opportunities; provide a secure and productive environment for agricultural producers and conserve scarce agricultural land resources for future generations and to enhance rangeland management.

The National Ecotourism Strategy (2005) complements the Botswana Tourism Master Plan (2000) and creates an environment in which all elements of tourism development planning and management facilitate, promote and reward adherence to the key principles of ecotourism by everyone involved in the tourism industry.

The Wildlife Conservation and National Parks Act has the aim to conserve and manage wildlife and implement international conventions to which Botswana subscribes, on the protection of fauna and management of national parks and game reserves. The Botswana Biodiversity Strategic Action Plan identifies challenges posed by climatic change especially to water resources as its effects are still not sufficiently known and as it cannot be addressed directly. Botswana has further developed several policies that support the implementation of biodiversity management.

#### 6.3.3.2 *Moçambique*

The Vision and Strategic Options of Agenda 2025 is an all-encompassing development vision for the country and guides its macro-level strategic planning. With respect to water resources management the Vision recognises that the country is extremely vulnerable to natural disasters and any change in the environment, such as droughts, floods, or cyclones, has serious consequences for the living quality of people and disorganises their livelihoods. Guided by the Vision the Moçambican government develops five year development programmes, which are operationalised by the Poverty Reduction Action Plan (Plano de Acçãopara a Redução da Pobreza - PARP) and anchored in the Agenda 2025. The current PARP (2011-2014) presents general objectives and priority areas that the country must address by 2014.

The National Irrigation Policy and its Implementation Strategy (NIPIS) were formulated in 2002 and recognised the great strategic importance of irrigation, and established a set of guiding policy principles. The guiding principles for the policy include ensuring integrated water management for multiple purposes in agriculture and rural development and activate the development of irrigation potential in Moçambique through the promotion of new irrigation schemes of medium and large scale. The Food and Nutritional Security Strategy (ESAN) was developed in 1998 and is the base for the overall government strategies related to rural development and food security.

The Poverty Reduction Strategy, (PARP II) mentions the Industrial Policy and Strategy (2007), the SME Strategy (2007) and the Business Climate Strategy (2008) as strategies aimed at national economic growth. The Industrial Policy and Strategy adopted in 2007 intends to stimulate production and productivity in the country. Amongst others, the policy aims to focus on areas that have a major economic and social impact, such as the food-processing industry, with its capacity to maximise agricultural and fishery potential, and in turn providing multi–sectorial linkages, employment, and import substitution as well as increased and diversified exports and promotion of the vertical and horizontal integration of the food security sector

The Forestry and Wildlife Policy and Strategy (Políticia e Estratégia de Desenvolvimento de Floresta e Fauna Bravia 1997) sets out the framework for protection, conservation and sustainable use of forest and wildlife resources for the economic, social and ecological benefits of present and future generation of Moçambicans (Candace, 2001). The Environmental Act (1997) provides the framework for environmental protection in the country. In addition, the Moçambique Biodiversity Strategy has the overall goal to conserve the biological diversity and the maintenance of the ecological systems and processes taking into account the need for sustainable development and fair and equitable distribution of the benefits arising from the use of biological diversity.

#### 6.3.3.3 *South Africa*

The National Development Plan (NDP) - Vision for 2030, is a long term national development framework with the overall goal to eliminate poverty and reduce inequalities. In its Chapter 4 on economic infrastructure the NDP deals with the development of water resources. The Department of Water Affairs has also developed the Water for Growth and Development Framework in 2009, which aims at providing sufficient water for the country to achieve its 6 per cent economic growth target.

The Integrated Food Security Strategy (IFSS) of 2002 aims to facilitate the right to have access to sufficient food as provided by the Constitution of the country. South Africa’s food security is susceptible to drought, therefore, the government formulated the Agricultural Drought Management Plan (ADMP), which points out that drought management will be enhanced through the implementation of water storage, water transfer and hydropower infrastructure required for agriculture, agro-processing, tourism and forestry projects.

The White Paper on Development and Promotion of Tourism in South Africa formulated in 1996 is the overarching policy framework and guideline for tourism development in South Africa. The Responsible Tourism Guidelines were designed during 2001 to provide national guidance and indicators to enable the tourism sector to demonstrate progress towards the principles of responsible tourism embodied in the 1996 White Paper. The Responsible Tourism Guidelines outlines a set of guiding principles for economic, social and environmental responsibility.

The Protected Areas Act requires that South African National Parks produces management plans for all national parks in consultations with relevant stakeholders. The National Environmental Management Act NEMA (1998) seeks to provide for cooperative environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote cooperative governance and procedures for coordinating environmental functions exercised by organs of state.

#### 6.3.3.4 *Zimbabwe*

The Medium Term Plan (MTP) 2010-2015 is Zimbabwe's National Development Plan which responds to the mandate set out in Article III of the Global Political Agreement (GPA) to support the restoration of economic stability and growth in Zimbabwe. National priorities in the MTP include water infrastructure development with the key objective to restore basic services, and to provide an efficient and reliable infrastructure network to facilitate smooth business and social operations, stimulate economic growth and socio-economic development.

The Zimbabwe National Agricultural Policy Framework (1995-2020) aims at facilitating and supporting the development of a sustainable and competitive agricultural sector that assures food security at national and household level and maximises the sector's contribution to GDP.

The Industrial Development Policy (IDP), 2012-2016 is the new overarching policy document for industrial development in Zimbabwe. The policy identifies four (4) priority sectors as the pillars and engine for the IDP 2012–2016, namely Agri-business (food and beverages, Clothing and Textiles, Leather & Footwear and Wood and Furniture), Fertiliser and Chemicals Industry, Pharmaceuticals, Metals & Electricals. The policy also recognises that the success of this IDP hinges upon addressing other issues that affect the industry, such as infrastructure and utilities.

The National Environmental Policy and the Environmental Management Act contain instruments that facilitate the sustainable management of natural resources at the local and national levels. Under the National Environmental Policy, the country has committed itself to the development of a National Environment Action Plan (NEAP), Local Environment Action Plans (LEAPs) and Environment Management Plans (EMPs) in accordance with its commitments made under the Rio Convention on Environment and Development (Agenda 21). The Policy for Wildlife (1992) is Zimbabwe's policy towards protected areas and wildlife.

## 6.4 INSTITUTIONS AND ROLES

***(Refer Technical Annexure Volume D2: Institutional Arrangements in the Limpopo Basin)***

### 6.4.1 Regional

#### 6.4.1.1 *SADC Water Sector*

SADC has the broad aim to support the economic growth and sustainable development of the Southern African region and in so doing to secure peace and security, to alleviate poverty and enhance the standard and quality of life of the peoples of the region. This support is based upon the principle of integration, democracy and equity.

The SADC Water Sector supports this intent at policy, programmatic and project level, as reflected in **Figure 6.2.**

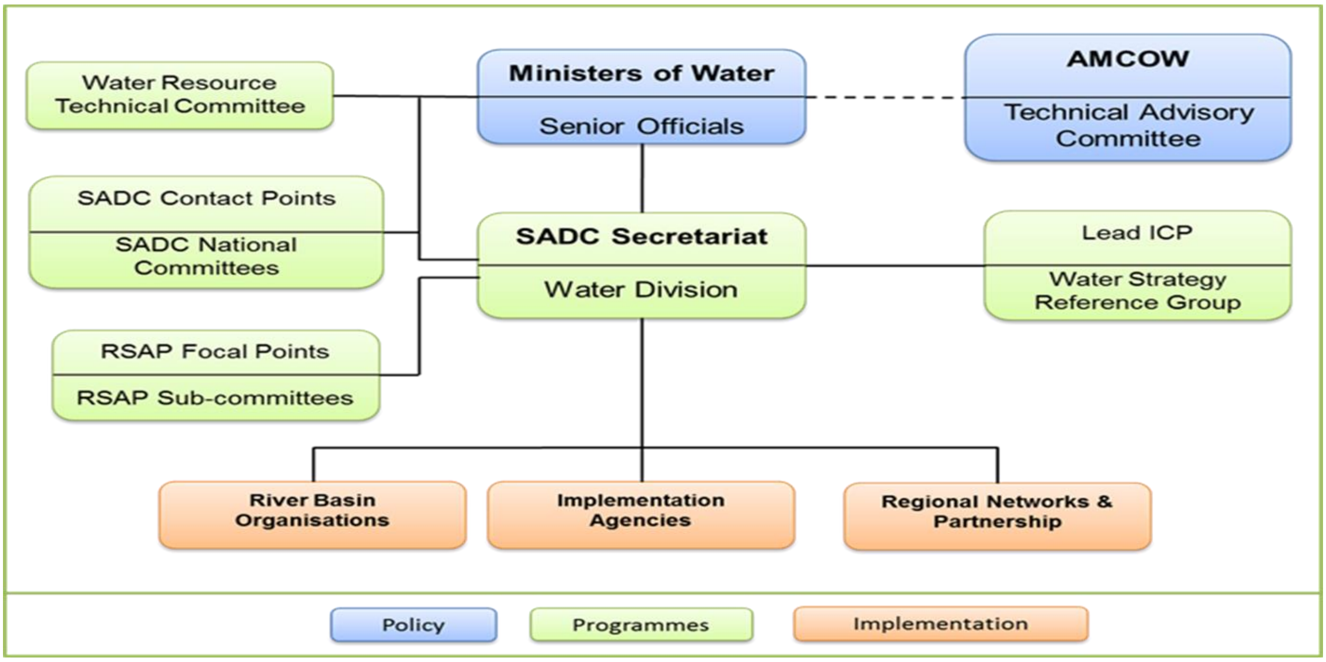



**Figure 6.2:** The SADC Water Sector (after SADC, 2011)

The **SADC Water Division** works together with SADC Member States in supporting, facilitating and coordinating the implementation of regional water related activities. This is done at regional, transboundary basin and national levels. In effect, the SADC has an advocacy objective to ensure that the shared water resources of the region are managed, protected, and used in a sustainable manner. This is encapsulated in a range of policy documents. Furthermore, and towards this end, the SADC Water Division encourages harmonisation in policy in support of IWRM.

At the level of River Basin Organisations, the SADC Water Division's role is to:

- Ensure the implementation of the Treaty and Revised Protocol on Shared Watercourses
- Identify and mobilise resources to support RBOs,
- Promote pilot/demonstration projects,
- Strengthen and capacitate RBOs,
- Develop and promote stakeholder participation strategy, and
- Sustain political support

The SADC Water Division has a number of work programmes which are all part of the Regional Strategic Action Plan. Launched in 2011, Regional Strategic Action Plan III has the focus of strengthening the enabling environment for regional water resources governance, management and development through the application of IWRM at the regional, river basin, member state and community levels.

As such the key challenges being faced within the Limpopo basin, namely water allocation, water quality management and disaster management, can be seen within the various support activities of the SADC Water Division, which hence must be seen as a key partner for the future.

### 6.4.2 Limpopo River Basin

A number of bilateral agreements exist and serve to coordinate technical matters between the two states. A Joint Water Commission exists between Moçambique and South Africa, whilst the Joint Permanent

Commission for Co-operation facilitates discussion between Botswana and South Africa. South Africa and Zimbabwe are in the process of establishing a Joint Water Commission.

**Table 6.1:** Transboundary Institutions established within the Limpopo Basin

| Institution | Responsibility |
|---|---|
| **Limpopo Basin Permanent Technical Committee (LBPTC)[2]** | Established in 1986 between Botswana, Moçambique, South Africa and Zimbabwe to advise the parties on transboundary issues related to the management and utilisation of the Limpopo |
| **Joint Permanent Technical Commission (JPTC)** | Formalised in 1987 between Botswana and South Africa on the management of Limpopo, Molopo and Nossob Rivers. One of the key outputs of the JPTC was the Joint Upper Limpopo Basin Study (JULBS),which was made to investigate a range of issues including evaluate the most successful and cost effective way of jointly exploiting and regulating the main stem river. |
| **Joint Water Commission (JWC)** | Formalised in 1996 to provide a technical forum to advise the two Governments of Moçambique and South Africa on technical matters relating to the development and utilisation of water resources of common interest. |
| **Joint Permanent Commission for Co-operation (JPCC)** | Established in 1997 between Botswana and South Africa with the aim of dealing with a variety of operational issues, including the transfer of water from the Molatedi Dam on the Marico River |
| **Limpopo Watercourse Commission (LIMCOM)** | Established in 2003[3] 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 |

The "Agreement on the Limpopo Basin Permanent Technical Committee" was signed by representatives from Botswana, Moçambique, South Africa and Zimbabwe in 1986 and provided the legal framework for the Limpopo Basin Permanent Technical Committee (LBPTC). The objective of the LBPTC was to advise the parties on transboundary issues related to the management and utilisation of the Limpopo River.

Whilst its appears that the LBPTC was relatively inactive for a period during the mid-1990s, the LBPTC was important in that it provided a platform to ensure that dialogue and negotiation occurred between the riparian countries leading to the establishment of the Limpopo Watercourse Commission (LIMCOM)[4].
Article 7 of the LIMCOM Agreement outlines the functions of the commission and notes that the Commission is a technical advisor with regards to the development, utilisation and conservation of the water resources of the Limpopo, but may take up additional functions related to the development and utilisation of water resources as agreed upon by all parties (see further detail in section 6.3.1 above). .

[2] The LBPTC was replaced by LIMCOM with the entry into force of the LIMCOM-Agreement

[3] While the agreement establishing LIMCOM (LIMCOM Agreement) was signed in 2003, it entered into force only in 2011, thus LIMCOM was formally legally established in 2011 and replaced the LBPTC from that time onwards.

[4] See detail on LIMCOM in section 6.3 above

The LIMCOM comprised of the Council, as the principal organ of the commission, as well as a secretariat and a number of task teams, **Figure 6.3.**

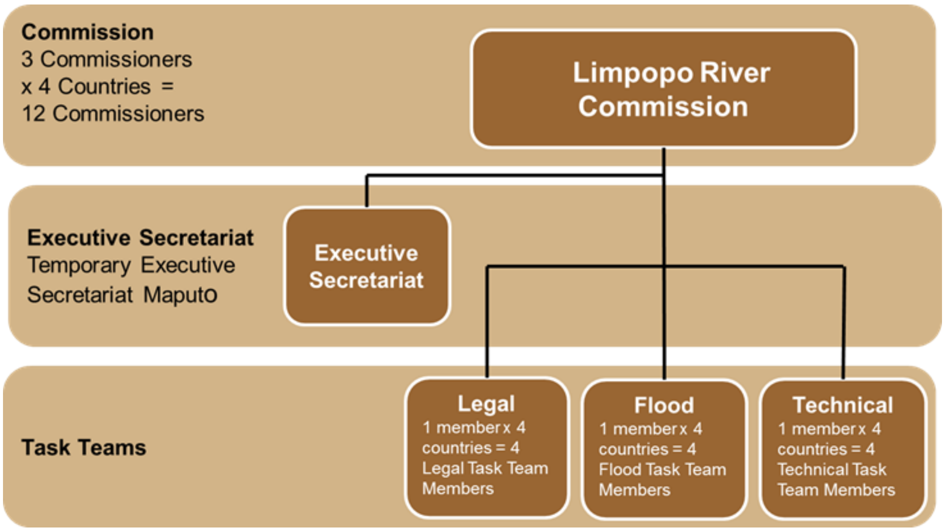



**Figure 6.3:** Structure of the Limpopo Watercourse Commission (from Limpoporak)

The Secretariat is established to coordinate and facilitate the functioning of the Council and related activities.

To date three task teams have been established to provide legal, flood (disaster management) and technical inputs and advice on specific matters and projects as identified by the Council. These comprise of four members, namely one representative per member state.

### 6.4.3 National

Fundamentally, water resource management within the basin is implemented at national levels through the various institutions and structures in-country. The states face similar challenges, albeit at varying scales, on a shared resource and recognise that the broad principles of IWRM are critical. It is of value to note that with the harmonisation of policy and law that has evolved over recent years, clearly with the SADC policy supporting and guiding this, that the institutional arrangements within the member states are showing a a high degree of commonality However, the member states do find themselves at varying levels of implementation at this juncture. This does have an impact upon how water resource management is implemented, and as capacity is a significant concern across the region, the ability of member states to actually adhere to the advice provided by LIMCOM could in effect be limited.

#### 6.4.3.1 *Botswana*

The Ministry of Minerals, Energy and Water Affairs (MMEWA) has overall responsibility for water policy, assisted by the Department of Water Affairs (DWA), Department of Geological Surveys (DGS), Water Utilities Corporation (WUC) and the Ministry of Local Government (MLG) through District Councils (DCs) (Kgomotso, 2005

Botswana's water sector is regulated by the Water Act of 1968 that provides for the establishment of the Water Apportionment Board (WAB). WAB is a quasi-judicial body charged with the responsibility of administering conditional rights to abstract and use both surface and ground water (Kgomotso, 2005; Earle et al, 2008). The planning, construction, operating, treating, maintaining and distribution of water resources in Botswana's urban centres and other areas mandated by the government are undertaken by the WUC.

The Ministry of Local Government and Lands (MLGL) whilst responsible for land use planning, environmental investigations and the preparation of the National Conservation Strategy is an important sister Ministry in that its responsibilities include the operation of water supply to the rural villages. This is undertaken through the more localised District Councils.

It is important to note that Botswana is undertaking a Water Sector Reforms Project (2008-2013). A draft Water Bill is in place that aims to put sustainable water resource development and sustainable water supply at the centre of policy. Botswana at present generally does not have provisions for the empowerment of stakeholder groups in water management, with the government generally structured in a more centralised manner. Therefore, one of the objectives of this project has been to redefine and change the roles of institutions and major stakeholders.

Accordingly, new institutions will be established via the new Water Act and include:

- **Water Resources Board**: An advisory body to the Minister of Minerals, Energy and Water Resources on water matters. It will have the responsibility to allocate water resources among users, monitor water resources, and to develop water resources management policy.

- **Water Management Area Bodies**: investigate and advise interested persons on the availability, protection, use, development, conservation, management and control of water resources in its water management area; contribute to the development of the national water resources strategy; in conjunction with the Water Resources Board, develop the area's water resources strategy and coordinate, and its implementation; co-ordinate the activities of water users within its management area; and promote community participation in the protection, use, development, conservation, management and control of the water resources in its area.

- **Village Water Development Committees**: advise residents on the protection, use, development, conservation, management and control of water resources in the village area; ensure that water is used in compliance with any regulations applicable to the water resource concerned; promote community participation in the protection, use, development, conservation, management and control of the water resources in its area; contribute to the development of the national water resources strategy.

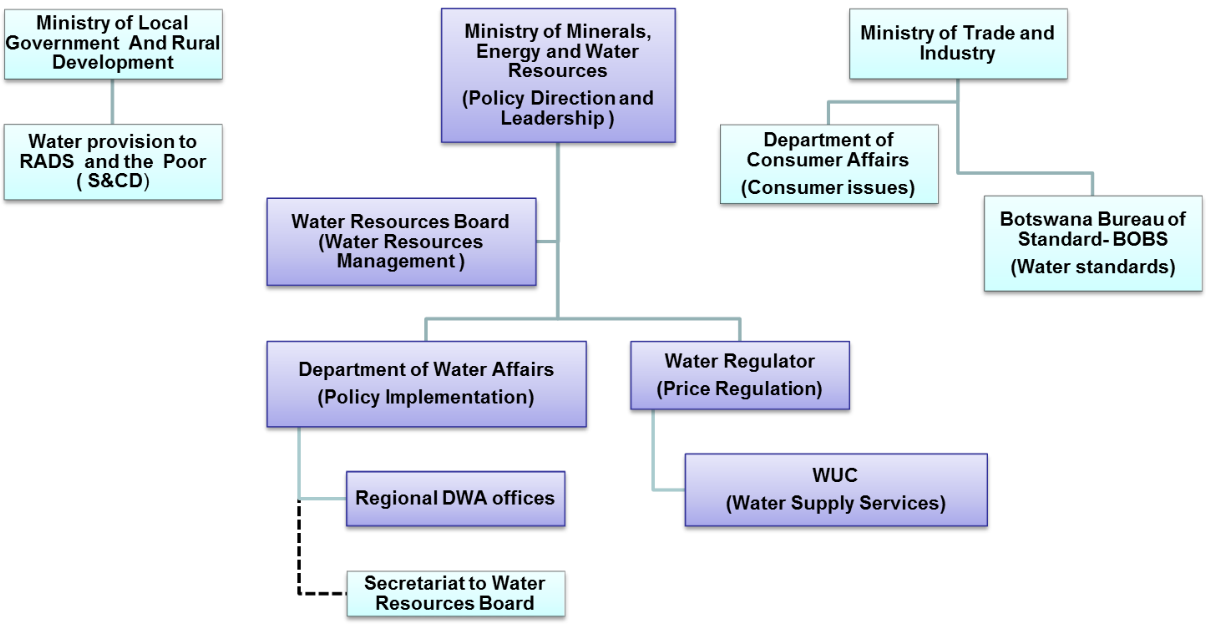



**Figure 6.4:** Future Water Sector Framework for Botswana after completion of water sector reform

### 6.4.3.2 *Moçambique*

Moçambique is in the process of transforming the water sector to a model of decentralised management. The National Water Policy aims to decentralise water resources management to autonomous entities at the basin and provincial levels. The National Water Council is the body that defines water policy whilst the National Directorate for Water (DNA), as part of the Department of Public Works and Housing, is responsible for planning, regulatory and monitoring functions regarding water resources as well as for the provision of water supply and sanitation.

The DNA has established an Department of International Rivers (Gabinete de Rios Internacionais – GRI), which is mandated with liaising with neighbouring countries and with the SADC Water Sector.

The National Directorate for Agricultural Hydraulics within the Ministry of Agriculture and Rural Development maintains responsibility for activities relating to irrigation and drainage.

The 1991 Water Law emphasises the need for inter-sectoral coordination and instituted an institutional framework to enable this through the National Water Council. The National Water Council was established as an advisory committee under the Water Law designed to advise the Government on issues related to water management and the implementation of water policy (DFID 1999; see also Limpopo River Awareness Kit).

The Technical Water Council (TWC) has the same representation as the NWC, but is represented at the more technical level (by National Directors) from the relevant ministries this being aimed for a more operational coordination. The TWC acts as advisor to the Department of Public Works and Housing and the DNA.

Article 18 of the Water Law gives jurisdiction over water management to Regional Water Authorities (RWA or Administração Regional de Águas – ARA), which were established on the basis of water basins (DFID 1999). The five RWAs (ARAs) are responsible for the management of water resources and each ARA manages several basins being simultaneously close enough to expedite management and coordination with political authorities (LBPTC, 2010). ARA-SUL is operational within the Limpopo basin and is responsible for a suite of water resource management and related functions including operation and maintenance of dams, monitoring, flood management, and water use licensing. The RWA/ARAs maintains financial and organisational autonomy, but report to the National Water Directorate that has an oversight responsibility.

River basin management institutions (UGBs) are intended to be established to manage water resources at a catchment scale. In order to create a more participative environment River basin management committees (RBCs) are being established as consultative bodies to work with the UGBs, and consist of government representatives, water users and representatives of civil society (GWP, 2009). The UGBs are to be focused on the actual management of water resources at these localised levels, to assess water situations (droughts/floods) as well as undertake the collection of fees at the local level. This framework is outlined in **Figure 6.5**.

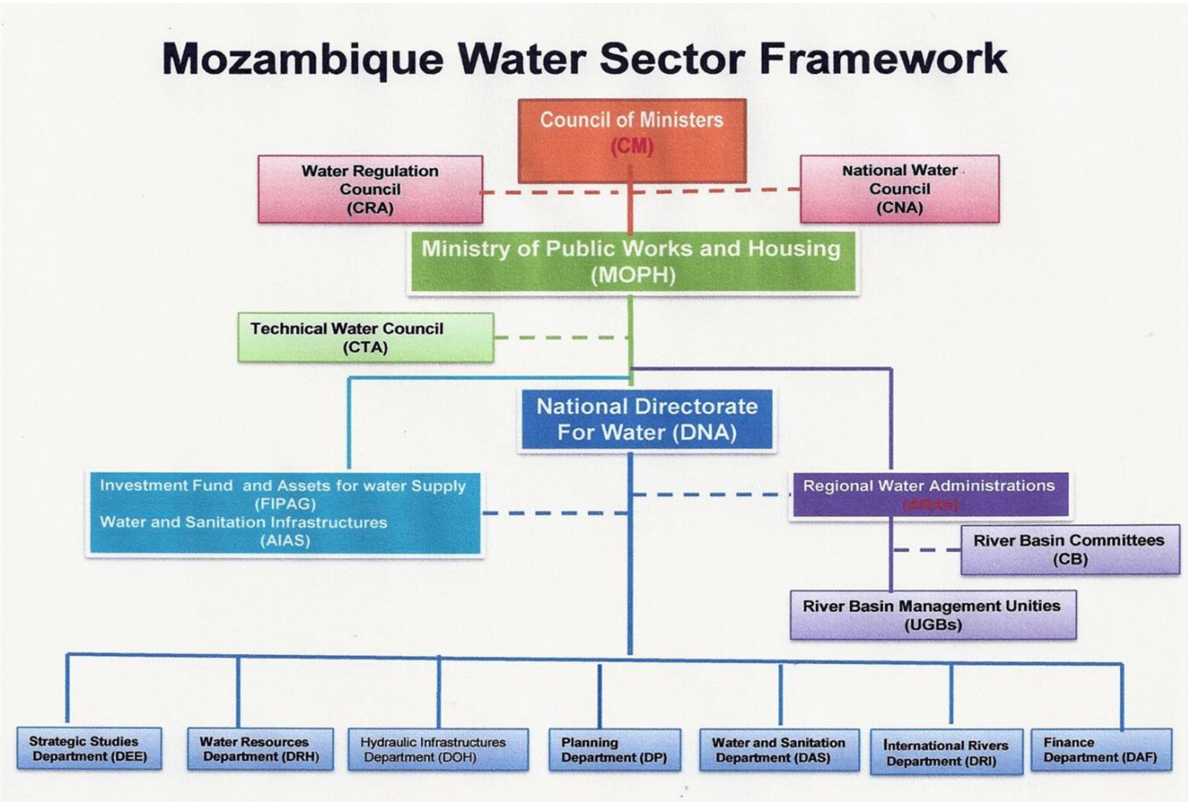



**Figure 6.5:** Water Sector Framework for Moçambique

By 2009, no UGBs or river basin management committees (RBCs) appear to have been established for the Limpopo River basin. This is due to capacity constraints both from a technical and managerial perspective as well as from financial basis (TPTC, 2008; GWP, 2009). Localised water users can establish water user associations and have very direct management and operational responsibilities. However, these have not been actively established to date and those that have appear institutionally weak and uncoordinated (TPTC, 2008).

#### 6.4.3.3 *South Africa*

As with all the member states within the Limpopo basin, South Africa has also embarked on decentralising the management of water resources. This has initially resulted in establishment of nine DWA regional offices nationally. Within the Limpopo basin two regional offices, namely the Mpumalanga Regional Office and the Limpopo Regional Office are present with the former taking responsibility for the Olifants water management area and the latter taking responsibility for the Limpopo water management area. Whilst the regional offices have a water resources and water sector support mandate, they also have a clear regulatory mandate. This means that in the key arenas of water quality management, water allocations and authorisations and disaster management, these offices have key functions.

The National Water Resource Strategy (NWRS) sets the framework for managing water resources in terms of water management areas, according to hydrological boundaries. This strategy recognises the need to establish suitable water management institutions, primarily Catchment Management Agencies (CMAs) and Water User Associations (WUAs), to be able to achieve the purpose of the NWA. The initial NWRS laid out a framework to establish a CMA in all the 19 Water Management Areas (WMA) of South Africa, but that has since changed with the latest revision of the strategy to only nine CMAs each being responsible for two or more WMAs. The purpose of establishing a CMA is to delegate water resource management to the regional or catchment level and to involve local communities, within the framework of the NWRS.

The Limpopo Catchment Management Agency (LCMA) will be responsible for the Crocodile (West) and Limpopo WMAs, which cover all of the Limpopo Basin in South Africa, except the Luvuvhu/Letaba and Olifants WMAs which are yet to be established and has been prioritised for establishment due to the water resource pressures that are being faced within this water management area. The function of the Limpopo CMA in the first instance, as set out in the National Water Act (Act 36 of 1998) will be to advise on water resource management issues, including water use authorisations, to develop and implement a catchment management strategy, to coordinate with all institutions and to facilitate stakeholder engagement. The functions of the CMA will develop over time as the CMA develops capacity. Within a five year time frame it aimed that the CMA will be a ‘responsible authority’ and will have powers and functions delegated to enable the CMA to issue water use authorisations and to issue compliance monitoring and enforcement directives.

The Trans Caledon Tunnel Authority (TCTA) is an institution that has taken responsibility for the construction of several bulk water infrastructure that had to be funded with funds outside National Treasury of South Africa. As the TCTA had access to loans from foreign institutions, e.g. the World Bank, the TCTA was the ideal vehicle to implement bulk water projects.

Water services provision is guided by the Water Services Act (Act 108 of 1997) which provides for Water Services Authorities (WSA) that have the responsibility to plan and oversee the provision of water services that are undertaken via a Water Services Provider (WSP). The Department of Water Affairs does play a role in overseeing the performance of water services provision in terms of meeting water provision and water quality standards.

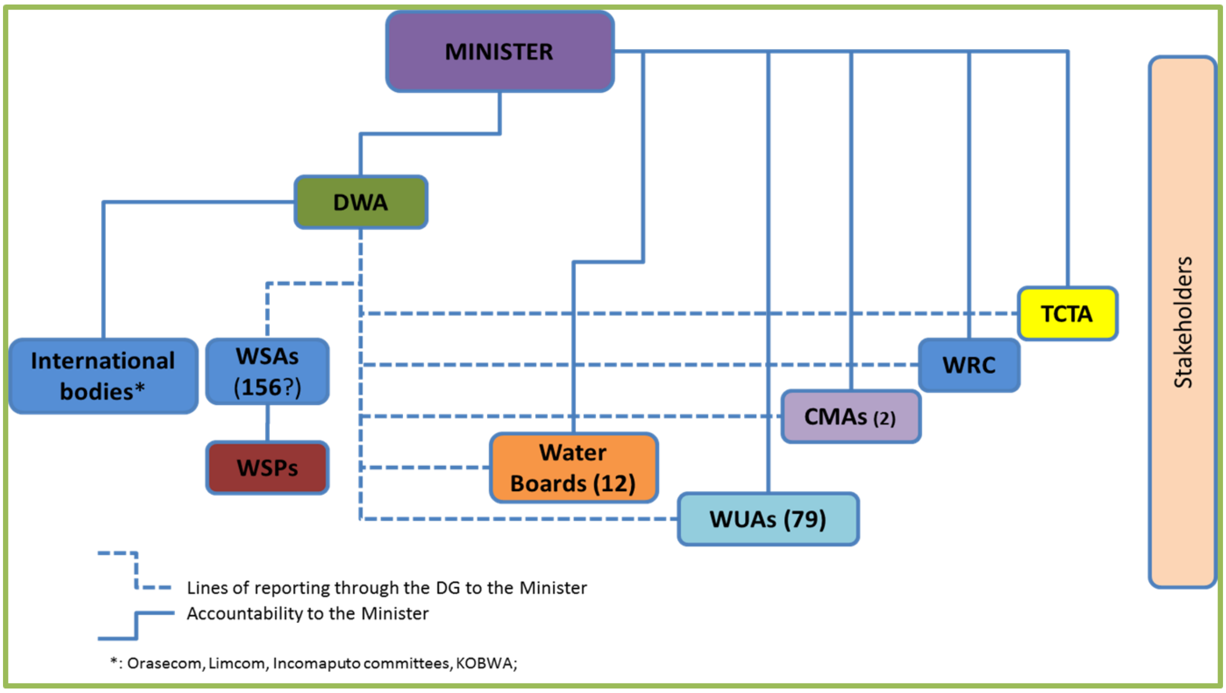



**Figure 6.6:** Institutional Arrangements for Water Resource Management in South Africa

### 6.4.3.4 *Zimbabwe*

In 1998, a new Water Act and the Zimbabwe National Water Authority Act (ZINWA Act, 1998) were passed providing for a shift from centralised water management to a decentralised system of water management. This system was structured around the hydrological boundaries of river basins. The ZINWA Act, Section 5(1) d, states a primary goal to: “Promote an equitable, efficient and sustainable allocation and distribution of water resources” and as such the legislation formalised IWRM as a principle with the key element of stakeholder engagement as a central thematic (Mapedza & Geheb 2010).

The Ministry of Water Resources Management and Development is the custodian of water rights and develops policies on water development. The Department of Water in the Ministry of Water Resources Management and Development maintains responsibility and oversight for the water sector. ZINWA is responsible for water supply to urban centres, while the municipalities supply water to smaller urban settlements. Rural water supply and sanitation is coordinated by the National Action Committee for Water and Sanitation, which is an inter-ministerial committee chaired by the Minister of Local Government.

The process to develop a Water Resources Management Strategy was completed in 2000, and from this process a new national Water Policy and a National Water Pricing Policy and Strategy were developed. The overall goal of the National Water Resources Policy is to “Promote the sustainable, efficient and integrated utilisation of water resources for the benefit of all Zimbabweans”. This resulted in the division of the country into seven Catchment Councils (CCs), consisting of Gwayi, Manyame, Mazowe, Mzingwane, Sanyati, Save, and Runde (Mapedza and Geheb 2010).
CCs are established by the Minister of Water Resources Management and Development, in consultation with the ZINWA. The functions of ZINWA are to advise the Minister on the formulation of national policies and standards on water resources planning, management and development, water quality and pollution control and environmental protection, hydrology and hydrogeology, dam safety and borehole drilling and water pricing among others. See **Figure 6.7.**

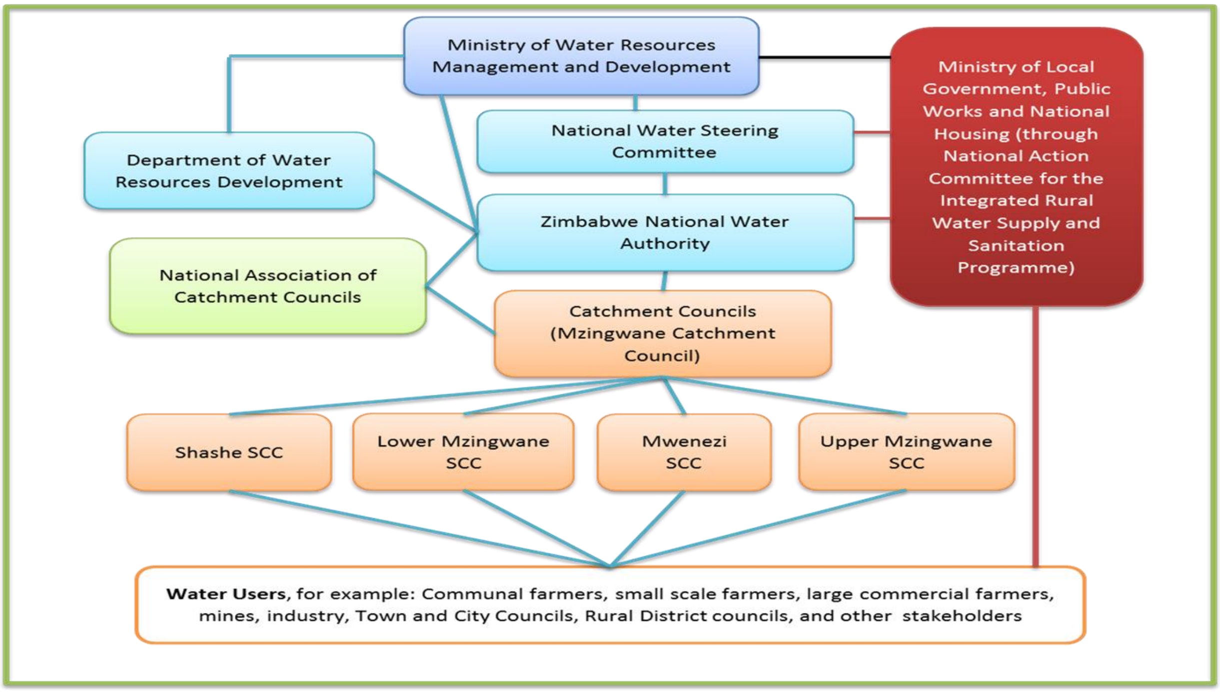



**Figure 6.7:** Institutional Arrangements for the Water Sector in Zimbabwe

The seven CCs established under the ZINWA Act are responsible for all aspects of water management within their responsive catchment areas. The Catchment Managers are employees of ZINWA, and not employed by the CCs.

Sub-basin Councils (SCCs) have jurisdiction over sub-basin areas, where the composition of SCCs does not differ from that of CCs. SCCs consist of elected representatives from all the stakeholder groups. The maximum number of the representatives per catchment or SCC is 15. Stakeholder representatives on the SCCs elect their own chairperson and vice chairperson who then represent them on the CC.

## 6.5 MAIN GOVERNANCE AND CHALLENGES

### 6.5.1 Policy and legal

At basin-level, there is a relatively strong legal framework for water management in the Limpopo basin, consisting of the LIMCOM-Agreement and the complementary regional framework agreement, the Revised SADC Protocol for Shared Watercourses as well as basin-specific (bilateral) agreements concluded between Limpopo basin states. Similar regional or multi-lateral agreements are in place for other related management areas such as biodiversity management and transboundary parks.

At national level all basin states have strong legal frameworks for water management in place (or will soon have, after the completion of on-going reform processes). The national water legislation in all basin states is driven by IWRM principles and, importantly in the transboundary context, recognises international obligations with respect to the management of shared water resources. However, in practice, the alignment between international legal obligations and water management in the framework of national legislation commonly requires further refinement.

All countries in the basin pursue economic development policies that are strongly dependent on water availability and recognise such needs. Generally there is only a limited degree of alignment between economic development goals between the various water use sectors. This causes the potential for policy conflicts both between different national sector policies as well as between economic development policies/ plans of the different basin states. Whether such policy conflicts materialise in practice depends both on natural factors (i.e. water availability etc.) as well as on to which extent the various economic development policies can be coordinated and integrated into a coherent management and development plan for the basin.

### 6.5.2 Institutional

The institutional arrangements, in the various member states, are at differing levels of progress across the Limpopo basin. Whilst this may not immediately appear to be a challenge, this can introduce a level of complexity in terms of ensuring effective and uniform water resource management across the basin. During processes of institutional change there are typically governance gaps that emerge and operational tasks that may not be undertaken. For example, without Catchment Management Agencies being established in South Africa the development of Catchment Management Strategies is being held back (legally this is the responsibility of the CMA). The current “plans”, which are the Internal Strategic Perspective and Water Resources Overview are all close to a decade old, and so the need for up to date planning is being held back.

This slow shift in institutional frameworks also means that with states all at different stages, there is a mismatch in the institutional discourse across the larger basin. For example, in some instances one must communicate with the national department, in other instances the decentralised institution (Catchment Council or ARA) must be contacted. This complexity can have an impact upon operational issues and, quite importantly in this basin, can result in poor levels of regulation across the basin. This is important in a basin where allocation and water quality challenges are increasing.

In addition, the joined-up planning, that is critical in managing water resources that are under increasing levels of pressure, is still not as desired creating operational challenges through misalignment. This misalignment in planning can be critical for management emergency and disaster management, in the short term, as well as for longer term water resource planning.

From international levels through to local levels, the monitoring of actions and impacts is not really in place. This includes the monitoring of specific projects and actions and as a result, there is only a limited sense of how advice to parties is being translated into action in-country, and the impacts that this is having. From a more regulatory perspective, compliance monitoring and enforcement is only taking place in a limited manner that is not sufficient to deal with the pressure the resource is facing. Institutional challenges are clearly part of this story with the more localised institutions not yet playing the role that they should be in supporting project monitoring and compliance monitoring and enforcement.

Financial challenges are hampering institutional development across the region. Institutions are reliant on funds from central government as well as revenue generated from permits and water use. In many instances, these resources are limited meaning that core functions are not being undertaken as desired and the capacity required to take up functions is also not in place.

Capacity constraints, both internally (staff) and externally (stakeholders), are significant in all four countries and as such water sector staff are extremely stretched resulting in a water resource management regime that is not as effective as required. Noting that the pressures on water resources will only increase in the coming decades, there is a dire need to build capacity across the region.

## 6.6 RECOMMENDATIONS FOR FURTHER WORK

### 6.6.1 Legal and policy

A key objective for the further strengthening of the management regime in the basin would be to further the integration of the international and national legal frameworks. While these are legally coherent, it remains challenging in practice to align national water resources planning within countries with requirements at international level. This can only be achieved through the development of a coherent, basin-wide IWRM plan.

Likewise, the majority of national development and sector policies in the four basin states have an impact on water demand and water resources development options in the basin. In several areas, however, the policy objectives remain generic and concrete development and implementation plans are only developed over time. It is essential that water demands potentially emerging from the progressive implementation of policy objective are assessed in the early stages of sector planning and integrated into the basin-wide IWRM plan with sufficient lead time for water resources planning and development. This requires increasing cooperation and coordination with the planning agencies from all relevant economic development sectors, most notably in the Limpopo basin, agriculture, mining, energy and tourism.

### 6.6.2 Institutional

The institutional frameworks are in flux with progress being uneven across the basin. This has impact upon the connected planning that is required across the basin, as well as upon operational aspects and the levels of effective regulation across the basin. Challenges in terms of ensuring efficient and effective governance exist, but most significantly capacity constraints, within all member states, are considerable and require attention. It is apparent that whilst there is discussion between states on key technical issues, there is only limited exchange on institutional aspects. Much can be shared through such a discourse and whilst this can help to build capacity, this can also encourage institutional development as well as provide a mechanism for supporting and monitoring key institutional processes.

# 7. LIMPOPO INFORMATION MANAGEMENT SYSTEM (LIMIS)

***(Refer Technical Annexures Volumes E1, E2, E3 & E4: Data Audit, User Needs & Requirements, Data Dictionary) & User and Administrator Guide***

## 7.1 INTRODUCTION

The approach is to create an information management system focussing on the most essential data for trans-boundary water resource management. In addition to this, the overall objective is to provide the stakeholders of the Limpopo River Basin with access to the required, reliable data, based on the countries' information.

A web based MIS is in the process of being developed where stakeholders can upload and visualize data and information and where the envisaged data unit of LIMCOM can manage the system. The MIS will incorporate user access, document (information) management and guidelines and rules for populating the database.

### 7.1.1 Need for Information System

#### 7.1.1.1 *Objectives of the LIMIS*

The objective of the LIMIS is to provide the water authorities of the four member countries with a Management Information System (MIS) in order to share and exchange data and information for the comprehensive and effective management of the LRB. Furthermore, the MIS need to adhere to the following objectives:

- Develop the databases in such a way that they can contain all the data and information to meet the requirements of the secretariat;
- The development of a GIS integrated into the MIS;
- Effective data management in terms of populating and maintaining the database.

In addition to the above-mentioned objectives, the development of the MIS has to incorporate the following activities:

- Collate and capture the spatial information that is required to undertake the technical assessments of the study;
- Develop a spatial information Web GIS based database to be used by the decision-makers and stakeholders as a decision-support tool; and
- Implement quality control measures and procedures that will ensure the integrity of the spatial information database, thus producing spatial data that is consistent across international borders, and to deliver the information in formats that are compatible.

The MIS will also address the following objectives as defined in the TOR:

- ..."collection, collation, analysis, and synthesis in a systematic manner, of all available relevant information of the basin, to support LIMCOM with the implementation of the Limpopo IWRM Plan"...
- The MIS produced as part of the Monograph Study will therefore provide a baseline of the current situation in the basin in terms of water resources availability and utilisation which will assist with the monitoring and the development of basin scenarios.

## 7.2 LIMIS STRUCTURE

### 7.2.1 Design (lay-out) of the LIMIS

The MIS is to act as a consolidated "container" of all available relevant information and data as can be seen in **Figure 7.1**, which indicates the various elements of the MIS, as well as the flow of information.

The principle of the LIMIS is reflected as the following:

- Base information and data that provided from the components of the Monograph,
- Data and information from external models,
- Component requirements,
- User requirements in terms of data and information.

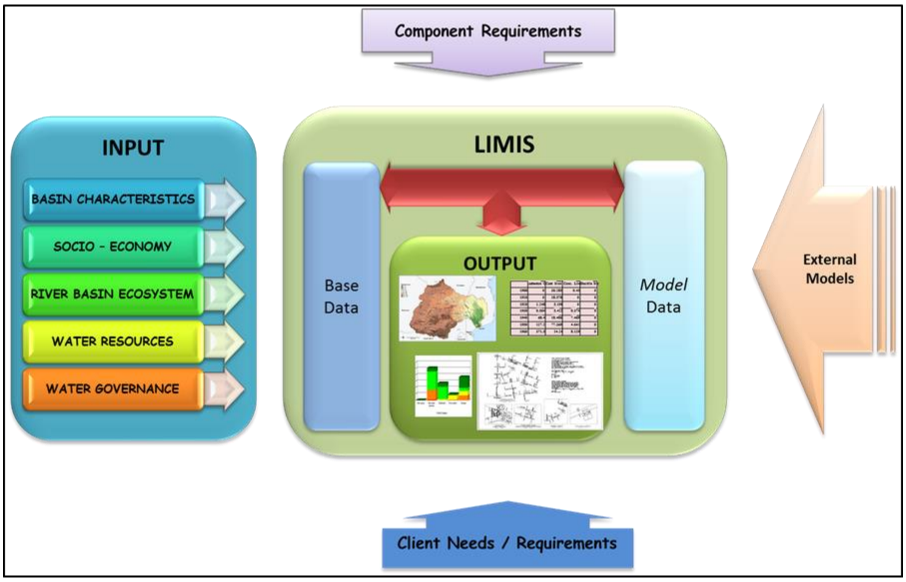



**Figure 7.1:** Layout of LIMIS

The design and the layout of the LIMIS are based on the functionality of a Management Information System, which provides information and data to the various users.

### 7.2.2 Detail Design

The detailed design of the LIMIS is based on the following broad components of a MIS, which are briefly described below. **Also refer to Volume E4 – User and Administrator Guide.**

- Logon page – user name and details,
- Home screen of the MIS – providing background information on the system and related aspects,
- Glossary – terminology and abbreviations,
- MIS – information and data functionality,
- Links –URLs to related sites,
- Documentation – relevant documents are made available,
- PDF maps – pre-generated maps that can be downloaded.

The LIMIS structure consists of five components, indicated by the LIMIS Page layout shown on **Figure 7.2.**

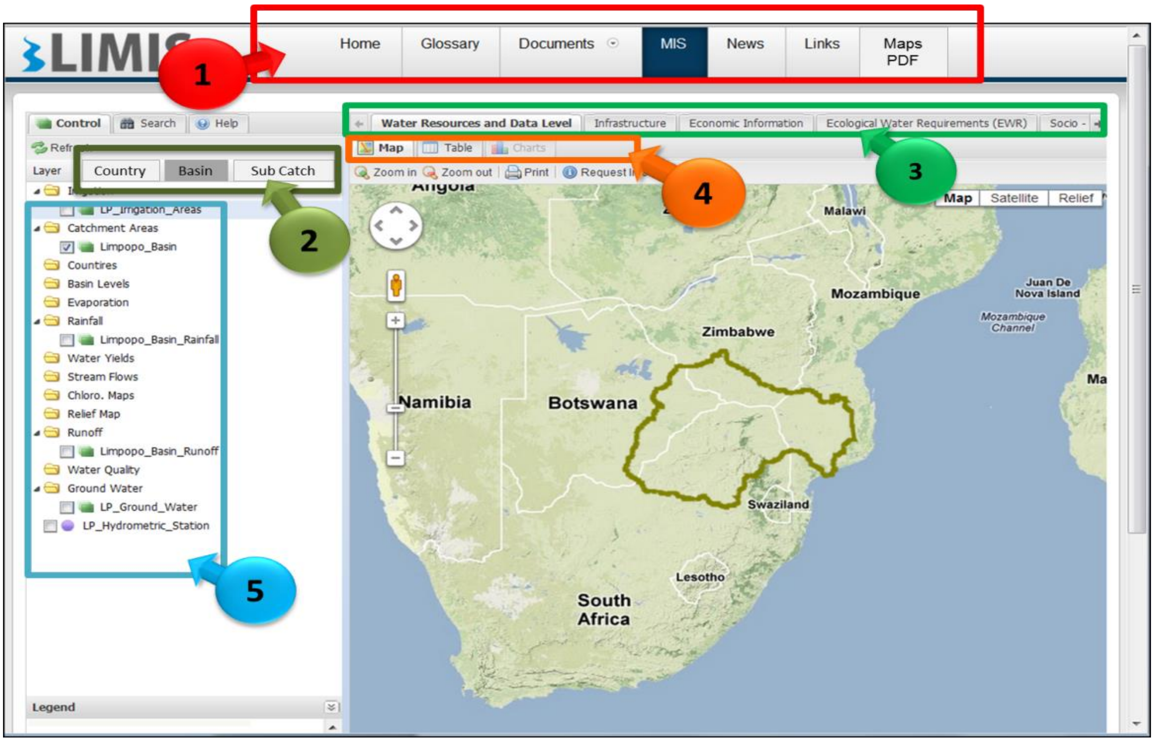



**Figure 7.2:** Selection bars in the LIMIS

The components are briefly described below in terms of functionality and user interface with the LIMIS. The first component is the "menu bar" that indicates the various groups of activities that can be selected by the user.

1 The first component of the LIMIS indicates the following:

- Home – landing page and related information,
- Glossary – provides information on terminology,
- Documents – will provide the user with documents that have been uploaded regarding the Limpopo Basin. Certain categories have been defined, in order to group the various documents.
- Management and Information System (MIS). This is where all the data is stored.
- News – any news that LIMCOM want to make available related to the basin,
- Links –links to related sites, which can be the Limpopo RAK, other basin MIS systems, etc.
- Maps PDF – are predefined maps that have been generated and saved in PDF format that can be downloaded and printed.

2 The second component will prompt the user to select or view the information on three levels:

- Basin – all information and data relates to the total basin,
- Country – information will be displayed on the selected country that will be available on a country level,
- Sub-Basin – the specific sub-basin will be selected and the data will be presented for this selected sub-basin.

3 The third component refers to the five themes as defined for the Monograph study. For purposes of the LIMIS this “bar” would refer to the monograph themes. The user can select a monograph theme option, which will then display the related data sets.

4 The fourth component refers to the option of presenting the data in a graphical manner, which will be either in a map, a table or a graph.

5 The fifth component displays the various data files that will be available, as these files have been predefined.

#### 7.2.2.1 *MIS (Information and Data Component) Development Platform*

The MIS was developed making use of Google API and Micro Soft ASP.Net development language. The database was developed in MS SQL, which hosts the data.

## 7.3 CONTENT

The LIMIS is totally dependent on data, that represents the five components of the monograph, as well as additional data that describes the basin, broad characteristics and related aspects. The objective of the MIS is to present correct and accurate data in a meaningful manner and to focus on the most essential data for management purposes. The data that are currently part of the LIMIS is indicated in the **Tables 7.1 – 7.5.**

### 7.3.1 Data types available in LIMIS

In order to achieve the objectives and deliverables, the LIMIS contains two major types of data, being spatial data and tabular data which specifically addresses the five components of the monograph, which has been slightly changed from the initial layout as seen in the previous section under 3

The themes in the LIMIS are based on the initial components of the project. The selected themes are:

- Water and Recourses,
- Socio- economic,
- Infrastructure,
- Environmental,
- Economic,
- Ecological Water Resources (EWR),
- General was added later to provide an “overview” or general review of base information of the basin.

The themes almost follow the themes (chapters) of the Monograph.

### 7.3.2 Reliability

The data that has been reviewed from the Scoping Study was found to be lacking in a number of areas as described in the Data Audit report. It is recommended that LIMCOM prescribe the data guidelines and standards as applied so far to ensure that future data does conform to agreed standards when the data is updated.

## 7.4 MAINTENANCE

### 7.4.1 Updating of Information

As part of the Standards, Procedures and Policies LIMCOM need to define the methodology for updating the data. It would be preferable for the member countries to send their data to a data coordinator in LIMCOM who would update the LIMIS in order to avoid duplication and to exercise version control. This task would be seen as part of the LIMIS administration tasks.

### 7.4.2 Data Collection

The LIMIS database has been designed with the objective of easy data maintenance. Furthermore, the LIMIS does provide the functionality that any other data set can be added and viewed in the LIMIS. This functionality is only available to the administrators of the system.

Future data collection needs to be done in terms of the procedure, standards and policy documentation in order to maintain system updating, accuracy, completeness, etc. As part of the documentation, data maintenance needs to be addressed.

### 7.4.3 LIMIS Administration

The administration of the server is currently with Aurecon as the application is being run by the service provider. The administration will become LIMCOM's responsibility once the application is loaded on the server at LIMCOM. The administration of LIMIS will then become part of the responsibility of the IT department at LIMCOM.

## 7.5 RECOMMENDATIONS FOR FURTHER WORK

Any MIS is totally dependent on information and data and we would recommend that the following work should be conducted in order to maintain the current LIMIS, but also to extend and grow the information management system within LIMCOM:

- Data maintenance should be a continuous process,
- Additional data, according to the LIMCOM's needs and requirements, which can be:
  - Geology,
  - Soils,
  - Etc.

# 8. STEPS TOWARD WAY FORWARD

The Scoping Phase of the Joint Limpopo River Basin Study was completed in 2008. This was the first stage towards the development of the Limpopo River Basin Integrated Water resources Development Strategy and Plan. The Limpopo River Basin Monograph Study completes the second phase of the study. The Monograph Study is a baseline study that collects, compiles and collates information necessary for the subsequent phases of the Limpopo Integrated Water resources development Strategy and Plan. **Figure 8.1** shows the sequence of steps towards the Limpopo IWRM Strategy and Plan.

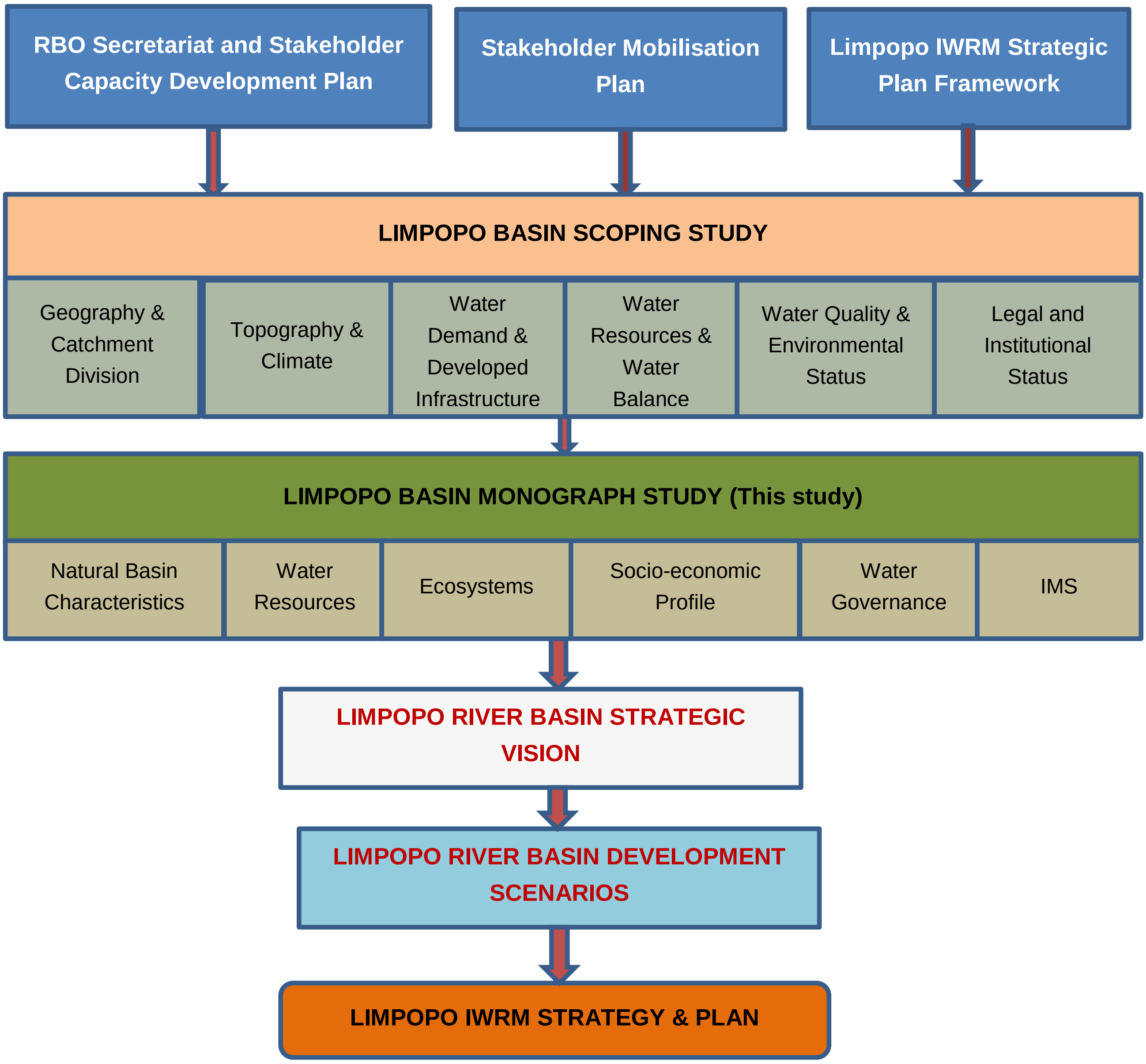



**Figure 8.1**: Illustration of the chronological activities related to the Joint Limpopo River Basin Study

With the completion of the Monograph phase of the study the next phase would be the development of the Basin Strategic Vision. The strategic vision captures the shared dreams, aspirations and hopes about the state, use and management of water resources in the Limpopo River Basin by the four riparian states. It is a statement of purpose that provides direction to the future actions about water resources and guides the planning process. An example of a strategic vision could be: ensure availability of adequate and quality water for economic development. In developing the Strategic Vision for the basin consideration is made of the opportunities and challenges faced by the basin as well as the driving forces behind these. Among the challenges are the following:

- Different sizes of the economies of the riparian states.
- Different national economic policy objectives.
- Different national economic drivers.
- Different national institutional set-up.

Opportunities include:

- A guiding policy and institutional framework at the regional level (SADC), to which all the riparian states belong to.
- Realisation and commitment by the member states to the joint development and management of the Limpopo River Basin.
- The existence of a basin institutional framework.

## 8.1 UPDATING THE MONOGRAPH

The Limpopo River Basin Monograph Study provides a baseline of the water resources situation currently available in all four Member States. The Monograph lays the foundation for LIMCOM to proceed to develop an Integrated Water Resource Management (IWRM) strategy and plan for the basin and the information contained in the Monograph provides a framework for Member States and LIMCOM to engage with each other on matters pertaining to the management of the water resources of the Limpopo River Basin. However, as explained above there are some challenges that were encountered in the development of the Monograph which have to be resolved in order to improve the quality and confidence in the Monograph information prior to proceeding to the development of the IWRM strategy and plan.

The disparity in data available between the riparian States has limited the level of detail at which the water resources modelling can be undertaken. The density and quality of measuring stations (rainfall, evaporation, and streamflow) for both surface and groundwater in Zimbabwe, Moçambique and to an extent in Botswana does not compare with that available in the South African part of the basin. Among the challenges encountered during the study include;

- Lack of monthly water abstraction and release time series from dams in Botswana, Moçambique and Zimbabwe.
- Lack of information on water transfers between sub-basins in Botswana and Zimbabwe.
- Lack of monthly dam balances in Botswana, Moçambique and Zimbabwe
- Lack of information on small farm and stock watering dams.
- Substantial data gaps in rainfall, evaporation and streamflow in Botswana, Moçambique and Zimbabwe

This limits the level of hydrological modelling accuracy and detail that can be undertaken. It is therefore recommended that LIMCOM undertakes a study to identify measuring stations in the Limpopo that are critical for future assessment of the water resources of the Limpopo.

Floods and flood peaks could not be assessed accurately because of a lack of flood peak data from Member States as a result of exceedence of stage – discharge rating curves of the gauging stations during floods. Limited flood peak surveys would have to be undertaken at strategic locations in the basin to better assess floods and flood peaks.

Groundwater quality in Zimbabwe and Moçambique was lacking especially electric conductivity, nitrates and fluorides. There is a need to identify strategic groundwater sites where this information can be collected for analysis. There is a lack of groundwater use information in the basin. Therefore, groundwater use was lumped together with surface water. It is recommended that efforts be increased to measure groundwater use in the basin.

The Limpopo River Basin is subject to the influence of Climate Change. While there have been several studies on the Limpopo on Climate Change, these have focused on the socio-economic aspects because there has not been a comprehensive water resources assessment undertaken. In this study, while water resources assessment has been undertaken at a more detail level, Climate Change was assessed at a very high level. It is recommended that Climate Change impacts on the water resources of the Limpopo River Basin be undertaken comprehensively.

The time and budget available for the study was limited and did not allow for a comprehensive assessment of the riverine and especially the estuary ecological water requirements. Only a few ecological water requirement monitoring sites were established in Botswana, Moçambique and Zimbabwe. It is recommended that more additional ecological water requirement stations be sited in Botswana, Moçambique and Zimbabwe to improve the estimation of the ecological water requirements for the Limpopo River Basin.

Ecological Water Requirement surveys for both the estuary and the riverine systems were only conducted once during the dry season. This limited the methodologies for estimating the ecological water requirement for these systems. It is recommended that ecological water requirement surveys be carried out over the entire season (wet and dry) and preferably over dry and wet years to increase the accuracy of the determined ecological water requirement for the estuary and the river.

To determine the ecological water requirement for the estuary, a range of streamflow scenarios into the estuary are required. It is therefore recommended that as part of the Development Scenarios a range of streamflow scenarios be produced in order to facilitate the determination of the estuary ecological water requirements.

The interaction between the riverine and estuary EWRs need to be studied. It could well be that the timing of prescribed riverine EWRs will not necessarily compliment the estuary EWR. The study’s objective should be to find EWR provisions that will both optimally satisfy the rivers and estuary.

Once a proper assessment of the ecological water requirement for the both the estuary and the river has been firmed up, it is recommended that an assessment of the impact of implementing the recommended ecological water requirement be undertaken.

It is also recommended that a comparison of the water allocation policies of the four member states be undertaken as part of the Development Scenario phase.

An Information Management System for the Limpopo River Basin (LIMIS) was developed as part of the Monograph. The LIMIS is a repository of vital data and information on the water resources of the Limpopo River Basin. It is essential that LIMCOM and the Member States continue to update the information in the LIMIS. It is therefore recommended that LIMCOM puts in place a mechanism for Member States to feed new information into the LIMIS. LIMCOM should consider the recommendations contained herein on the updating of information on the LIMIS to ensure that the LIMIS contains verifiable information trusted by all Member States.

The Monograph provides a snap-shot of the Limpopo River Basin at a given time. It is recommended that once every three to five years, LIMCOM embarks on a study to update the Monograph to keep it relevant. In the short-term LIMCOM must identify the infrastructure (server, software, etc.) required to maintain LIMIS as well as the human resources (technicians, etc.) to keep LIMIS up-to-date and operational. The infrastructure and human resources should be identified at LIMCOM Secretariat as well as in the member states and establish a protocol for collaboration between the two.

The helicopter survey was useful and it is recommended that a similar survey is done on a regular basis (say every 5 years) to monitor the changes in the basin. It is further recommended that a helicopter survey is undertaken during a major flood similar to the one in January 2013 in order to study the behaviour of the system.

## 8.2 BASIN DEVELOPMENT SCENARIOS

Basin water resources development scenarios is a crucial step in the formulation of a basin wide, integrated Water Resource Management (IWRM) strategy and plan. The fundamental goal of water resource planning and management is to match the demand for water by the socio-economic system with the supply (quantity and quality) of the water system through administrative control and management (water regulations/laws and infrastructure), without compromising ecosystem sustainability. The assessment criterion for basin development scenarios covers the triple bottom line of economically beneficial, socially just, and environmentally sound development.

Changes in water resource systems are driven by changes in three related sub-systems; the climate system, the socio-economic system and the management system. Water consumption patterns and water demand by different users in a basin are directly affected by important socio-economic variables including population growth, economic development, technological change, and water and land use practices. Changes in temperature, precipitation and evaporation have a direct impact on water availability and water demand (i.e. climate system). Management intervention such as water allocation strategies, legislative standards, and political intervention play an important role in influencing future pathways of water resources development and management.

### 8.2.1 Guidance for the development of water resource management scenarios

Key requirements for Co-operative Governance of shared river basins include:

- Basic information about the water resources, natural environment and the water using activities in the basin(s), which is shared, agreed and trusted by the parties
- Trust and mutual understanding of the National Objectives for socio economic development and challenges.
- A Vision and Objectives for each River basin that is shared by the riparian countries
- Agreed water resource development and management interventions and economic development scenarios, supported by IWRM strategies and plans for each river basin

The following steps are generally followed in formulating water resources development scenarios:

- Purpose and scope of the scenario assessment
- Scenario formulation
- Scenario assessment process
- Reporting of scenario assessments
- Limitations of the assessment process
- Risks and uncertainties associated with the developed scenarios
- Management implications for the developed scenarios

There are numerous scenario assessment methodologies for water resources. These loosely involve a series of iterative steps (Congli Dong, *et al*, 2012), as shown in **Figure 8.2.**

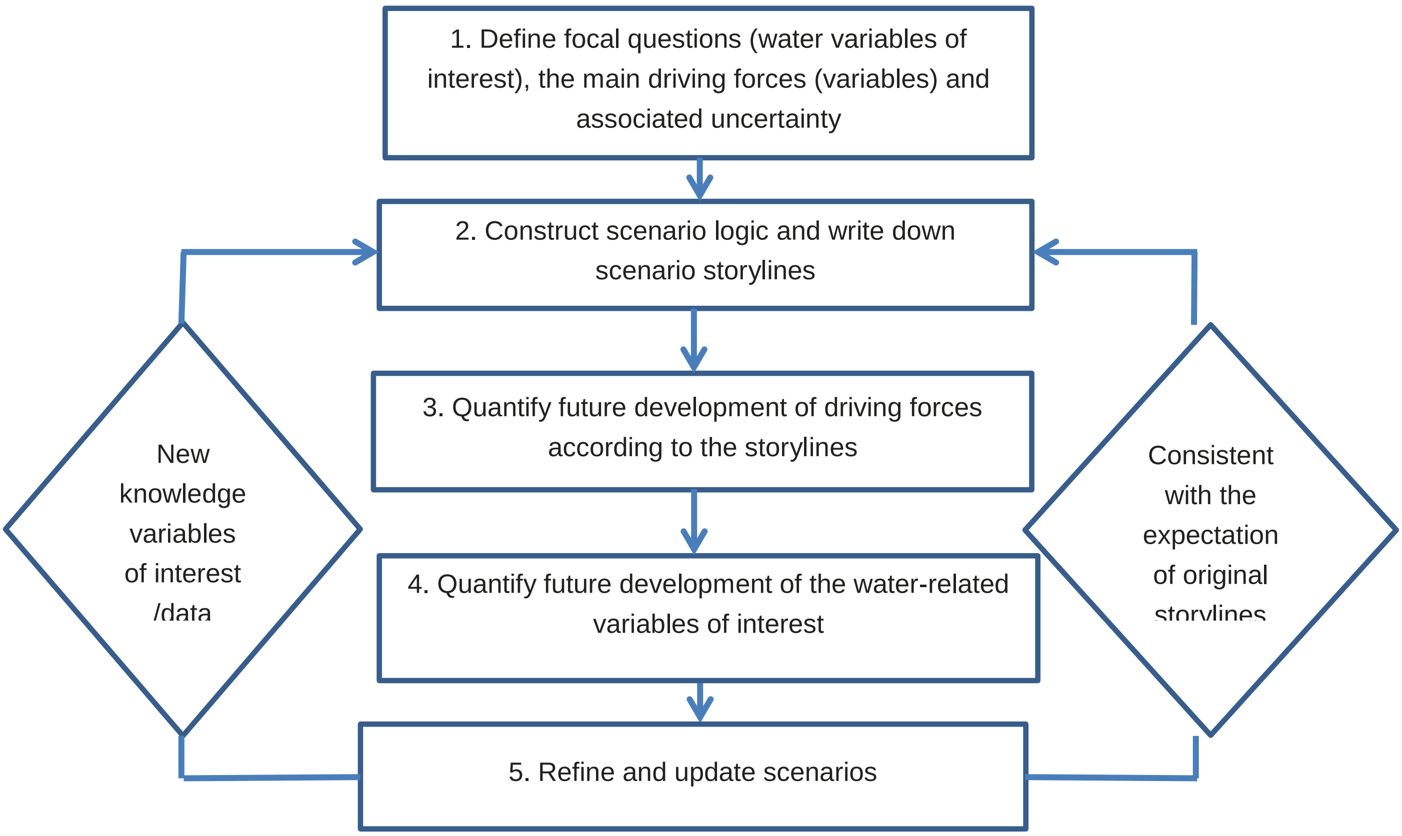



**Figure 8.2:** General iterative procedures for water resource scenario development

The iterative procedure for water resources scenario development is explained in **Table 8.1** below.

**Table 8.1:** Purposes of the steps involved in scenario development in Figure 8.2

| Step | Procedure |
|---|---|
| 1 | This step involves understanding the current situation and identifies key variables representing the driving forces and main uncertainties affecting the stakeholders' objectives. |
| 2 | The goal is to qualitatively describe a small number of scenarios that essentially map out the boundaries of what the future may bring. |
| 3 | The goal is to assign probabilities to the driving forces, e.g., future changes in population growth rate, irrigation area, and temperature. |
| 4 | The goal is to translate quantitative scenarios for the driving forces into corresponding quantitative scenarios for water-related variables. |
| 5 | The goal is to refine the scenarios based on new information. |

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# APPENDIX A : Large Dams in the LRB

| Name of Dam | Country | River | Capacity in million $m^3$ | Lat | Long |
|---|---|---|---|---|---|
| Bokaa | Botswana | None | 19000 | -24.4417 | 26.0189 |
| Dikabeya | Botswana | Lotsane | 2876 | -22.5583 | 27.1328 |
| Gaberone | Botswana | Ngotwane | 144000 | -24.6992 | 25.9258 |
| Nywane | Botswana | Nywane | 2300 | -25.1156 | 25.69 |
| Shashe | Botswana | Shashe | 85000 | -21.3667 | 27.4292 |
| Ntimbale | Botswana | Tati River | 27000 | -20.8681 | 27.46925 |
| Thune | Botswana | None | 90000 | -22.2711 | 28.80069 |
| Lotsane | Botswana | None | 40000 | -22.592 | 27.61443 |
| Dikgatlhong | Botswana | None | 400000 | -21.549 | 27.98103 |
| Letsibogo | Botswana | Motloutse River | 100000 | -21.8284 | 27.71301 |
| Macarretane | Mozambique | Limpopo | 15000 | -24.4044 | 33.0428 |
| Massingir | Mozambique | Elefantes | 2256000 | -23.8747 | 32.1467 |
| Albasini | South Africa | Luvuvhu | 25200 | -23.1075 | 30.1253 |
| Bierspruit | South Africa | Bierspruit | 3515 | -24.9119 | 27.1411 |
| Bischoffs | South Africa | Plat | 3564 | -24.8272 | 28.2111 |
| Blyderivierspoort | South Africa | Blyde | 55644 | -24.5367 | 30.7983 |
| Bon Accord | South Africa | Apies | 4293 | -25.6222 | 28.1897 |
| Bospoort | South Africa | Hex | 18900 | -25.5636 | 27.35 |
| Bronkhorstspruit | South Africa | Bronkhorstspruit | 58902 | -25.8872 | 28.7214 |
| Buffelskloof | South Africa | Waterval | 5270 | -24.9564 | 30.265 |
| Buffelspoort | South Africa | Sterkstroom | 10328 | -25.7803 | 27.4869 |
| Charles Engelhard | South Africa | Great Letaba | 3750 | -23.8167 | 31.5833 |
| Dangadzivha | South Africa | Njelele | 13000 | -22.6311 | 30.2217 |
| Dap Naude | South Africa | Broederstroom | 2076 | -23.8167 | 29.9667 |
| Donkerpoort | South Africa | Klein Nyl | 3420 | -24.6711 | 28.3217 |
| Doorndraai | South Africa | Sterk | 47254 | -24.28 | 28.7769 |
| Doornpoort | South Africa | Olifants | 5697 | -25.8636 | 29.2956 |
| Driekloof | South Africa | Nuwejaars-spruit | 36549 | -26.0003 | 28.0053 |
| Ebenezer | South Africa | Groot Letaba | 68995 | -23.9417 | 29.9842 |
| Molatedi | South Africa | Marico | 230000 | -24.87 | 26.4531 |
| Tsaneen | South Africa | Great Letaba | 160223 | -23.7997 | 30.1664 |
| Glen Alpine | South Africa | Mogalakwena | 21928 | -23.1919 | 28.6978 |
| Gompies (L) | South Africa | Gompies | 9529 | -24.3039 | 29.3186 |
| Mokolo | South Africa | Mogol | 148700 | -23.9844 | 27.7208 |
| Hartebeespoort | South Africa | Crocodile | 194626 | -25.7256 | 27.8478 |
| Jan Wassenaar | South Africa | Klaserie | 5779 | -24.5283 | 31.0583 |
| Klein Maricopoort | South Africa | Klein Marico | 7073 | -25.5219 | 26.15 |
| Klipvoor | South Africa | Pienaars | 43800 | -25.1319 | 27.8086 |
| Kosterrivier | South Africa | Koster | 12176 | -25.7003 | 26.9044 |
| Kromellenboog | South Africa | Klein-Marico | 9371 | -25.4433 | 26.3458 |
| Lindleyspoort | South Africa | Elands | 14417 | -25.4983 | 26.6911 |
| Lorna Dawn | South Africa | Middle Letaba | 11748 | -23.4828 | 30.1267 |
| Loskop | South Africa | Olifants | 348100 | -25.4181 | 29.3592 |
| Luphephe | South Africa | Luphephe | 15019 | -22.6333 | 30.4 |
| Magoebaskloof | South Africa | Politsi | 5608 | -23.8175 | 30.0558 |
| Marico-Bosveld | South Africa | Groot Marico | 27705 | -25.4703 | 26.3928 |
| Middelburg | South Africa | Klein Olifants | 48435 | -25.775 | 29.5461 |
| Middle Letaba | South Africa | Middle Letaba | 173000 | -23.2722 | 30.4019 |
| Mogoto | South Africa | Mogoto | 2924 | -24.2667 | 29.2333 |

| Name of Dam | Country | River | Capacity in million $m^3$ | Lat | Long |
|---|---|---|---|---|---|
| Nwanedzi | South Africa | Nwanedzi | 5559 | -22.6333 | 30.4 |
| Nzhelele | South Africa | Nzhelele | 57274 | -22.5744 | 30.0956 |
| Ohrigstad | South Africa | Ohrigstad | 14442 | -24.9331 | 30.6317 |
| Phalaborwa Barrage | South Africa | Olifants | 5650 | -24.07 | 31.1456 |
| Premier Mine | South Africa | Wilge | 5036 | -25.8008 | 28.8631 |
| Mkhombo | South Africa | Elands | 205800 | -24.9333 | 28.9333 |
| Rietvlei(2) | South Africa | Hennops | 12197 | -25.8786 | 28.2653 |
| Roodekopjies | South Africa | Crocolile | 102600 | -25.4069 | 27.5775 |
| Roodeplaat | South Africa | Pienaars | 43691 | -25.6211 | 28.3725 |
| Rust De Winter | South Africa | Elands | 28483 | -25.2292 | 28.4761 |
| Vaalkop(2) | South Africa | Elands | 55889 | -25.3086 | 27.4742 |
| Witbank | South Africa | Olifants | 104019 | -25.8908 | 29.3047 |
| Flag Boshielo | South Africa | Olifants River | 185000 | -24.7833 | 29.42778 |
| Klaserie | South Africa | Klaserierivier | 6000 | -24.5355 | 31.05756 |
| De Hoop | South Africa | Steelpoort River | 347000 | -24.961 | 29.9486 |
| Nandoni | South Africa | None | 166000 | -22.9775 | 30.59795 |
| Nsami | South Africa | None | 22000 | -23.2415 | 30.76309 |
| Tours | South Africa | None | 6000 | -24.0995 | 30.25257 |
| Vondo | South Africa | None | 31000 | -22.9412 | 30.33342 |
| Antelope (or Gulameta) | Zimbabwe | Shasani | 14970 | -21.0547 | 28.4333 |
| Beitbridge ORS II | Zimbabwe | None | 5575 | -22.2264 | 29.9908 |
| Blanket | Zimbabwe | Mchabezi | 5300 | -20.8661 | 28.9556 |
| Doddie Burn | Zimbabwe | Sibizini | 3650 | -21.4061 | 29.3642 |
| Ingwesi | Zimbabwe | Ingwesi | 69810 | -21.02 | 27.9008 |
| Inyankuni | Zimbabwe | Inyankuni | 81800 | -20.3675 | 29.1214 |
| Makashi | Zimbabwe | Bubi | 3270 | -20.8917 | 29.1556 |
| Manyuchi | Zimbabwe | Manyuchi | 3280 | -21.0811 | 30.4272 |
| Manyuchi II | Zimbabwe | Mwenezi | 319000 | -21.0733 | 30.385 |
| Matopos | Zimbabwe | Ir=Maleme | 4300 | -20.3806 | 28.5139 |
| Mayfair | Zimbabwe | Insiza | 96000 | -19.9194 | 29.1917 |
| Lower Ncema | Zimbabwe | Ncema | 18240 | -20.3636 | 29.0158 |
| Pioneer (or Makado) | Zimbabwe | Umtsabezi | 10910 | -21.4739 | 29.6628 |
| Ripple Creek | Zimbabwe | Bubi | 4060 | -21.3308 | 29.9333 |
| Rixon | Zimbabwe | Insiza | 9130 | -20.0131 | 29.2044 |
| Silalabuhwa | Zimbabwe | Insiza | 23450 | -20.7781 | 29.3631 |
| Thornville | Zimbabwe | Sibankatzi | 3450 | -21.0461 | 28.1461 |
| Tongwe | Zimbabwe | Tongwe | 38000 | -21.9342 | 29.9811 |
| Tuli Makwe | Zimbabwe | Tuli | 8330 | -20.9608 | 28.8033 |
| Umhlangwa | Zimbabwe | Umhlangwa | 4310 | -20.5692 | 27.8903 |
| Umzingwane | Zimbabwe | Umzingwane | 57000 | -20.3933 | 28.9742 |
| Upper Ncema | Zimbabwe | Ncema | 4482 | -20.3036 | 28.9867 |
| Upper Insiza | Zimbabwe | Insiza | 7818 | -20.011 | 29.20475 |
| Insiza | Zimbabwe | Mzingwane | 173491 | -20.8422 | 29.30099 |
| Mtshabezi | Zimbabwe | Chabezi | 51996 | -20.5402 | 28.83911 |
| Lower Mujeni | Zimbabwe | Chabezi | 10126 | -20.8465 | 28.94958 |
| Shasahani | Zimbabwe | Shasahani | 27338 | -20.71 | 28.23 |
| Zhovhe | Zimbabwe | Mzingwane | 13046 | -21.8 | 29.69 |