The Limpopo River Basin System: Climate Impacts and the Political Economy

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The Limpopo River Basin System: Climate Impacts and the Political Economy

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Executive summary

Enhancing transboundary water and biodiversity management within the constraints of climate change will enhance the resilience of the ecosystems and people in the Limpopo River Basin (LRB). That is the objective of the Resilience in the Limpopo Basin (RESILIM) Program.

A previous study undertook a risk and vulnerability hotspot analysis, which captures the spatial variability of different biophysical, biological and socio-economic factors into models of risk and vulnerability. Then, through modelling, a combination of exposure and sensitivity, eight hotspots were identified that described particular problem areas. These are 1) the Upper Limpopo River basin, on the Botswana / South Africa border, 2) Pretoria North / Moretele, 3) the Shashe / Limpopo rivers confluence at the border of South Africa, Botswana and Zimbabwe, 4) the upper Mzingwane River basin in Zimbabwe, 5) the Soutpansberg, 6) the Pafuri triangle border area of Zimbabwe, Mozambique and South Africa, 7) the Lebowa / Middle Olifants River catchment, and 8) the Chokwe – Lower Limpopo River floodplain in Mozambique.

This report produces the research and analysis of the biophysical, economic and socio-political system which characterizes each hotspot and gives rise to its identified vulnerability. It further analyzes the politic economy governing the LRB as a system, providing a political economy context to the identified hotspots and potentially contributing to the status of each as a 'tipping point', or sub-system that has crossed or is likely to cross a critical threshold.

The organizing principle of the impact assessment work on each hotspot is what is called the 1st to 4th Order Impacts Framework. This is a cascade of impacts and linkages between basic climate parameters (1st order), the resulting physical and chemical processes in the physical and biotic environment (2nd order), the resulting ecosystem services and production potential (3rd order), and finally the resultant social and economic conditions (4th order), which arise. Feedbacks exist between all four orders.

The historical evolution of transboundary LRB institutions, its management and agreements across borders, is provided in the political economy analysis section. Such agreements provided for the earlier joint management of resources in some cases (e.g. between Botswana and South Africa) but not in others. With the establishment of the Limpopo Watercourse Commission (LIMCOM) in 2003 and ratified in 2011, the commission is mandated to oversee the management of the basin to mutual benefit. In reality, the commission is an embryonic institution as it is still in the early stages of development with limited resources at present. Therefore, most management and technical power resides with national water departments meaning that national vested interests continue to prevail in spite of the establishment of the transboundary institution. A common platform for data sharing could be one of the most important steps towards transboundary decision-making, but this is still to happen. The role of external funders also gives them an inordinate control over key information and studies.

The hotspot analysis provides for different trajectories of climate and socio-economic development in the LRB. One ensemble of global climate models (GCMs) projects that much of the LRB will become drier, there will be fewer tropical cyclones and risks of flooding, but with more frequent droughts. The other ensemble considers a general slight wetting of the basin, but that summer

drying is consistent in both sets of ensembles of GCMs. This dichotomy of views requires that decisions must be taken that is valid for whatever climate future evolves. All climate trajectories project significant warming across the basin (noting the uncertainties relating to the projections), with consequences for water resources management, agricultural water demand and allocations to ecological function.

Socio-economic developments in each hotspot also mean that a future climate will be imposed on a changed socio-economic outcome, because there will be socio-economic change and growth with time. For example, populations may grow strongly in some places but not others. These development futures are evaluated for each hotspot as well. In the Upper Limpopo and Pretoria North regions, high levels of poverty remain into the future and economic growth is constrained, including through the lack of water resources. At the Shashe hotspot, a sparsely populated region, people may tend to migrate out, but that mining (of coal, *inter alia*) is a strong driver of change and is conflictual with the demands of ecotourism. In the upper Mzingwane area, economic growth is likely to stagnate but populations grow slowly over time, with people struggling to sustain livelihoods. In the Soutpansberg, key drivers of change are high rainfalls and runoff, high fertility and productive farms but a high population density pressing on the resources and population growing relatively strongly. In the Lebowa / Middle Olifants region, environmental degradation and a high population density has severely limited options for economic growth unless new technologies and management can change agricultural practices. At the Pafuri hotspot, also sparsely populated, the intensity of ecotourism increases, as does the concerns around movement of people through the Zimbabwe / Mozambique / South African borders. Finally, in the Chokwe/ Lower Limpopo region, intensification of agriculture is balanced by the needs to mitigate against the devastating floods which occasionally hit the area.

The limited water resources and degraded nature of important parts of the LRB already constitute a serious constraint on sustainable livelihoods in the LRB. It is likely that projected climate changes and socio-economic developments may aggravate the sensitivity of exposed populations and increase their vulnerability to the prime hazards. Multilateral cooperation on water resources is typically weak and upstream-downstream conflicts are a latent risk in the LRB system. Therefore, improved international cooperation and governance will substantially strengthen the ability to adapt to these changes and even in some places improve on the current situation, to the mutual benefit of all the riparian countries.

The outcome of this analysis should help the Resilim program assist LIMCOM in developing more effective responses within the LRB by the various responsible entities, which would be aimed at preventing shifts of hotspots to "tipping-point" status. In essence, these would increase the intersection between the political and social economies, and the way the natural resources are managed, which in turn increases the resilience of the whole of the LRB.

Contents

1. Introduction and objectives

The Resilience in the Limpopo Basin (RESILIM) Program seeks to improve resilience in the Limpopo River Basin System (LRB system) by focusing on enhanced transboundary water and biodiversity management whilst considering the added stress of climate change, and so enhance resilience of the ecosystems and people of the LRB.

As a preface to building resilience to the threat of future climate change, the mapping, identification and assessment of climate risk and vulnerability (R&V) hotspots must be performed. This report provides a preliminary analytical assessment that allows for the integration of data and expert input, and creates an evidence base for selecting locations in the Limpopo River Basin that are particularly vulnerable to climate change now and into the future.

Climate change is an important phenomenon because it can reduce resilience, particularly where natural resource dependencies for development are high. Therefore, understanding how LRB management decisions are made and where the balance of power lies in the Basin is critical. This necessitates applying an approach that considers water in a broader development context in the LRB system, or put another way, taking a political economy approach. We therefore also describe the institutional and policy framework on a basin, regional and national level, highlighting key actors and policies that operate within the decision-making processes in LRB system. We further provide an analysis of key areas of potential and existing conflict in the basin by examining the power dynamics that exist between relevant stakeholders, and the decisions that are produced as a result of these dynamics.

Lastly, we review the current state of information gathering and dissemination between the relevant institutions, recognizing that control over data and communications systems is a strong indication of both historical and current power balances in the system. This report therefore contains two key elements: i) an overview of the political economy of the LRB as a system, providing the development context of the basin; and ii) an analytical assessment of the most vulnerable areas or 'hotspots' within the LRB, providing further insight to climate risk and vulnerability in the LRB system.

1.1 Risk and Vulnerability Hotspot Analysis

The R&V hotspot analysis was conducted for RESILIM during July and August 2013 (Midgley et al., 2013). Individual data layer maps were produced and then combined in order to create the summary category layers of Exposure (current and future) and Sensitivity (current), and the combination of these two representing Impact (current and future). The combination of Impact and the summary layer Adaptive Capacity ultimately allowed for the creation of the Vulnerability (current and future) overlay maps.

The methodology captures the spatial variability of different biophysical, biological and socio-economic factors into models of risk and vulnerability. These are presented as spatially varying indices, identifying those hotspot areas upon which further actions can be taken. By identifying important drivers of vulnerability, the maps provide insights into which adaptive responses are likely to have the highest impacts on livelihoods and the environment in specific hotspot areas.

Ten climate R&V hotspot areas were initially identified. These were then validated and filtered to reach a final set of eight climate R&V hotspots (Figure 1). The validation and filtering process was informed by feedback from stakeholder engagements and expert consultations.

The 'problem areas' map (current Impact, the combination of Exposure and Sensitivity) was used to indicate the selection of ten hotspots identified on the basis of all the individual, summary and overlay maps. We chose to identify the hotspots on this map rather than the vulnerability map, which includes the adaptive capacity layer. This was because exposure and sensitivity represent potential environmental problems rather than the resources that people have available to them. We wanted to know where the problem areas were across the whole of the LRB without the subjective assumptions associated with applying the adaptive capacity layer, which has the effect of masking the problem areas in certain areas.

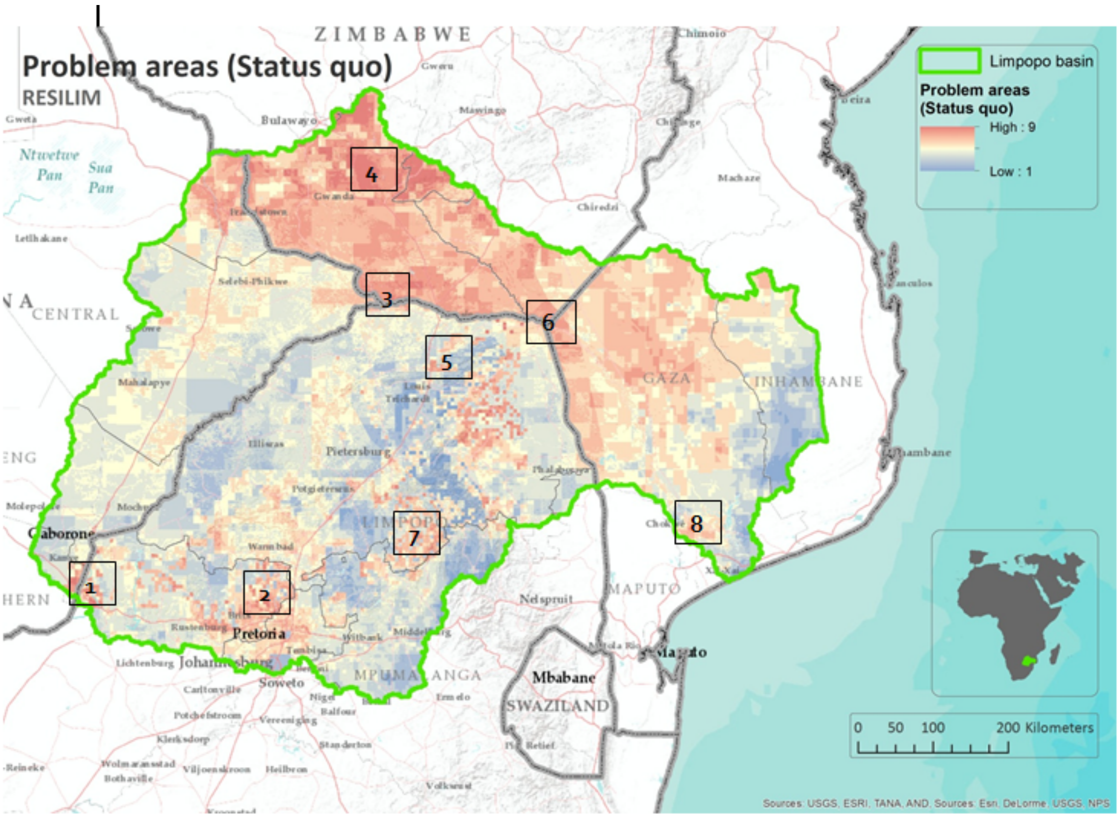

Figure 1 Eight identified climate risk and vulnerability hotspots for the Limpopo River Basin

Each of these selected areas brings out particular issues of vulnerability within the LRB that require more detailed analysis, and an early identification of possible responses (adaptation options). To ensure relevance to RESILIM objectives, each of the eight selected hotspots areas has been cross-checked against a set of the relevant LRB themes, being biodiversity, water, climate, land-use, transboundary relevance, and vulnerable livelihoods (Table 1). This exercise confirms the relevance of these hotspot areas to the objectives and themes of RESILIM. The numbers in Table 1 correspond to the number of the hotspot in Figure 1, and are subsequently analysed in detail in this sequence in Section 5.

Table 1 Matrix of hotspot site against relevant RESILIM themes

No.	Hotspot	Trans-boundary	Bio-diversity	Water	Climate	Land-use	Vulnerable livelihoods
1	Upper Limpopo: Botswana–South Africa border	X	X	X	X	X	
2	Pretoria North–Moretele			X	X	X	X
3	Shashe–Limpopo confluence	X	X	X	X	X	
4	Upper Umzingwane			X	X	X	X
5	Soutpansberg		X	X	X	X	X
6	Pafuri triangle	X	X	X	X	X	
7	Lebowa– Middle Olifants		X	X	X	X	X
8	Lower Limpopo–Chokwe			X	X	X	X

This component of this report provides the basis for the next phase of the overall study, where the findings presented here will be cross-checked and validated through a series of participative, stakeholders workshops. In this next phase there will be one workshop in each of the eight hotspots analyzed here. The objective of this report is to produce desktop-based research and analysis of the biophysical, economic and socio-political system which characterizes each hotspot and gives rise to its identified vulnerability. This research includes a preliminary assessment of first to fourth order climate impacts and critical thresholds, and the preliminary analysis and identification of plausible impact scenarios. Critical thresholds or tipping points are particularly relevant in analyzing ecosystems and their services, but could also be driven by demographic changes. Locations in the LRB where adaptation and resilience-building investments are needed the most are likely to be both vulnerable to current and future climate risk, and close to or at a tipping point.

A series of individually-located climate impact scenarios, based on consolidated the findings of First to Fourth order impacts and critical threshold assessments, will be the analytical output of this analysis, which will also include further research (mainly obtained from consultations with LRB stakeholders and experts including the RESILIM Olifants team) to fill in any gaps in our data. Participatory analysis with carefully selected Focus Groups from each hotspot location will also add depth to the outcomes. Here stakeholder input will be used both to identify priorities and concerns that should focus these impact scenarios, and to validate the findings. An important secondary benefit will be capacity strengthening as key stakeholders work together to develop scenarios, as facilitated by experts, in applying their knowledge and insights, and which they will subsequently apply in decision-making and planning processes. Between six and eight case studies and a consolidated set of climate impact assessments will then be produced, as validated.

1.2 Political Economy Analysis

Four countries share the LRB system: South Africa, Botswana, Mozambique and Zimbabwe. The basin is thus an international river basin, one of 14 international or shared basins in the southern African region. Important decisions are made regularly as to how to manage this increasingly stressed river basin's resources, and although the basin is transboundary, vested national interests and history play a significant role in how these decisions are made. The broader development context in which water (and biodiversity) is currently managed and in which decisions about minimizing the negative impacts of climate change are being made can be defined as the political economy of the LRB system.

An analysis of the LRB system's political economy underpins this report and will assist in strengthening the adaptive capacity assessment in our overall analysis of R&V in the LRB system. An analysis of the social economy of the LRB system is also critical, and this will be carried out during the participatory analyses to be conducted in the eight identified hotspots.

Analyzing the political economy has built on current literature, knowledge of the basin through the lenses of credible experts with extensive experience of contributing to decision-making processes in the Basin, and desktop research. Particular attention has been paid to institutional arrangements and how these do or don't work at a transboundary, regional and national as well as sub-catchment level.

2. Methodology

2.1 Political Economy Analysis

This desktop study and analysis was conducted in two phases:

1. Building on and adapting recent analyses conducted under the Regional Climate Change Program (RCCP implemented by OneWorld) and current research on Transboundary Water Governance developed by the Danish Institute for Security Studies (DISS) and OneWorld (Jensen et al., 2013). Various studies on climate and relevant sectors in southern Africa were developed under the RCCP and were drawn on for this analysis. Specifically, the transboundary water analysis (Pegram et al., 2010) and the regional systems and political analysis (Borain and Petrie, 2011) assessed the implications of managing the effects of

climate change under the prevailing institutional frameworks and political economies in southern Africa. The Transboundary Water Governance research focused on a comparative analysis of two major international river basins, the Mekong and the Zambezi, with a view to providing benchmarks and lessons learned for other international basins. Furthermore, the Zambezi has strong institutional and governance parallels with the LRB system and falls under the same regional institutional water management framework. Of the four riparian countries of the LRB system, three are also part of the Zambezi. These studies and recent RESILIM analyses and workshops gave rise to a set of key questions that underpinned the desk review conducted in the second phase of this political economy assessment. These questions include:

- What is the extent of political will underpinning climate change, water resource (and related) development and biodiversity management decisions in the Limpopo Basin and its riparian states?
- To what extent do social economy decisions and realities impact and/or influence political economy decisions in the Limpopo Basin System, and vice versa?
- How do natural resource and ecosystem functioning and information inform and/or influence key, related development decisions in the riparians as well as at a transboundary level?
- Where development decisions are likely to impact scarce resources or ecosystem functioning, how do these decisions consider these impacts?
- How do national governments in the basin manage conflict and disputes that arise, or may arise, from allocation and development decisions affecting key basin resources?

2. Noting that the second question has still to be researched through the participatory analysis process, the research and questions outlined above underpinned this desktop review phase. Interviews with key stakeholders and experts in the LRB system have informed the analysis conducted thus far. In addition, a comprehensive literature review was conducted. Whilst some conclusions have been drawn (see the final section of this report, Section 5), these will be strengthened once the participatory analysis is complete.

2.2 R&V Hotspot analysis

This desktop study and analysis was conducted in six phases:

1. Identification of the administrative unit(s) and spatial boundaries to be used for the analysis. At the same time, identification of the sub-basin(s) containing the hotspot, and the sub-basin areas outside of the hotspot which inform the local water catchment management context (upstream and downstream linkages).
2. A review of literature and documents to gain a systems- and place-based understanding of the current biophysical, economic and socio-political situation of the hotspot area, including any specific pertinent features such as recent history. The focus was, however, on the

relevant LRB themes for RESILIM, namely biodiversity, water, climate, land-use, transboundary issues, and vulnerable livelihoods.

3. A review and summary of the specific climate and development futures of each hotspot. The timeframe used was end-century (2100), but 2060 for temperature changes. These were framed as probable ranges and trajectories, recognizing the differences between various model outputs and the uncertainty this creates. We also emphasized climate variability and extremes, together with population changes, since they are likely to be the main drivers of climate change impacts over the medium term, with linkages to thresholds / tipping points.
4. An assessment of the current impacts and pathways of climate variability and extremes on the environment and inhabitants of each hotspot, using the First to Fourth Order Impacts Framework.
5. An overlay of climate and development futures on the current Impacts analysis, again using the above framework, to yield an assessment of possible future impacts and pathways.
6. A preliminary identification of possible adaptation options that would provide increased resilience to the hotspot in the face of future climate change and development.

2.3 First to Fourth Order Impacts Framework

This conceptual approach to an integrated place-based climate impacts and vulnerability assessment was developed by the Regional Climate Change Program (RCCP) in 2007, and was widely applied during this Program. The framework makes the linkages between basic climate parameters (1^{st} order), the resulting physical and chemical processes in the physical and biotic environment (2^{nd} order), the resulting ecosystem services and production potential (3^{rd} order), and finally the resultant social and economic conditions (4^{th} order) that arise. Feedbacks exist between all four orders.

The phenomenon and impacts of climate change are wide-ranging and highly complex. It is common practice in climate change assessments to take a sectoral approach, but this invariably leads to lack of cross-sectoral integration, which is critical when assessing economic and social system responses. In this framework, even though the focus remains on the RESILIM themes, the overall approach to analyzing climate impacts is more hierarchical, starting with the basic climate parameters, and gradually scaling up to organism and system levels. This framework is particularly suited to spatially-defined places with common bio-physical and socio-economic systems and drivers (e.g. sub-catchment, hotspot, as used in this study).

The levels are defined as shown in Figure 2. The upper figure shows the framework as a nested integrated one, whereas the lower figure shows the framework in a more linear manner (preferred by some).

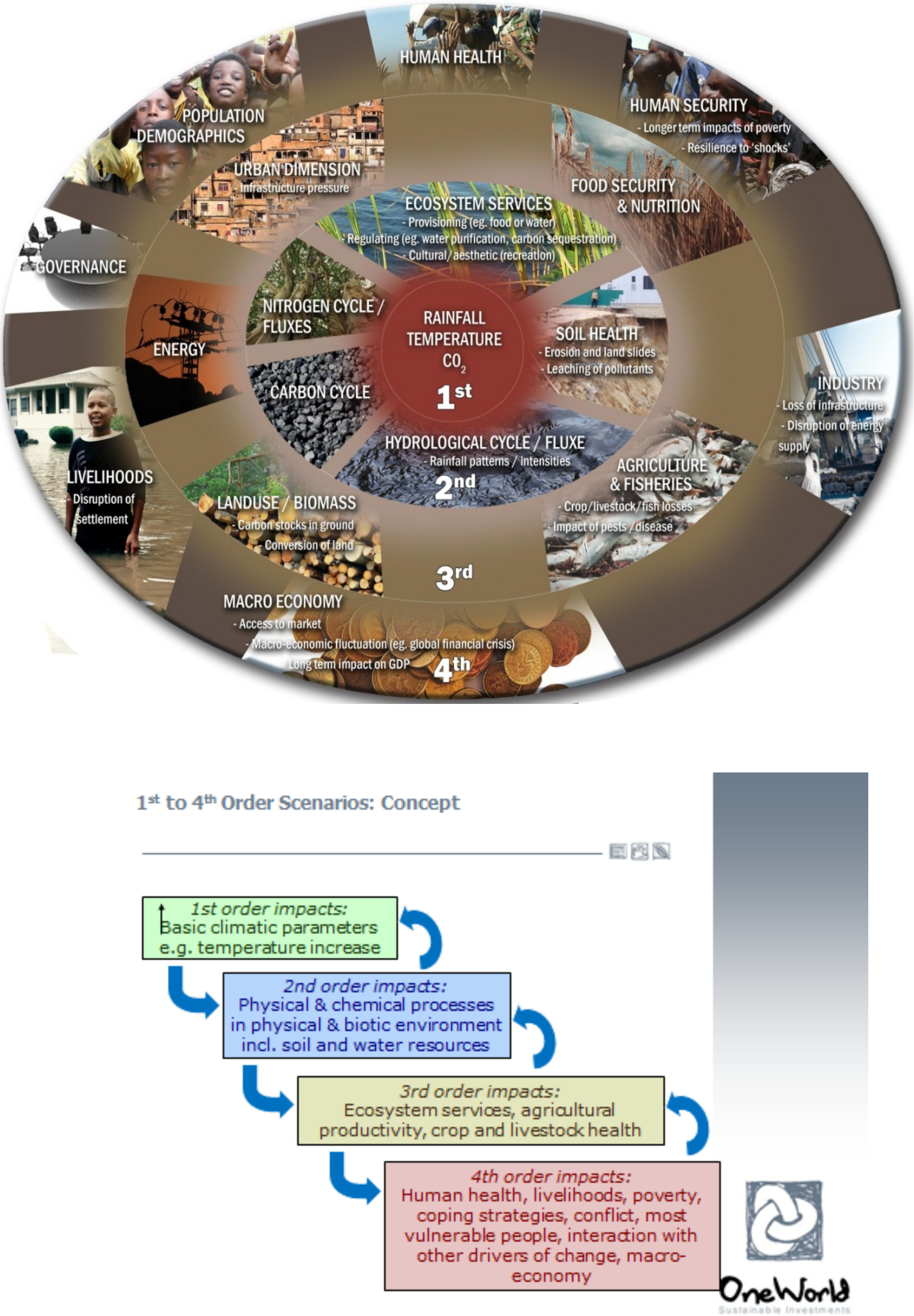

Figure 2 Diagrammatic representation of the First to Fourth Order Impacts Assessment Framework

3. The Political Economy of the LRB System

3.1 Characteristics of the Limpopo River Basin

The Limpopo River runs through fours riparian states. Beginning in the Limpopo Province of South Africa, it flows east, delineating South Africa's border with both Botswana and Zimbabwe before entering Mozambique and flowing into the Indian Ocean. The Limpopo River Basin area is approximately 408 000 km^2 and is home to approximately 18 million people.

The heterogeneity of the environment, activities, and populations of the basin translates into a variety of demands from the river basin, both between riparian states and within state borders. Water usage in the Limpopo River Basin System is currently dominated by irrigation—the agricultural sector accounts for the half of total water usage, urban usage accounts for 30%, and the remaining demand is divided evenly across the rural, mining, and power sectors (LBPTC 2010). However, by 2025, expected growth in irrigation is expected to remain relatively modest, while rapid growth in urban populations and mining and energy projects is anticipated to place enormous pressure on LRB water resources (Ashton et al., 2008).

In South Africa, Botswana and Zimbabwe, the upstream riparians, the river supplies the major urban centers of Gaborone, Francistown, Johannesburg, Pretoria, and Bulawayo. South Africa, Botswana and Zimbabwe also have major mining projects and power stations that utilize the river's resources.

Water usage for commercial irrigation is mainly focused in Zimbabwe and South Africa. Water from the Limpopo is also essential for sustaining the livelihoods of subsistence farmers in sparsely populated rural areas across all four countries, relying on small-scale irrigation schemes and boreholes for domestic use. In Mozambique, the downstream riparian, subsistence farming by rural families constitutes the majority of water usage from the basin, with the exception of some large-scale irrigation schemes in Chokwé.

At present, South Africa contains 45% of the catchment area, but uses 60% of the total water usage (LBPTC 2010). The current distribution of water usage will grow increasingly harder to sustain as Botswana, Zimbabwe, and Mozambique experience rapid urban growth and begin large-scale national development projects.

Pressure on the river's resources is further exacerbated by the nature of the river system itself. The climate of the LRB is semi-arid with highly erratic rainfall, ranging from 1 200 mm per annum in the southeast to 200 mm in the central-west, with an average of 530 mm per annum across the whole basin (LBPTC 2010). The LBR is classified as a 'closed' basin, meaning that all of the basin's water resources have been allocated to activities already in operation. In reality, South Africa's water usage alone exceeds the basin's yield by 800 mm per annum. South Africa. Water demands are supplemented through physical water transfers from the Vaal River (UNEP 2005, 60). Future projects that raise water requirements will necessitate the development of additional water transfer schemes from alternative sources, placing pressure, not only on downstream users, but on nearby water systems as well.

While the effects of climate change on the river has not been quantified, it is expected that increased volatility in rainfall will occur, escalating the threat of droughts and flooding. This leaves the rural subsistence farmers, a population already suffering from insufficient water resources—only two out of every five seasons produce sufficient crop yields—especially vulnerable (Earle et al., 2006, xi).

Concerns over water security have escalated into geopolitical conflicts surrounding water allocation in several international river basins (e.g. the Mekong, the Indus, and the Nile River Basins). The riparian states of the LRB system, however, have yet to experience serious conflict and have maintained a general environment of cooperation. The absence of hostility has given regional institutions like the SADC Water Division (SADC/WD) and Limpopo Watercourse Commission (LIMCOM) an opportunity to build a foundation for equitable and responsible transboundary water management before tensions rise. As both institutions continue to build their capacity, the challenge for SADC/WD and LIMCOM will be navigating the political, social and economic aspirations of multiple stakeholders within the region.

3.2 Institutional and Policy Framework

3.2.1 Basin and Region Level

Historically, regional regime creation, through bilateral water use agreements, has been an important feature in the LRB system. A series of agreements between South Africa and Portugal, beginning in 1926, recognized the 'mutual interest' of the colonial powers in the Limpopo, later culminating in a 1971 agreement between the two countries for the building of the Massingir Dam (which draws its water from the LRB, at the confluence of the Olifants and Letaba rivers). The Massingir Agreement made no attempt to restrict South African development in the basin, acknowledging that future dam construction by South Africa would lead to decreasing water flows downstream (UNEP 2005, 61). The series of bilateral agreements between Portugal and South Africa provides important insight into South Africa's ability to wield power and advance the nation's economic interests within the bounds of bilateral cooperative agreements. Having said that, these agreements were concluded at a time when water was considered an infinite resource and included a regional colonial power.

In 1983, Mozambique, South Africa, and Swaziland established the Tripartite Permanent Technical Commission (TPTC) to guide the management of water usage in the Limpopo, Nkomati, and Maputo rivers. This was the first attempt to establish a multilateral cooperative regime and failed to make a meaningful impact, stemming from the fact that it did not include Botswana or Zimbabwe, and did not have the political backing of Mozambique. In light of the flaws of TPTC, the Limpopo Basin Permanent Technical Commission (LBPTC) was established in 1986 as the first basin-wide regime to include Botswana, Mozambique, South Africa and Zimbabwe. The organization was mandated to provide guidance on basin-wide water management issues, although little progress was made due to political friction caused by Mozambique and Zimbabwe's support for the South African liberation movement.

The failure of multilateral efforts by the TPTC, paired with the increasing need to find solutions to transboundary water management problems, prompted South African and Botswana to establish the Joint Permanent Technical Committee (JPTC) in 1983. The bilateral arrangement functioned well, producing the Joint Upper Limpopo Basin Study (JULBS) in 1991, which evaluated water levels and quality; the current and future requirements of water for both countries; and the feasibility of constructing three dams to regulate the river flow for development purposes. The study was significant because it marked a successful joint effort to produce a cohesive and uncontested compilation of data that spanned national boundaries. This success was followed by the establishment of the Joint Permanent Commission for Cooperation (JPPC) in 1997 that fostered a closer collaboration between South Africa and Botswana on a number of issues, including the establishment of a water transfer system from the Molatedi dam to the Marico River to supply the growing population of Gaborone.

Botswana's willingness to cooperate with South Africa during the apartheid era allowed the two countries to build a foundation for joint water management and a mutual understanding of each other's interest in the basin. In contrast, Zimbabwe and Mozambique's opposition to the National Party regime and support for the liberation movement led to a lack of cooperation with South Africa and the subsequent failure of the LBPTC. Although the end of apartheid normalized political relations within the LBRS, South Africa and Botswana, the two upstream riparians with large population centers on the LRB, had already built a working relationship. In the new setting of basin-wide cooperation, Botswana and South Africa had the advantage of an established system of data sharing and communication, which gives them considerable leverage in basin-wide collaborative efforts.

3.2.2 The Limpopo Watercourse Commission (LIMCOM)

Given the new climate of peace and good political will after 1994, the LBPTC, a non-functional organization for nearly a decade, readdressed its mandate and initiated a new round of negotiations between the four riparian states. The renewed effort resulted in (1) the Agreement on the Establishment of the Limpopo Watercourse Commission, signed in 2003; (2) The LIMCOM Action

Plan, produced in 2005 in partnership with SADC/WD; and (3) the Joint Limpopo Scoping Study, completed in 2010.

All three outputs were steps towards the creation of LIMCOM, a river basin organization (RBO) aligned with SADC's Revised Protocol on Shared Watercourses, enacted in 2004, and both the UN Convention on the Law of Non-Navigation Uses of International Watercourses (UN Watercourse Convention) and Agenda 21 of the United Nations Conference on Environment and Development. Shifts in internationally accepted practices of transboundary water management necessitated the creation of a new governing body that recognized Integrated Water Resource Management (IWRM) principles.

The LIMCOM Agreement established the RBO as a legal entity, with the ability to enter into contracts and agreements with other parties. The Agreement outlines the objective of LIMCOM: 'to advise the Contracting Parties and provide recommendations on the uses of the Limpopo, its tributaries and its waters for the purposes and measures of preservation and management of the Limpopo', and also provided the following Council functions (LIMCOM 2003):

1. Measures and arrangements to determine the long-term safe yield of the water available from the Limpopo.
2. The equitable and reasonable utilization of the Limpopo to support sustainable development in the territory of each Contracting Party and the harmonization of their policies related thereto.
3. The extent to which the inhabitants in the territory of each of the Contracting Parties concerned shall participate in the planning, utilization, sustainable development, protection and conservation of the Limpopo and the possible impact on social and cultural heritage matters.
4. All aspects related to the efficient and effective collection, procession and dissemination of data and information with regard to the Limpopo.
5. Contingency plans and measures for preventing and responding to harmful conditions whether resulting from natural causes such as drought or human conduct as well as emergency situations that result suddenly from natural causes such as floods or human conduct such as industrial accidents.
6. The investigations and studies, separately or jointly by the Contracting Parties, with regard to the development of the Limpopo including the construction, operation or maintenance of any water works.
7. Measures with a view to arriving at settlement of a dispute.
8. Any other matters affecting the implementation of the Protocol.

In addition, the Agreement outlines the structural arrangement of the Commission. The Council is the main governing body and acts as a technical advisor to the member countries, made up of three permanent members from each of the four states, and will meet at least twice a year (and in practice meets more frequently). The Executive Secretariat will oversee the implementation of the Agreement. Three Technical Task Teams (Legal, Flood, and Technical), comprised of one specialist from each country, have already been formed and provide guidance for the Council in specialized areas. With regard to dispute resolution, the Agreement states that any conflict, if not resolved by the Council within six months, will be brought to the SADC Tribunal.

In 2011, the LIMCOM Agreement was ratified and replaced the LBPTC as the acting body for transboundary water governance in the LRB system. At present, the LIMCOM office in Maputo consists of the Interim Secretariat, (currently Sergio Sitoe), and minimal staff required to run the office (Interview with GWP, August 2013). There are plans to establish the Legal, Flood, and Technical Task Teams, but no progress has been made in this area. At this stage in its development, the Interim Secretary, Sergio Sitoe, maintains that LIMCOM is concerned with 'capacity building, awareness, and development of trust between states', lacking the financial and personnel resources to advance other objectives at this time (Owen 2011).

LIMCOM is still in the early stages of establishment; however several issues will need to be addressed for LIMCOM to develop into a significant catalyst for transboundary collaboration in the LRB system:

- Specific requirements for information sharing and procedures for communication have not been established. Communication of relevant information concerning national projects that impact the LRB system is dependent on country representatives sharing this information with the Council. The issue lies in what information each national water department determines is relevant to share with the Council. For example, the South African representative would notify LIMCOM of a large dam project that will affect downstream river flow, but would not share information regarding the drilling of new boreholes in the Limpopo Province (AGWNET 2011). Yet, the borehole project, although not as large-scale or public as a dam, will impact transboundary groundwater levels on which multiple stakeholders rely for irrigation and domestic use. The inconsistency and amount of discretion involved in LIMCOM communication channels is a reflection of greater issues of trust and national sovereignty that will be discussed to a greater extent in Section 4.
- In the case of a disagreement between Council members, there is currently no conflict resolution mechanism within LIMCOM. The Commission's ability to settle disputes is one of the most important functions of the RBO. It gives stakeholders, regardless of how much *de facto* power they wield within the system, a platform to voice their concerns. The LIMCOM Agreement relies on negotiations within the Council to resolve disputes between the members states, and, in the case of a gridlock, conflicts will be brought to the SADC Tribunal. However, the Tribunal was suspended in 2010 with no timeline in place for its reinstatement. In the Tribunal's absence, LIMCOM is left without any third party capable of settling disagreements within the Council, providing an opportunity for more powerful parties (i.e. South Africa) to dominate the decision-making process. At present, most disputes are settled at the bilateral level and LIMCOM has minimal experience in conflict management and dispute resolution.
- There is currently no water allocation or Limpopo-Basin specific benefit-sharing strategy (SADC is responsible for promoting benefit sharing in the region) between the four riparian

> countries. Although one of LIMCOM's functions, as dictated by the Agreement, allows for the 'equitable and reasonable utilization of the Limpopo', any meaningful strategy for regulating water usage will be impeded by the fact that there is no fully functional system for consistent and uncontested data gathering and sharing. Without accurate knowledge of current water use and demand, accurate regulation of future national development projects will be impossible. The increasing infrastructural and industrial ambitions of the member states, with a particular emphasis on Mozambique's rapid development, will only magnify the tension surrounding future benefit sharing in the region.

Without the key procedures and institutional structures to provide basin-wide information sharing, conflict resolution, and water allocation strategies in LIMCOM, the power very much lies within the national water departments and agencies who remain the implementing agents in projects that involve water usage in the LRB (GTZ 2005, 4). The concentration of power is compounded further by the fact that South Africa's Department of Water Affairs (DWA) possesses greater financial and technical capacity than the water departments of Botswana, Mozambique and Zimbabwe. The lack of multilateral capacity is likely to require future basin-wide decisions or collaborations to be implemented by South Africa, perpetuating the asymmetrical balance of power that currently exists in the basin.

3.2.3 The SADC Water Division (SADC/WD)

Within the SADC there are 14 international river basins. As a result, transboundary water management is a key element within the regional body's operation. Housed within the Directorate of Infrastructure and Services, the SADC Water Division (SADC/WD) is an important institutional actor in the LRB. The division's main objectives are to develop, implement, and monitor a regional water policy and strategy that reflects the international water management norms advanced by the UN Watercourse Convention, the Helsinki Rules, and the Dublin Principles. The water reforms that have taken place in the SADC Water Program have been greatly influenced by IWRM principles with an emphasis on a holistic approach to water management and increased stakeholder participation.

The SADC Protocol on Shared Watercourses, first developed in 1995, was revised in 2000 to align with the 1997 UN Watercourse Convention. The Revised Protocol is the legal and policy framework that guides the Water Division's actions in the region, focusing on (1) basin-wide cooperation; (2) the exchange of relevant information between parties; and (3) the judicious and environmentally conscious use of water resources for equitable development in the region (SADC 2005). The Revised Protocol was followed by two supporting documents, the Regional Water Policy (2006) and the Regional Water Strategy (2007), that further develop the division's goals and implementation strategies.

One of the main mechanisms for achieving its objectives is the establishment and support of RBOs. The role of the SADC/WD is to ensure the implementation of the RBO treaty, mobilize resources to support RBO functioning, promote environmentally conscious strategies, build capacities within the organization, and aid in the implementation of a stakeholder participation strategy. The SADC/WD published Guidelines for Strengthening RBOs in 2010 to assist RBOs in achieving their goals.

The SADC/WD is a new relatively new institution. Established in 2003, the development of the SADC/WD has been largely supported and funded by the German government through the state-owned German Technical Cooperation Agency (GTZ). GTZ has played an instrumental role in establishing and equipping LIMCOM and the Orange-Senqu River Basin Commission (ORESCOM). The GTZ Coordinator at SADC attends all of the Council meetings of both LIMCOM and ORESCOM, providing advisory support and reporting progress to both SADC/WD and the German Ministry for Economic Cooperation and Development. GTZ, in collaboration with SADC and LBPTC, has produced several basin-wide reports—the Assessment of Stakeholder Participation within the Limpopo River Basin (2005), the Progress Review of Promotion River Basin Organizations Project (2005), and the Scoping Study for the initial phase of the Joint Limpopo River Basin Study (2010)—providing much needed cohesion and structure to basin-wide research in the LRB. The partnership between GTZ, SADC/WD, and LIMCOM is expected to continue for the foreseeable future.

At this stage in the SADC/WD's development, there are two main causes of concern. The first key issue is the division's lack of financial, technical, and personnel capacity. This is a pervasive issue throughout the entire LRB institutional structure. LIMCOM's limited development requires SADC/WD to play a significant role in carrying out RBO functions and coordinating basin-wide initiatives. However, SADC/WD itself does not have the capacity to adequately fill this role and is therefore required to rely on outside organizations, like GTZ or the South African DWA, to play the role of implementing agency. The involvement of external parties requires SADC to relinquish some element of control and ownership over the decision-making process and, in the case of basin-wide information gathering (Section 4), leaves regional projects open to political-economic influence and asymmetrical power dynamics.

The multiplicity of actors participating in basin-wide coordination efforts lead contributes to the second key problem confronting SADC/WD: confusion over roles and responsibilities within the institutional framework. Article 4 of the Revised Protocol provides a legal framework for the intended division of responsibilities between SADC/WD, the RBOs, and the national water agencies regarding monitoring and implementation of data gathering, equitable water usage, and environmental protection. However, capacity issues in all three levels of governance lead to a confusion of roles in practice, causing duplication of effort for some tasks and complete neglect of others. This issue is aggravated by the lack of clear channels of communication and procedures for reporting bilateral or multilateral regional activities. The current level of direct communication between SADC/WD, LIMCOM and the national water agencies is limited to LIMCOM Council meetings where, in praxis, reporting on riparian developments is subject to national discretion. (Interview with GWP, August 2013).

3.2.4 National Level

Within the past two decades, Mozambique, South Africa, Zimbabwe and, more recently, Botswana have gone through a period of water policy reform to incorporate new international norms for integrated water management. In each country, these reforms have taken a similar shape, placing an emphasis on decentralizing power to catchment-level management in order to localize control over water resources. These water policy reforms are a continuing process.

In theory, the states of the LRB have achieved great progress toward the harmonization of water polices and institutions. Sweeping policy reform in the region, though still in progress in Botswana, has demonstrated a consensus between the riparians on the importance of adopting IWRM principles within their national water management systems. Yet, implementation on the ground has not kept pace with policy changes, resulting in the establishment of catchment and sub-catchment agencies with very little capacity to achieve their directives. At this stage in development, most regional management agencies in the basin are institutional shells with no actual power within the system.

National water departments, under which water management tasks were centralized in the past, have transferred key responsibilities—data collection, water use licensing, resource development, dispute settlement—to ill-equipped organizations that are unable to carry out the tasks adequately. Some elements of water management continue to remain under the control the national water departments while the regional agencies build their capacities. However, many important functions such as information gathering, data collection and water licensing have fallen through the cracks (See Section 4) in this transitional period.

Botswana

Currently, Botswana has the most centralized institutional structure of the four riparians. National water policy has not altered significantly since the 1968 Water Act, which established the Water Appointment Board for issuing water licenses and set conditions for the equitable management of public water use.

In recent years however, Botswana has undergone a number of water sector reforms, including review of the National Water Master Plan (NWMP) over 2005-2006, the main recommendation of which was to implement a major restructuring of the water sector, in an effort to rationalize the water sector. More fundamentally this implied a separation of water resource management from water service delivery.

Prior to these reforms, water policy has been implemented by a number of institutions. This includes the Department of Water Affairs (DWA), housed within the Ministry of Minerals, Energy, and Water Resources, whose mandate was to ensure the efficient management of water resources for socio-economic benefit. The Water Utilities Corporation (WUC), established in 1970, is a state-owned enterprise tasked with the provision, management, and development of the nation's water resources. The Water Resources Council is an independent regulatory body (WRC) that advises the Minister of Minerals, Energy, and Water Resources on the allocation of water resources to the industry, mining, agriculture, and urban sectors.

In 2008 Botswana initiated a Water Sector Reforms Project (WSRP) with the objective of reforming the institutional structures and policies that guide water management. The project reiterated the predefined roles of the WUC, the DWA, and the WRC. The project also emphasized the role of the *kgotla*, traditional community councils, in resolving water disputes at the local level.

As a result of these reforms, by 2014 the WUC will assume responsibility for water and wastewater service delivery, whilst the DWA will become responsible for water resource planning, development and management. Whereas water supply has previously been a shared function between the DWA, WUC and District Councils; the ongoing water reforms (to be completed in 2014) will see an expansion of the WUC's mandate to include the takeover of water supply and waste water management from the DWA and District Councils. The DWA will therefore focus its efforts on water resources planning and management, which includes dam construction, defining groundwater reservoirs and the development of well fields.

Botswana has just concluded its national IWRM plan, which was prepared with support from UNDP-GEF, the Global Water Partnership (GWP) and the Kalahari Conservation Society (KCS). The government has recognized that further reforms are necessary in order to meet the needs of its citizens.

Mozambique

Two government ministries oversee water management in Mozambique. The National Directorate of Water Affairs (DNA) within the Ministry of Public Works and Housing is the leading government authority for water policy making and implementation, charged with overseeing the overall management of water resources by the *Administração Regional de Águas* (ARA). The National Directorate for Agricultural Hydraulics (DNHA) within the Ministry of Agricultural and Rural Development directs water management for irrigation and drainage.

The National Water Law (1991) and the National Water Policy (1995) lay the legal and policy foundation for water management in Mozambique, with the primary objective of creating a decentralized institutional structure organized by river basins to ensure local participation.

Water allocation is divided into free public use for households and small-scale farmers, and licensed private use for commercial activities. Water management is delegated to five Regional Water Authorities (ARAs) established around the main water basins. The ARAs are intended to be financially and operationally autonomous, responsible for the collection of water utilization fees, gathering hydrologic data, and managing water allocation for commercial and agricultural usage. ARAs is composed of both government officials and private stakeholders. By 2000, the ARA-Sul, which governs the LRB in Mozambique, was the only functioning ARA. The other four have since been established, but are operating at varying degrees of competency.

The National Water Law also mandates the creation of River Basin Management Units (RBMU) within ARAs, which will manage local Water Committees. These committees are eventually intended to carry out the tasks of data collection, water allocation, and conflict resolution at the local level. Both the RBMUs and WCs are in very early stages of development.

South Africa

The South African Department of Water Affairs (DWA), is responsible for the nation's water management system. The department oversees the provision of water by provincial and municipal authorities and regulates the allocation of water through controlling the licensing process. The Water Tribunal is an independent body that handles legal disputes over water resources.

The National Water Policy White Paper (1997), Water Services Policy (1997), and National Water Act (1998) provide the framework for South Africa's current institutional structure. Established in light of the Helsinki Rules and IWRM principles, the documents highlight the importance of equitable benefit sharing, decentralization of management structures, and consideration of transboundary effects of national water use. While South African policy does involve the devolution of power to the regional level, the White Paper maintains that the national government has central control and responsibility over water resources.

The policy reforms of 1997 and 1998 transformed water management structures, dividing the country into 19 Water Management Areas (WMAs). The LRB in South Africa is comprised of four WMAs: the Limpopo, Luvuvhua & Letaba, Olifants, and Crocodile WMA. Within each WMA is a Catchment Management Agency (CMA), headed by a board that reflects the demographics of the surrounding commercial and domestic community. Below the CMA are Water User Associations (WUAs) put in place to provide a platform for stakeholder participation.

Progress has been made toward establishing the structures necessary for a decentralized water management system; however, both CMAs and WUAs lack the capacity to fulfill their mandates adequately. As a result, power over the system remains concentrated in the DWA.

Zimbabwe

The Zimbabwe Ministry of Rural Resources and Infrastructural Development manages and develops water policy. Water policy implementation is divided under two entities. Rural water management is conducted by the National Action Committee for Water and Sanitation under the Ministry of Local Government. The Zimbabwe National Water Authority (ZINWA), a government-owned enterprise under the Ministry of Water Resources Development and Management, and is responsible for urban water planning and supply; water allocation and provision for industry, agriculture and mining; dam management; and Catchment Council oversight.

The 1995 Water Resources Management Strategy initiated a series of water sector reforms in Zimbabwe in order to align policies with the IWRM principles of equitable water management and greater stakeholder participation. In 1998, the revised National Water Policy and ZINWA Act prompted a shift from centralized water management to a decentralized system centered on river basins.

More recently, Zimbabwe has established a new government ministry, housed within the Ministry of Environment and Natural Resources. The Ministry of Environment, Water and Climate, previously known as the Ministry of Water Resources Development and Management (MWRDM), was conceived in September 2013 and is responsible for managing issues around the environment, water and climate. The formation of this ministry demonstrates a key policy shift, and progress towards addressing issues of water management in particular and climate change in general.

As with the current system in Mozambique, Zimbabwe has a framework for decentralized water management, but it has not yet been fully implemented. However, the Umzingwane Catchment Council, which is responsible for management of the LRB in Zimbabwe, has made considerable progress in developing its capacities and increasing stakeholder participation in the decision-making process (Owen 2011).

3.3 Main Actors, Dynamics and Areas of Conflict

The following section will explore three areas of ongoing and potential conflict in the basin with the objective of illustrating how a vast range of actors, incentives, and goals intersect in the LRB. The previous section provided a description of the institutional framework within which decisions about water resource management are made. The description is an indication of the ideal that SADC, LIMCOM, and the national water departments would like to realize in the future and the steps that have been made toward that ideal, however, it provides little insight into the reality of decision-making processes at work: how water gets allocated and who benefits.

3.3.1 Mining and Energy Development

The mining and energy sectors currently require relatively small amounts of water resources form the Limpopo, accounting for 10% of total water usage (LBPTC 2010). However, the expected growth of water demand in these sectors is significant: mining is expected to grow by 30% and power generation by 26% by 2025 (Ashton et al., 2008).

Currently, mining and power generation activities in the Limpopo are mainly limited to Botswana, South Africa, and Zimbabwe.

The water requirement for Botswana's rapidly growing urban and industrial sectors is at present the fastest growing sector of total water demanded in the LRB (LBPTC 2010). Significant industrial projects that utilize water from the LRB include Debswana's Morupule coalmine along the Lotsane River, and the Selebi-Phikwe Copper-Nickel mine along the Motloutse River. Future progress made toward the development of the Mmambula and Mmamantswe energy projects, located along tributaries to the Limpopo, will impact water usage considerably.

The mining and power production sectors in South Africa require the third largest water supply, behind irrigation and urban usage. The Crocodile, Marico, and Olifants catchments contain vast majority of mining and industrial development in the LRB. The Crocodile sub-catchment alone has 61 mines in operation (Ashton et al., 2001).

The acceleration of developments in South Africa's Waterberg, Limpopo, Soutpansberg and Mpumalanga coalfields in response to increasing energy requirements of the Southern African Power Pool (SAPP) will place further pressure on South Africa's water management system (see Box 1).

Box 1: Coal of Africa and the Vele Colliery

Coal of Africa (CoAL), an Australian owned company, operates three collieries, with two projects in development, in South Africa. The construction and operation of the Vele and the Makhado collieries, located along the Limpopo River east of the Mapungubwe National Park, have been plagued by controversy due to conflicts with environmentalists and farmers in the region. Growing interest by two additional mining groups, Universal Coal and Anglo-American, in the area, have heightened resistance to CoAL operations.

The Vele mine received approval for its New Order Mining Right (NOMR) in March 2010, but in August was forced by the Department of Environmental Affairs (DEA) and the Department of Water Affairs (DWA) to cease activities because it had not yet attained the required Integrated Water Use License (IWUL). The halt in construction activities lasted until April 2011, which resulted in a major increase in project costs, the firing of 596 workers, and plummeting CoAL stock prices (Bridge 2010).

During this period, the Save the Mapungubwe Coalition (the Coalition)—a multi-stakeholder coalition, including Endangered Wildlife Trust, the Peace Parks Foundation, the World Wide Fund for Nature South Africa, and local farmers and lodge owners—built up resistance against the Vele project. When the IWUL was approved April 2011, the Coalition lodged an appeal against the issuing of the license, arguing that mining activities should be prohibited in the area due its proximity to the Mapungubwe, a key region of the Transfrontier Conservation Area (TFCA), and scarce water resources in the area. The appeal automatically suspended the IWUL in July 2011, pending the Water Tribunal's ruling.

Eventually, CoAL gained approval from the DEA for the project and the Water Tribunal granted clearance to the IWUAL. By October 2011, CoAL recommenced construction. In November 2011, CoAL signed a Memorandum of Understanding (MoU) with the Coalition to withdraw the coalition's legal appeals. A month later, construction of the mine was completed and production began.

The UN World Heritage Committee and the UN Educational, Scientific and Cultural Organization (UNESCO) became involved in the debate when, in June 2012, officials expressed their dismay at the approval of the Vele mine construction and promised future action to impose a moratorium on developments in the region (Janse van Vuuren 2012).

In October 2012, CoAL agreed to sell $100 million in shares (a 23.6% stake in the company) to China's state-owned Beijing Haohua Energy Resource Co. Limited. The deal was intended to finance the expansion of the Vele mine, however, progress in the expansion has been slow, following (1) the withdrawal of the Coalition from the MoU in December 2012 due to 'past and on-going non-compliance with water legislation at Vele'; and (2) severe flooding of the mine in January 2013 (Zoutnet, 2013).

In 2008, before construction on Vele began, CoAL announced that it was partnering with Mulilo Energy and AES Energy Developments at the Vele and Makhado sites for two proposed independent power producer (IPP) projects that were pre-qualified to produce electricity for Eskom's IPP programme (Ryan, 2008). The Vele mine is expected to sell lower grade middlings thermal coal product to Eskom for use in power stations, following the planned expansion of the Vele mine (CoAL, 2013, 2).

The story of the Vele mine provides valuable insight into how multiple stakeholders—a foreign-owned MNC, a Chinese state-owned enterprise, multiple environmental NGOs, United Nations officials, Eskom, three South African state departments, local laborers, farmers and lodge owners—with conflicting interests: energy security, job creation, environmental sustainability, company profits—intersect in the LRB.

In Zimbabwe, water usage data is reported as an aggregate for urban, industrial, and mining use, which accounts for 50% of the total water requirements from the LRB. The majority of Zimbabwe's water requirements are located in the Upper Umzingwane sub-Catchment, which provides water to Bulawayo, the second largest city in Zimbabwe, and is home to the three largest mines in the LRB, producing clay minerals and limestone (Ashton et al., 2001)

Currently, Mozambique's water requirements for mining and industry from the LRB are negligible: less than 2% of total demand (LBPTC 2010). However, recent discoveries of large deposits of coal and natural gas in the Lower Limpopo catchment will alter Mozambique's development trajectory significantly and impact future water requirements (Section 4.3).

Why is growth in mining and energy development a potential problem?

Each member state's water allocation system reserves a set amount of water usage for environmental flows and household users, and then requires large-scale commercial users in areas of agriculture, mining, energy, or industry to apply for a water usage permit from the national department of water affairs. This provides a binding legal agreement to limit commercial water usage and ensure enough resources for domestic use. In reality, these systems are flawed: in 2010, the South African Parliament uncovered that 125 mines in South Africa were operating without a water license (Morgan 2011).

An additional concern is that, while the demand for water from the mining and energy sectors is growing rapidly, there is very little focus on the water requirements of the key ecosystems in the LRB. In fact little is known about either the current, or future, overall water requirements of these ecosystems. This implies that the continuing focus on abstraction of water for mining and energy, in isolation from a consideration of the water needs of ecosystems, represents a major threat to the viability and sustainability of biodiversity in the LRB and overall ecosystem health.

Mining companies wishing to begin construction on a mine must acquire the necessary mining, water, and environmental permits from multiple departments each with separate mandates. This opens the door to multiple issues involving conflicting national interests in economic development, energy security, equitable water allocation, and environmental conservation, often leading to intergovernmental disputes (see Box 1). This problem is further compounded by the lack of clear policies and procedures regarding the prioritization of national development objectives and delineation of departmental powers and responsibilities.

Each of the four member countries within the LRB, have ambitious national development plans that rely heavily on the exploitation of mineral resources as a means to provide energy security, job creation, and economic growth. In reality, the implementation of national economic strategies is done in collusion with large private corporations or parastatals, both domestic and foreign. Within the political context of Southern Africa, boundaries between industrial and political power are often blurred with powerful actors holding positions in both spheres. Mining and energy development is complicated further by the growing role of foreign investors with their own national and commercial interests in mind. The resulting power dynamic places considerable weight behind economic growth objectives and individual profit seeking, causing mineral and energy development objectives to take precedence over environmental and water management concerns.

3.3.2 Stakeholder Participation in the LRB

The acceptance of IWRM principles has led to an increasing effort by SADC/WD, LIMCOM, and the national water departments to promote greater stakeholder participation in local water management. Recent water reforms detailed in Section 2.2 have resulted in devolution of water management responsibilities to localized catchment agencies in order to provide an institutional and legal framework for broader participation in decision-making.

However, due to the lack of operational and technical capacity of these agencies, they are unable to fulfill their mandates and provide a voice for local stakeholders. At this stage in their development, these new institutional arrangements provide a basic structure, but not any meaningful mechanisms for participation (Earle et al., 2006, 32). Consequently, responsibility for water management remains centralized in national departments where it becomes embroiled in the political-economic dynamic (Section 2.1) and further removed from the needs of the citizens that populate the LRB.

Collaborative efforts by local communities, environmental NGOs, and commercial farmers (e.g. Save the Mapungubwe Coalition, the Tuli Block Farmers Association, and the Makhado Action Group) have had limited success in countering powerful mining and energy interests. The extent of a coalition's success or failure is tied to its ability to finance the legal and environmental assessment services necessary to counter the decisions of MNCs and state departments. Given the vast disparity between resources available to community-based coalitions and large mining, energy, and industrial companies, a MNC is able to outspend, and, therefore, outlast the ability of coalition to wage an opposition.

The conflict surrounding CoAL's construction of the Vele mine highlights key issue in the reality of stakeholder power imbalances in the region: the lack of representation for the rural subsistence farmers that populate the LRB. Organized resistance to the Vele mine is composed of environmental NGOS and large-scale farmers. Similarly, the Makhado Action Group is comprised of commercial farmers and lodge owners formed in opposition to the planned construction of the Makhado mine, CoAL's second project in the Soutpansberg coalfield. While these actors cannot match the resources at the disposal of CoAL and its investors, the coalitions have demonstrated the capacity to take legal action and achieve international recognition of their complaints.

Noticeably missing from the debate are the voices of the subsistence farmers who populate the LRB and rely on the river to for their livelihoods. An assessment of stakeholder participation in the LRB, completed through a partnership between SADC and GTZ, found that a large imbalance exists between stakeholder capacities for participation in the water management system. Commercial farming and private industry interests are represented in debates over water utilization, but these interests are very different from those of poor rural communities suffering low crop yields and water shortages (GTZ 2005, 24).

In the absence of practical mechanisms for participation, the rural poor may turn to local governance structures, often in the form of tradition village leaders, to secure water resources outside of the legal water management system. To meet the requirements of the village, locals will either connect to municipal resources illegally or take directly from the river source (Malzbender et al., 2005, 4). These water management systems, rooted in traditional decision-making processes, are undocumented and unregulated by any national authority. Instead of creating new institutional bodies to encourage stakeholder participation in the LRB, member states could incorporate pre-established systems of local water allocation to provide a more effective mechanism for democratized decision-making.

3.3.3 Downstream Vulnerability: Mozambique

Emerging from an extended period of civil war and political conflict, Mozambique is only just beginning to realize its economic growth and development potential. Like its neighbors, Mozambique has adopted a resource-driven development strategy, fuelled by the recent discovery of large coal and natural gas deposits. Future endeavors in mining, natural gas extraction, hydropower, and large-scale irrigation schemes will exponentially increase the country's water requirements, placing pressure on the LRB to accommodate the downstream riparian.

Due in part to the country's history of protracted violent conflict, Mozambique has weak institutional arrangements in place to regulate the environmental implications of a rapid rate of economic expansion. The 1991 Water Law set a general framework for a water allocation system, requiring commercial parties to obtain a permit for water use, but failed to establish an implementation agency for water licensing. Following a series of water reforms, the Regional Water Administrations (ARAs) became responsible for water licensing, data collection, and pollution control (SIDA 2008, 10). However, the paucity of knowledge, skill and personnel within the ARAs, means that these functions are rarely realized.

In the absence of functional environmental and water use regulation, the Ministry of Mineral Resources and Energy controls the approval of hydropower and mining projects without strict enforcement of water and environmental licensing laws (SIDA 2008). These projects are focused largely on the coal deposits and hydropower potential of the Zambezi in the northern Tete Province; however, the current influx of foreign investment and interest Mozambique will have development repercussion throughout the country. The country's key struggle will be the development of meaningful water and environmental management systems that will curb the rapid advancement of projects backed by powerful domestic and foreign actors.

The continued development trajectory of Mozambique is dependent upon on the supply of water resources for growing industrial, agricultural, and domestic use. Over half the country's area is positioned in an international water basin, with more than 50% of the country's surface water emanating from river inflows from upstream countries (Tauacole 2002, 3). Mozambique serves as the downstream riparian for eight international river basins systems, and this equates to highly vulnerable national water security.

Mozambique's dependence on upstream riparians for responsible and equitable water use explains the country's level of commitment to transboundary water management through SADC/WD, ZAMCOM, and LIMCOM. Due the DNA's close proximity to LIMCOM—LIMCOM's Interim Secretary, Sergio Sitoe, is Mozambican and the headquarters is located in Maputo—Mozambique has been able to form a closer channel of communication with the RBO than have the other three riparians. Concern about large-scale upstream development projects affecting river flows has prompted Mozambique's national representatives to call for more stringent procedures and requirements for information sharing amongst member states (Okwenjani 2012). It is expected that Mozambique will continue to exert pressure on capacity building initiatives within transboundary governance bodies in order level the power asymmetries in the LRB.

In spite of Mozambique's commitment to regional integration of water management, several key issues exacerbate Mozambique's weak position as the downstream riparian in LRB decision-making processes:

- Mozambique has a limited operational capacity within the DNA and ARAs, which will continue to impede necessary advancements in data collection, water licensing, and stakeholder participation.
- As the only non-English speaking country in the LRB, communication and information sharing requires the timely translation of both past and current water utilization data and analysis. The language barrier also results in weaker negotiation capabilities with regard to basin-wide conflict resolution (Turton et al., 2006).
- Unlike Botswana, Mozambique does not have a history of close ties with South Africa (the hegemon of the LRB) due to its support of the South African liberation movement during the apartheid era. Although political relations have since normalized, the two countries lack the trust that comes from a long-term collaborative relationship (Turton et al., 2006).
- Mozambique has been largely excluded from basin-wide data collection and information gathering schemes. The impact this has on power dynamics within the LRB will be discussed in the following section.

3.4 Information and Communication Systems in the LRB

Effective water resource management requires accurate and consistent collection of many different types of data across many different fields of expertise. The quality of data, the methodology of collection, the mechanism through which it is communicated, the institution or governing body that controls the gathering of data, and any significant gaps in the body of information are significant elements that shape the decision-making processes throughout the LRB. It is necessary to examine the process behind information generation and dissemination in a basin system in order to understand how decisions get made. Systems of information generation reflect, as well as reinforce, current power dynamics within the region. Actors that control the collection of data hold an upper hand in the decision-making process, while those that have neither the financial means nor the skill capacity to undertake monitoring and data collection have little backing for decision-making.

3.4.1 National Level

At present, hydrological data collection is controlled and managed at the national level. Given the vast disparities in institutional maturity and capacity, each riparian state differs in quality of data collected and effectiveness of data transmission to relevant actors within the LRB. Across all data fields, South Africa has a far more extensive and consistent collection of geographical, climatic, and hydrogeological data. Data collection in the other three countries is significantly less comprehensive due to insufficient financing, a lack of technical capacity, and, as in the case of Zimbabwe and Mozambique, long stretches of civil war and political strife.

Botswana

Two Government departments, operating under the Ministry of Minerals, Energy and Water Resources (MMEWR) include amongst others, the Department of Water Affairs (DWA) and Department of Geological Surveys (DGS). In addition, the Water Utilities Corporation (WUC) operates as a government parastatal under the MMEWR.

The DGS is charged with conducting groundwater assessments, capturing and disseminating data to the public, monitoring private sector groundwater exploration programs. Whilst groundwater assessment is shared between the DWA and DGS, the DGS is not mandated with conducting and surface water assessments. The department maintains the National Borehole Archive (NBA), which is restricted to access within the DWA. In 2002, the DWA launched a hydrogeological database, utilizing the German GeOD in geological software, however content was limited to the information that could be transferred from the NBA, and the system encountered issues with user-friendliness and accessibility. In the absence of one national platform for hosting hydrogeological data, the DWA maintains several separate datasets, which were last compiled in the National Water Master Plan Review, completed in 2006.Following the restructuring of role and responsibilities within the water sector, the WUC will be charged with managing water services in the country. This includes testing, treating and distributing water services in the country's urban centers and other areas within their mandate.

Mozambique

The National Directorate of Water (DNA) oversees the ARA-Sul's collection and management of hydrogeological data in the LRB. Data collection is sparse due to inconsistent accessibility to sample collection sites (due to flooding or physical distance from testing facilities) and few operational hydrometric stations. Data is limited to water levels and stream flow, and does not yet include groundwater levels, water quality or sediment transport. All data collected in Mozambique is linked to the SADC-HYCOS system.

South Africa

South Africa has the most advanced data collection and reporting system, and therefore provides the bulk of reliable data for the basin. Data is collected through a network of regional monitoring stations and is compiled by the DWA into the three main systems:

- The National Groundwater Information System (NGIS) is a portfolio that compiles data from DWA projects concerned with groundwater information and the monitoring of boreholes, dug wells, and seepage ponds in South Africa. Data is collected from reports completed by the DWA and private consultants and can be accessed through web-based archives and analytical tools by registered users.
- The Water Management System (WMS) allows access to an integrated computer database of three subsystems: Monitoring Management, Water Resource Management, and GIS Data. The database provides information on water quality and the monitoring of data gathering and reporting procedures in regional hydrometric stations.
- Hydstra is a DWA project that monitors dam water levels, rainfall quantities, and stream flow volumes for the purpose of maintaining and analyzing long time-series data to assess the overall state of the national aquatic system.

Zimbabwe

ZINWA is responsible for overseeing the collection and publication of hydrogeological data, the implementation of which is delegated to the Catchment Council level. However, the decentralization of the water management structure, paired with Zimbabwe's political instability, has resulted in a paucity of reliable data. Very little information exists regarding water quality, surface water levels, borehole locations, or groundwater levels. The data that is accessible for the Umzingwane Catchment is sourced from recent studies conducted by IUCN and the University of Zimbabwe.

3.4.2 Regional and Basin Level

Regional collaboration in basin-wide research and communication projects has been limited. The SADC Revised Protocol provides an institutional foundation for basin-wide data collection. As part of the objectives of the SADC Revised Protocol, the members commit to 'the exchange of available information and data regarding hydrological, hydrogeological, water quality meteorological, and ecological condition of shared systems' (SADC 2000). However, at present, the basin lacks a fully functional and comprehensive platform for data sharing, as well as a solidified protocol for communication between the riparian nations.

The SADC has made some progress in pursuing this objective. The South African DWA is currently overseeing the implementation of the second phase of SADC Hydrological Cycle Observing System (HYCOS). The objectives of the project are improved capacity within each member state to achieve accurate and comprehensive water systems monitoring in the region and the development an integrated online water resource database.

SADC/WD is also developing the SADC Water Information Sharing Hub (SWISH) to support and facilitate information sharing on water related issues within the region. With support from the GTZ, the SADC has launched SWISH in a number of pilot sites, including the SADC/WD and OKACOM websites, with the intention to eventually include all regional RBOs into the information database.

Beginning in 2008, the LBTC and the national water authorities participated in a Scoping Study financed by the GTZ as the initial phase of a comprehensive Joint Limpopo River Basin Study that is still in development. Prior to the GTZ study, transboundary data collection was limited to the Joint Upper Limpopo Basin Study (JULBS), conducted in a bilateral agreement between South Africa and Botswana in 1991, and feasibility or academic studies limited to specific locations or projects.

The Scoping Study draws geographical, climatic, water quality, groundwater levels and water use data from all four countries, filling in the gaps and extrapolating where data from Botswana, Mozambique, and Zimbabwe is incomplete or inaccurate (where measuring infrastructure has not been maintained and calibrated, or the correct measuring infrastructure is not available). The study is part of a larger effort to quantify accurately the current state of the Limpopo water system for the purpose of developing a Water Resources Development Strategy (WRDS) for the basin in line with IWRM principles. A major component of the WRDS will be building institutional and technical capacity within the LRB in order to maintain and update relevant data for improved decision-making.

3.4.3 Key Issues

A common platform for data sharing is one of the most important steps toward meaningful transboundary decision-making in the LRB, yet a functioning platform for hydrologic data has not been realized. Interviews from each national water agency completed for the Groundwater Needs Assessment for LIMCOM in 2011 indicate that the slow progress toward the completion data-sharing platform and basin-wide data gathering procedure is threefold (Owen 2011):

1. Interviews from ZINWA (Zimbabwe), DNA (Mozambique), and DGS (Botswana) officials reveal that there is an underlying issue of distrust surrounding data sharing in the LRB. There is a concern that if data were released to a central platform it would be freely available to consultants and third party research projects. This apprehension about relinquishing aspects

of control over internal information generation and utilization reflects an underlying opposition to regional cooperation that is based in issues of national sovereignty.

2. The different levels of economic development in the four riparian states produce varied levels of funding for data gathering. Botswana, Mozambique, and Zimbabwe do not have the financial resources to sufficiently address the data quantity and quality shortcomings of national data capturing systems. This imbalance will lead to a continued disparity between the hydrological data gathered in South Africa and data from the other three LRB countries.
3. Botswana, Mozambique, Zimbabwe, and to lesser degree, South Africa, lack the technical and personnel capacity to implement and maintain extensive data gathering projects. Furthermore, even if the national water agencies agreed to devolve some responsibility for data collection and reporting, neither SADC/WD nor LIMCOM have the capacity to undertake basin-wide testing, monitoring, and hosting of data, as is evident in the DWA's role as the implementing agency in SADC's HYCOS project.

The lack of trust, funding, and skill behind an information sharing system centralized under a regional body means that national water agencies continue to be the main source of information for the LRB. Due to the unequal capacities of the member countries, any joint effort requires either South Africa or an outside party, such as the GTZ, to play a coordinating and implementing role. The DWA's current possession of basin information, as well as the ability to take a leadership role in data-gathering studies within the region, gives South Africa a certain power in the decision-making processes that effect the development of the basin region. Similarly, the role of GTZ as both a financer and implementer of the Joint Limpopo River Basin Study gives GTZ an amount of control over the direction of the study and, to a certain extent, the development decisions that are made as a result of the study's findings and recommendations.

4. R&V hotspot analysis of the LRB

4.1 Identification of administrative boundaries and sub-catchments

Table 2 summarizes the administrative units and sub-catchments for each hotspot. Some of the hotspots straddle two or three countries; in these cases the information is provided for each country. The administrative units and sub-catchments have a wider spatial scale than the actual hotspot, but provide a basis for the gathering of data and information. In Section 5, the impacts analysis focuses in on the actual hotspot, but within the wider context of the political, economic and hydrological situation and planning usually conducted at local administrative and sub-catchment levels.

Table 2 Administrative units and sub-catchments for each hotspot

No.	Hotspot	District / District Municipality (DM)	Local Municipality (LM) / Administrative Post (AP) / Sub-district (SD)	Sub-catchment
1	**Upper Limpopo: Botswana–South Africa border**			
	Botswana	South-East, City of Gaborone	Ramotswa and Tlokweng SDs	Notwane
	South Africa	Ngaka Modiri Molema DM	Ramotshere Moiloa LM	Marico
2	**Pretoria North–Moretele**			
	South Africa	Bojanala Platinum DM	Moretele LM	Crocodile (West)
3	**Shashe–Limpopo confluence**			
	Botswana	Central		Shashe
	South Africa	Vhembe DM	Musina LM	Mogalakwena
	Zimbabwe	Beit Bridge		Shashe
4	**Upper Umzingwane**			
	Zimbabwe	Gwanda, Umzingwani		Upper Umzingwane
5	**Soutpansberg**			
	South Africa	Vhembe DM	Makhado LM	Nzhelele, Levuvhu
6	**Pafuri triangle**			
	Mozambique	Chicualacuala	Pafuri AP	Lower Middle Limpopo
	South Africa	Vhembe DM	Mutale LM	Levuvhu
	Zimbabwe	Chiredzi		Bubi
7	**Lebowa– Middle Olifants**			
	South Africa	Capricorn DM	Lepelle-Nkumpi LM	Middle Olifants
8	**Lower Limpopo–Chokwe**			
	Mozambique	Bilene-Macia, Chokwe, Xai-Xai	A number of APs	Lower Limpopo

4.2 Climate and development futures

This section provides projections for climate change and development over the LRB at the scale of each hotspot area. The timeframes used are primarily 2080–2099, although the mid-century timeframe is also referred to where possible. These are determined to a large degree by the methodologies used by the two main groups of climate modelers in the region, namely CSAG (UCT) (focus on ~2050) and CSIR (Pretoria) (focus on 2100).

4.2.1 Climate change

For background, we briefly present some pertinent information on the current climate and hydrology of each hotspot area, before discussing the climate change projections.

Current climate and hydrology

Topography is an important determinant of local climate and hydrology. Figures 3 (topography) and 4 (seasonal total rainfall) show that hotspots 1, 2, 4, 5 and 7 are elevated catchment areas. In some cases (hotspots 4, 5 and 7) they can be termed 'water towers' (major water catchment areas). Hotspots 3, 6 and 8, on the other hand, are located in the river valley or floodplain of the main stem of the Limpopo River, at lower elevations, and hotspots 3 and 6 receive low rainfalls.

The variability of rainfall is high both between years and within the growth season, as shown in Figures 5 and6. Hotspots 2 and 7 show the lowest variability and hotspots 3, 4 and 6 the highest. On the aridity scale (Figure 7), hotspots 3 and 6 are classified as arid, hotspots 1, 4 and 5 are semi-arid (but more arid within this class), hotspots 2 and 7 are semi-arid (less arid within this class), and hotspot 8 is dry/sub-humid.

Other sources of climatic stress include:

- risk of drought (all areas except hotspot 8)
- risk of floods (especially in hotspot areas 2 and 8;
- risk of tropical cyclones (hotspot 8);
- risk of wildfire (hotspots 1, 2 and 7)

The current climate stressors are given again in Table 3.

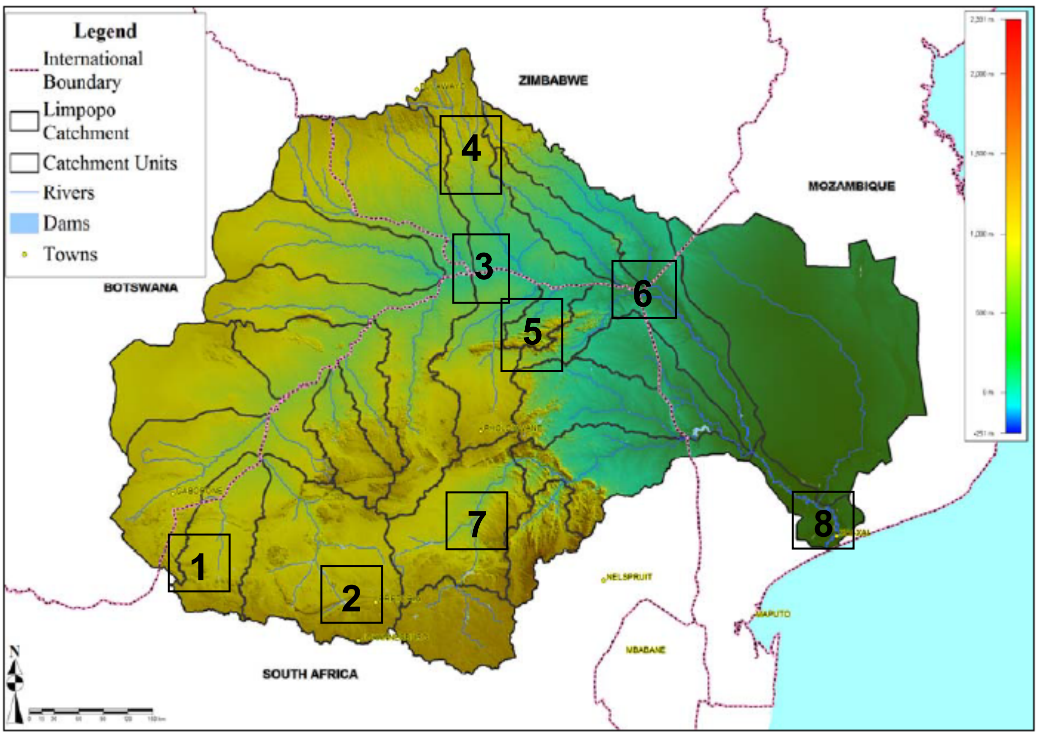

Figure 3 Topography of the LRB. Source: LBPTC Joint Limpopo River Study Scoping Phase Final Report (2010c).). Eight hotspot areas shown as described in Midgley et al. (2013).

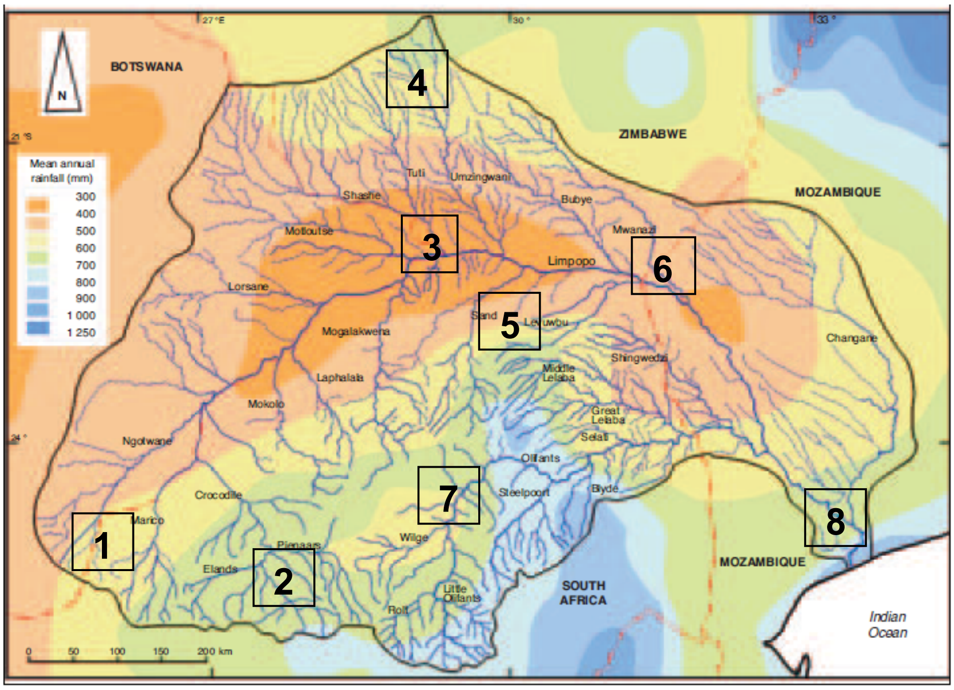

Figure 4 Average seasonal total rainfall in the LRB. Source: UNCTAD (2003) in FAO (2004).). Eight hotspot areas shown as described in Midgley et al. (2013).

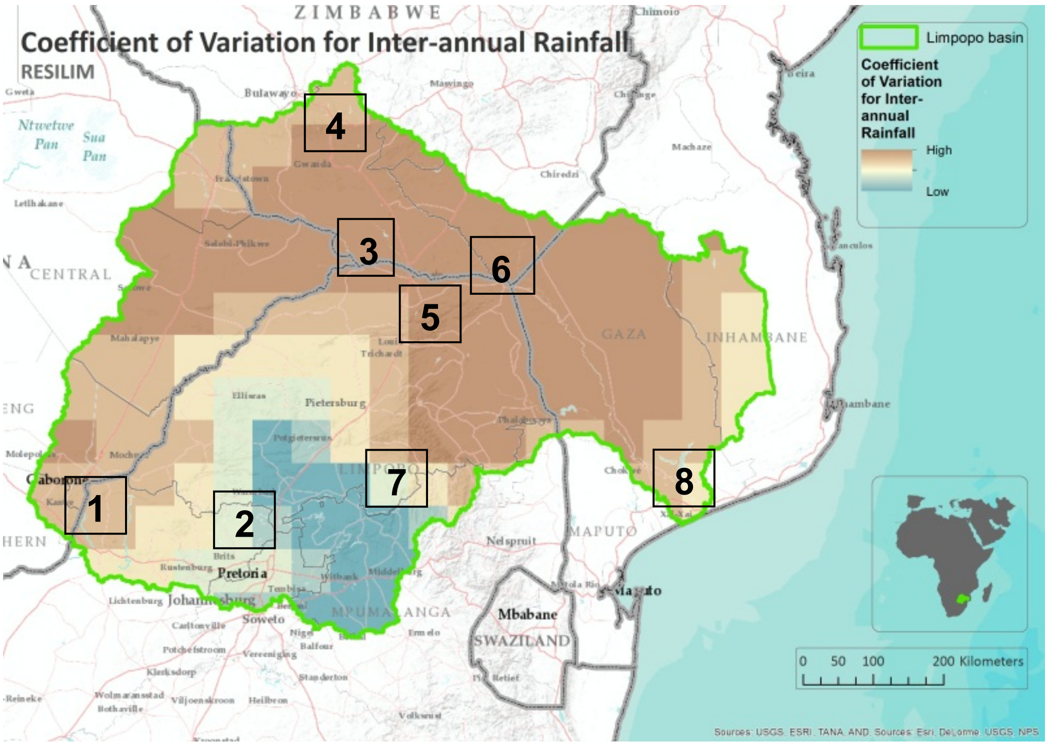

Figure 5 Map of the coefficient of variation for inter-annual rainfall for the LRB, with eight hotspots. Source: Midgley et al. (2013)

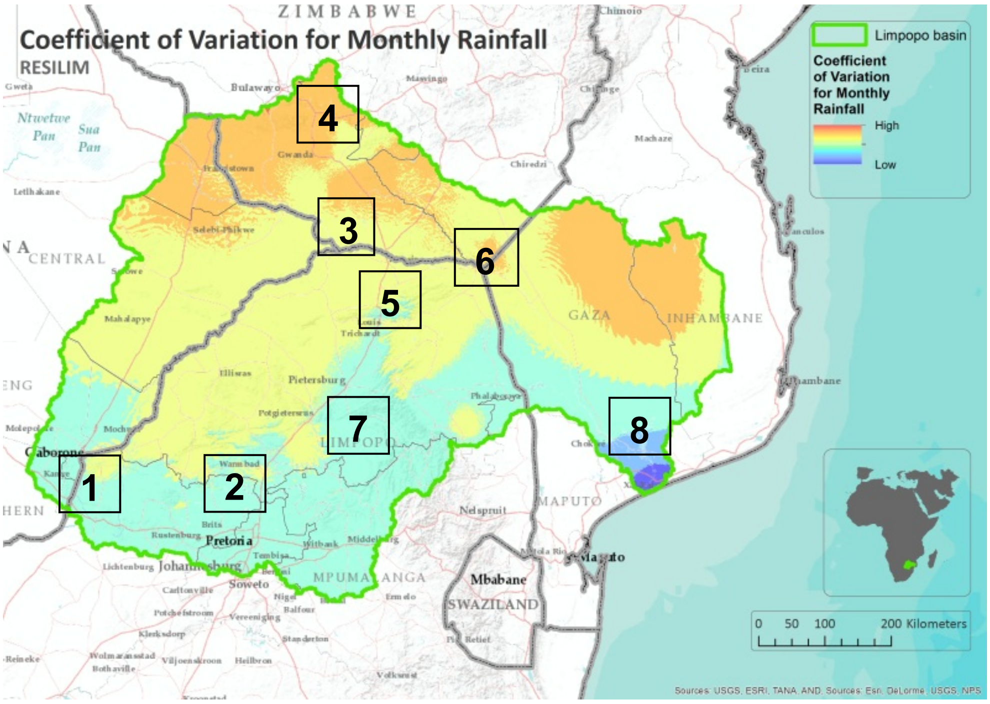

Figure 6 Map of the coefficient of variation for monthly rainfall for the LRB, with eight hotspots. Source: Midgley et al. (2013)

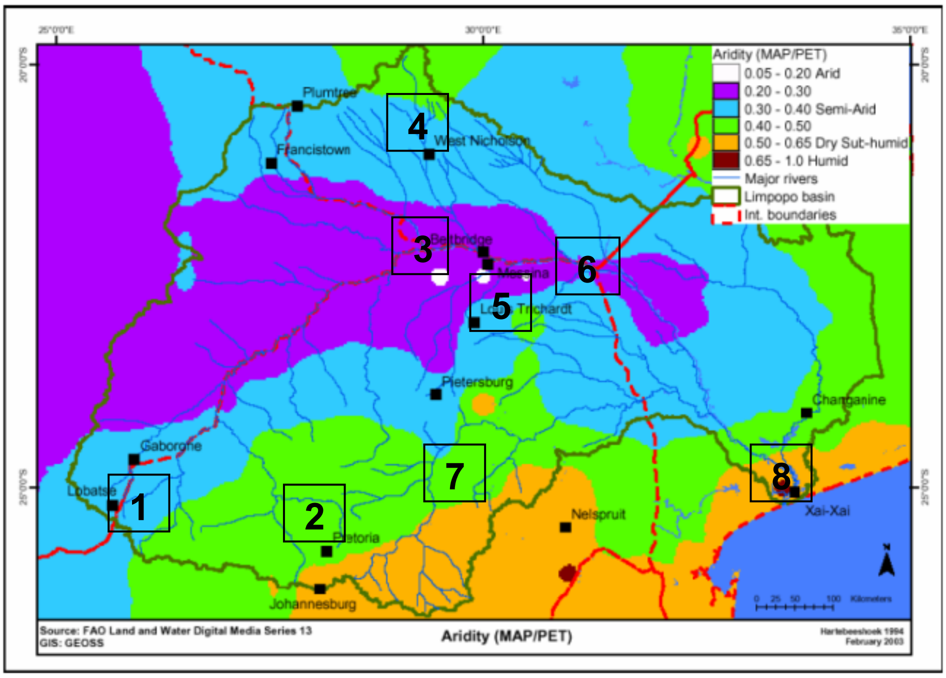

Figure 7 Map of the aridity index defined as mean annual precipitation divided by the potential evapotranspiration. Source: LBPTC Joint Limpopo River Basin Study Scoping Phase Final Report (2010c) based on CSIR (2003). The eight hotspot are identified by the boxes.

Current climate trends

Studies across the basin areas of all four riparian countries confirm that significant warming has occurred over the last few decades. Extremely hot days have increased significantly and extremely cold nights have become fewer.

The most recent analysis of rainfall trends for the South African part of the LRB (SANBI, 2013) shows that there is a tendency for reductions in rainfall at most stations in autumn, and fewer rain days in summer and autumn. Increases in high rainfall events suggest a possible increase in rainfall intensity.

Regional climate change projections

The previous report submitted to RESILIM (Midgley 2013) gave an account of expected regional climate change patterns. Before scaling down to hotspot level, it is important to place the Limpopo basin climatology in the regional context, with due reference to the complex regional climate systems which drive the current and future climates of the region. In particular, the influences of the seasonal oscillations of the Inter-tropical Convergence Zone (ITCZ) across Africa, and multi-year cycles of sea surface temperatures (El Niño Southern Oscillation) give rise to observed annual-to-decadal-scale variability in rainfall. The Limpopo basin is part of this larger system and as such cannot be understood in isolation. The regional and basin-wide climate change projections are therefore summarized in the following section. We then present projections at national basin level, before focusing more closely on projections for the hotspot areas.

Christensen et al. (2007) presented the regional projections for the period 2080–2099, including for southern Africa, in the Fourth Assessment Report of the IPCC. For temperature, the projections are for a median warming of 3.1 °C (summer, min-max range 1.8 to 4.7 °C), 3.1 °C (autumn, min-max range 1.7 to 4.7 °C), 3.4 °C (winter, min-max range 1.9 to 4.8 °C) and 3.7 °C (spring, min-max range 2.1 to 5.0 °C), with annual mean warming of 3.4 °C (1.9 to 4.8 °C). The outcomes, when presented spatially, show that the level of warming in the Limpopo basin region will increase from the coastal areas towards the inland continental areas, being highest in the Botswana basin area and lowest along the coastal plains of Mozambique.

Median projections for seasonal rainfall in summer and autumn show no change (min-max range of –10% to +6% in summer, and range of –25% to +12% in autumn). However, the frequency of extremely wet summers is expected to increase by 11% (at least 14 out of 21 models agree on this increase). Winter rainfall is projected to decrease by 23% (min-max range –43% to –3%) with strong certainty in the direction of change. Similarly, spring rainfall is projected to decrease by 13% (range –43% to +3%) with strong certainty in the direction of change. The frequency of extremely dry winters and springs is projected to increase by 23% and 20% respectively. Overall, annual rainfall may not change significantly across southern Africa (although there is a higher certainty of annual drying across the LRB area), but extremely dry years may become more frequent. Changes in the distribution and intensity of tropical cyclones in the eastern coastal regions including the lower Limpopo basin remain uncertain.

Regional projections have also been developed by the University of Cape Town's Climate Systems Analysis Group (CSAG) using statistical downscaling methodologies, and by the Council for Scientific and Industrial Research (CSIR, Pretoria) using dynamic downscaling based on GCMs and projections of changes in extreme events. We sought data from both groups to identify 'envelopes' or ranges of climatic change for each hotspot. This data was used further in the study to assess how changes would impact as they scale through the system/location being assessed.

GCM-based modeling (for end-century)

The median changes in rainfall and levels of model agreement suggest that during summer (Dec–Feb), the main rainfall season for large parts of southern Africa, there is a tendency for drying over central southern Africa. Similar tendencies are noted during autumn (Mar–May). For winter (Jun–Aug) the majority of models simulate a decrease in rainfall over most of the region. However, since these changes are small and winter is the dry season in most countries, the impact of this decrease is likely to be minimal. Also of importance is the consistently simulated decrease in rainfall during spring (Sep–Nov) across much of the southern African region. This is the period incorporating the start of the rains and suggests a reduction in early season rainfall. For the Limpopo River Basin, there is good model agreement for drying in spring and summer.

Average annual surface temperatures are expected to rise between 1 and 3 °C over most land areas by approximately 2060. Temperatures are expected to rise more during the dry seasons of winter and spring than during the wetter summer and autumn seasons. Temperature increases along the coastal regions are projected to be generally lower compared to the interior regions, due to the moderating effects of the ocean.

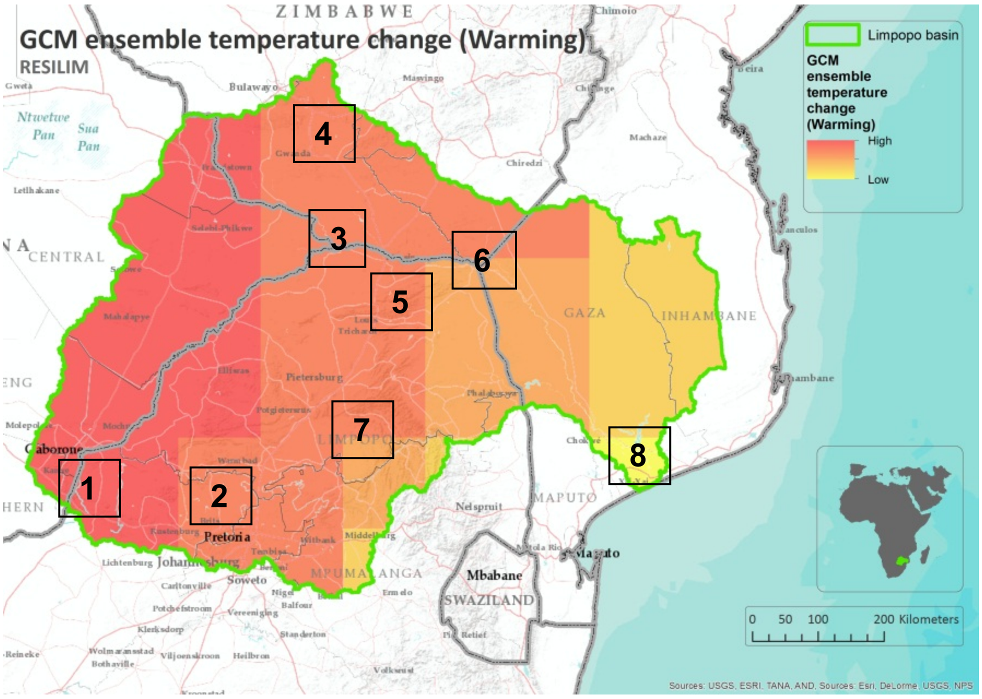

Figure 8 Projected changes in temperature (warming) for the LRB based on five GCMs. Source: Midgley et al. (2013).

Statistically downscaled GCMs (for the period 2036–2065)

The Climate Systems Analysis Group (CSAG) of the University of Cape Town has produced a set of projected rainfall and temperature changes in the Limpopo River Basin, statistically downscaled from an ensemble of 10 Global Circulation Models, using CMIP5 for the Representative Concentration Pathway (RCP) 4.5. The RCP is the new terminology that is similar to the old Special Report on Emissions Scenarios (SRES). The RCPs are for are four greenhouse gas concentration trajectories that have been adopted by the IPCC for the preparation of its fifth Assessment Report (AR5). RCP 4.5 is equivalent to the old A1B1 SRES and RCP 8.5 is similar to SRES A2. The projected rainfalls over the LRB do not vary that much between RCPs, but RCP 8.5 projects even higher temperatures.

For most of the southern African region, an increase in rainfall of between 10 and 130 mm per year is projected from the median of the model ensemble. Parts of the Limpopo basin suggest a small decline in annual rainfall, driven by declining rainfall in the summer rainfall season, although small increases are projected for the rest of the year.

An increase in temperature is expected across Southern Africa of between 1.0 and 2.88°C (depending on the model), with a similar range of between 0.7 and 2.8 °C from the mouth of the Limpopo River to its most interior sources in Botswana and north-west South Africa by 2060. Spring is expected to experience the greatest increase in temperature compared to the other seasons.

Table 3 The projected rainfall and temperature changes in the Limpopo River Basin statistically downscaled from an ensemble of 10 Global Circulation Models, using CMIP5 for the Representative Concentration Pathway (RCP) 4.5. Source: Climate Systems Analysis Group, University of Cape Town.

RCP	4.5					
Variable	Annual total rainfall					
Reference Period	1979-2009	542.64		mm/year		
Future Period		Mininum	%	Maximum	%	
2020	2040	-31.78	-5.9	82.05	15.1	
2030	2050	-44.49	-8.2	61.17	11.3	
2040	2060	-67.29	-12.4	81.64	15.0	

Variable	Mean annual maximum temperature (degrees C)				
Reference Period	1979-2009	28.57	degree C		
Future Period		Mininum	%	Maximum	%
2020	2040	0.72	2.5	1.48	5.2
2030	2050	0.9	3.2	1.96	6.9
2040	2060	1.04	3.6	2.37	8.3

Table 4 The projected rainfall and temperature changes in the Limpopo River Basin statistically downscaled from an ensemble of 10 Global Circulation Models, using CMIP5 for the Representative Concentration Pathway (RCP) 8.5. Source: Climate Systems Analysis Group, University of Cape Town.

RCP	8.5					
Variable	Annual total rainfall			mm/year		
Reference Period	1979-2009		542.64	mm/year		
Future Period			Minimum	%	Maximum	%
	2020	2040	-35.97	-6.6	70.66	13.0
	2030	2050	-44.46	-8.2	71.09	13.1
	2040	2060	-49.32	-9.1	69.43	12.8

Variable	Mean annual maximum temperature (degrees C)					
Reference Period	1979-2009		28.57	degrees C		
Future Period			Minimum	%	Maximum	%
	2020	2040	0.66	2.3	1.79	6.3
	2030	2050	1.19	4.2	2.14	7.5
	2040	2060	1.57	5.5	2.75	9.6

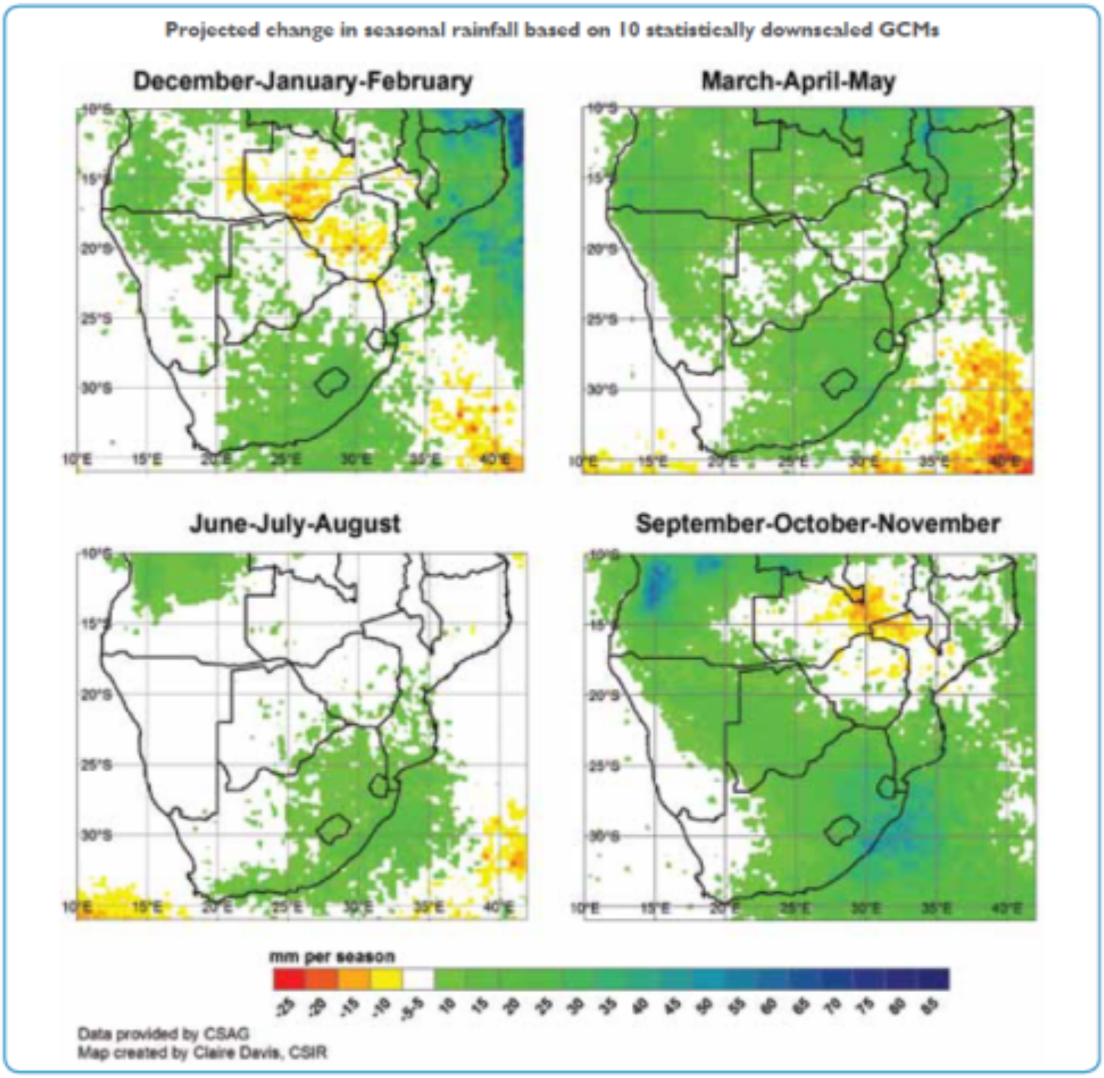

Figure 9 Projected changes in mean summer (DJF), autumn (MAM), winter (JJA) and spring (SON) rainfall (by 2036–2065, relative to 1961–2000) expressed as the change in millimeters and based on the median of 10 statistically downscaled GSMs.. (Source: Davis, 2011).

Dynamically downscaled GCMs (for 2071–2100)

According to a six-member Cubic Conformal Atmospheric Model (CCAM) dynamically downscaled ensemble, based on the A2 SRES scenario, the number of cyclones entering the SWIO (South West Indian Ocean), making landfall and having an effect on the Limpopo Basin are expected to decrease towards the end of the 21st century (Malherbe et al., 2011; Malherbe et al., 2013). These studies expect tropical cyclone tracks to shift northwards, out of the zone of making frequent landfall in the LRB. (It should be pointed out that other studies do not show agreement with this projection, INGC 2009.) This set of models and downscaling also projects a strengthening of the subtropical high pressure system over the northern and eastern parts of South Africa (LRB), resulting in a general warming. The increased stability in the lower to middle atmosphere (fewer convection cells or thunderstorms) is projected to cause a general drying in the Limpopo River Basin (LRB), specifically lower rainfall in the December–February quarter. Zhu and Ringler (2010) obtained similar results.

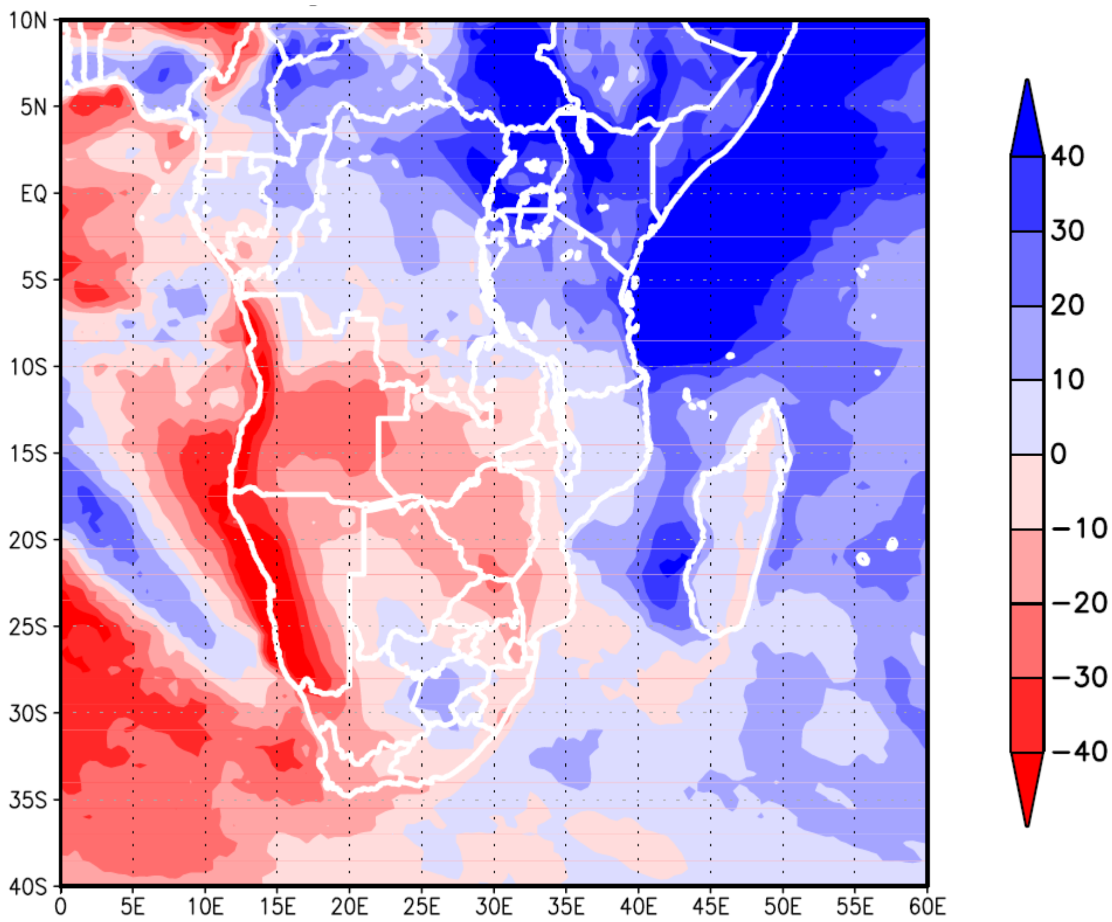

Figure 10 Median projected change for the DJF months of rainfall for the period 2071–2100 relative to 1961–1990, downscaled using CCAM from a six-member ensemble. Source: Malherbe et al., 2011.

The basin-wide implications for climate change for 2100 include:

- Reductions in rainfall in all riparian countries and in all seasons, but more strongly in summer; annual reductions could be as high as 30% by 2100.
- Increases in temperature of between 0.3 and 3.2 ˚C depending on the model. Again, it is expected that the interior regions will experience more intense warming than the coastal areas.
- Increases in potential evapotranspiration of 6–8%, but lower in Mozambique (lower Limpopo); largest increases in September – November (when local heating takes place, wind velocity picks up, but the rainfall season has not yet started).
- Lifting of the cloud base, resulting in loss of mist interception in the cloud forest of the southern mid-basin (Soutpansberg and Wolkberg).

- Reduced runoff production at high altitude where the rainfall–runoff ratio is the highest, with knock-on effects of reduced runoff downstream (importance of mountain catchments).

Climate change may manifest itself not only through changes in the long-term mean rainfall, temperature and circulation patterns, but also through an increase in the frequency of extreme weather events such as tropical cyclones and heat waves. Of the most important such weather systems are tropical cyclones that may bring widespread flooding to Mozambique and north-eastern South Africa, and thus the eastern parts of the LRB. Possible changes in tropical cyclone frequencies and tracks are still inconclusive and not well understood, although Malherbe et al. (2011, 2013) project a reduction in frequency. However, it is possible that the intensity of cyclones will increase.

Thunderstorms that frequent the eastern parts of the subcontinent may on occasion be severe and cause localized flash flooding and damaging winds. The ensemble median of the projected change in the frequency of occurrence of extreme rainfall events over southern Africa for the period 2035–2065 relative to the baseline period 1961–2000 indicates slight decreases in frequency for the Limpopo River Basin area. At the other end of the spectrum, periods of sustained anti-cyclonic circulation and subsidence may cause the occurrence of heat waves and prolonged dry spells over the southern African region.

The increase in average temperature is projected to occur in association with an increase in very hot days (here defined as days when the maximum temperature exceeds 35 °C). The ensemble median of the projected change in the frequency of very hot days over southern Africa for the period 2035–2065, relative to the baseline period 1961–2000, indicates drastic increases in the annual frequency of very hot days for a very large part of the subcontinent, including the LRB.

Issues of uncertainty

There are two types of uncertainty regarding climate model projections. The first is whether the model outputs will forecast future changes reasonably accurately in terms of direction and quantum of change (wetting or drying) and by what amount. The second relates to the differences between model outputs, given the same inputs.

Firstly, from the studies presented above, it is apparent that the patterns of change (drying) projected by dynamical downscaling (DD) are to a large extent consistent with those of the GCM median projections, indicating that the tendency of the set of models in each case is similar. In contrast, the statistical downscaling (SD) shows a bias towards wetting over much of southern Africa. However, in the northern parts of the LRB area there is agreement between SD and DD with respect to summer drying.

Secondly, there are sometimes large differences in outcomes between different models. For example, Malherbe et al. (2011) used an ensemble of 'the sea-ice and bias-corrected sea surface temperatures (SSTs)' of six GCMs (CSIRO Mk 3.5, GFDL2.1, GFDL2.0, HadCM2, ECHAM5 and Miroc-Medres) from AR4 of the IPCC. In the model runs, the CSIRO Mk 3.5 generally runs counter to the others. Confidence in model outcomes is then ranked as a 5/6 outcome. This is regarded as a relatively consistent outcome and classified as 'very confident'.

In Figure 11 below, for just the South African portion of the LRB, the CSIRO Mk3.5 model projects wetting of the north-eastern portion of the LRB (top figure), while the other five, represented by the ECHAM5 model output here (bottom figure), represent drying. In general, five out of six models produced consistent results between them, but the CSIRO Mk3.5 runs counter to the trend.

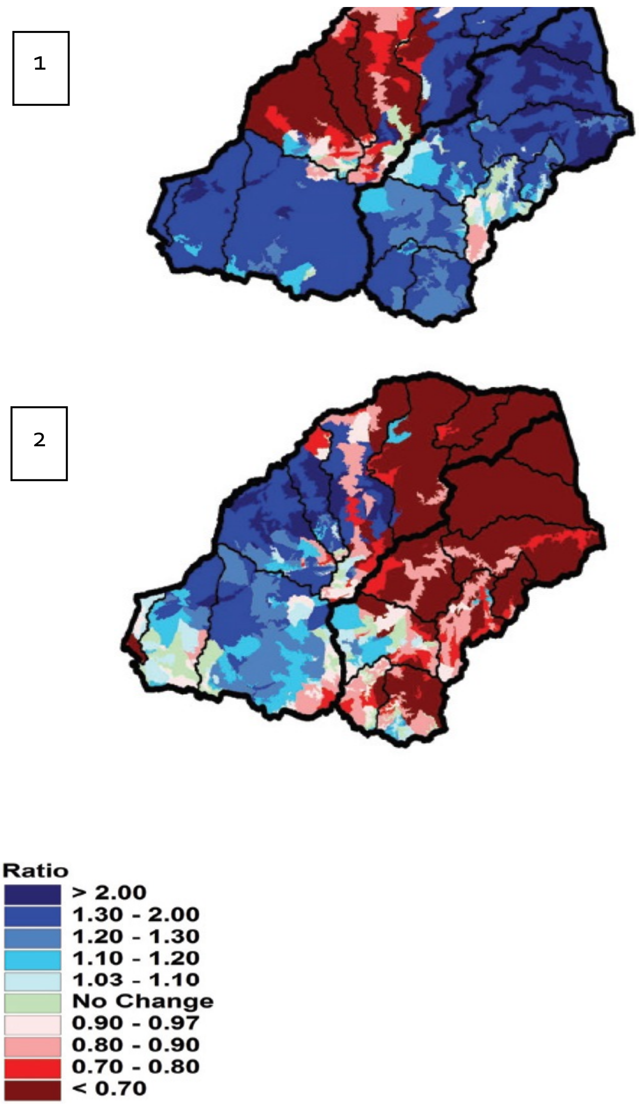

Figure 11. Two competing projections: (1) CSIRO Mk 3.5 and (2) ECHAM5. (source: Lumsden et al., 2011) for Limpopo Province, comparing ratios of future to present one-day design flood estimates (i.e. future/present values), used as a proxy for general wetting and drying.

The CSAG results are based on statistical downscaling from the CMIP5 outputs. CMIP5 is the fifth iteration of the Coupled Model Inter-comparison Project, which is a global collection of GCM outputs used to study the differences of outputs between the models given the same inputs. The sources of the differences between model systems are not yet clear. Yet this presents the need to consider two scenarios that encapsulate the general trends and directions of the climate projections. Decisions and adaptations that are made now and are valid across both scenarios can then be considered as 'no regrets' adaptations, meaning that they contribute positively in the future, whichever climate scenario more faithfully represents the actual future climate trajectory.

Thirdly, an issue of concern is the differing ocean climate change models, which are concerned with whether the south-west Indian Ocean off the coast of Mozambique becomes relatively cooler or warmer. These scenarios are not currently addressed in the coupled ocean-atmosphere GCMs. Cooling versus warming scenarios impose substantially different regional climate change outcomes and this is still an area for further research.

These inconsistencies and weaknesses are currently the subject of much research and debate that will not be entertained in this report. However, in the remainder of our study we recognize the broad potential probabilities of climate change direction and magnitude across the LRB, and this is captured in the scenarios discussed under each hotspot.

Summary of regional climate change projections

When the spatially-explicit national and regional level climate projections are consolidated to identify key messages specifically for the Limpopo River Basin area, it appears that the LRB is likely to become dryer, more so in winter and spring (although there is uncertainty around the seasonal patterns and magnitude of this trend), and warmer (very likely), especially in spring and more so toward the inland parts of the basin. Some models project possible wetting in the upper (western) basin and the lower (eastern) basin, with indications of more frequent extremely wet summers. The start and end of the rainy season will shift, affecting the duration of the rainy season, but the patterns will differ across the basin. Rainfall events are expected to become heavier, with increased risks of local and regional flooding. Dry spells and droughts are expected to increase in frequency and severity. The projections for changes in tropical cyclones along the Mozambique coast remain uncertain, but cyclones could become more intense. The combination of rainfall and temperature changes will result in decreased soil moisture, reduced runoff and reduced infiltration to groundwater.

The climate change modeling that has been conducted for each country, as summarized in the respective national communications to the United Nations Framework Convention on Climate

Change (UNFCCC), is reflective of the assessment above with respect to the basin areas of each country (Midgley et al., 2013).

What does this mean for each hotspot?

The following table shows more specifically the expected climate trends for each hotspot area.

Table 5 Current climate stressors and expected climate trends for the middle to the end of the 21st century

No.	Hotspot	Current climate stressors	Expected climate trend towards 2100 (2060 for temperature)
1	Upper Limpopo: Botswana–South Africa border	Drought, heat, water resources demand-supply	General wetting (10% increase in mean annual rainfall) especially in summer (DJF). Increase in mean number of rain days. Earlier beginning and later end of rain season. Increase in number of convective rainfalls (thunderstorms). Change in drought frequency undetermined. Significant warming, reaching 3 °C by 2060, especially during spring. Fewer days with frosts, warmer night-time temperatures.
2	Pretoria North–Moretele	Heat, localized floods, drought, water resources demand-supply	Positive wetting trend but weak and ambiguous changes (–10% to +10%). Small increase in mean number of rain days. Earlier beginning and later end of rain season. Small increase in number of convective rainfalls (thunderstorms). Change in drought frequency undetermined. Significant warming, reaching 2.5–3 °C by 2060, especially during spring. Fewer days with frosts, warmer night-time temperatures.
3	Shashe–Limpopo confluence	Irregular rainfall, drought, localized floods, heat, short growing periods, low soil moisture	Discernible drying in DJF quarter (summer). Fewer rain days. Later beginning and earlier end to rain season. Rainfalls decrease by 20–30%. Significant warming reaching 2.5 –3 °C by 2060, especially during spring.
4	Upper Umzingwane	Irregular rainfall, droughts, water resources demand-supply	Discernible drying in DJF quarter (summer). Fewer rain days. Later beginning and earlier end to rain season. Significant warming reaching 2.5 –3 °C by 2060, especially during spring.

No.	Hotspot	Current climate stressors	Expected climate trend towards 2100 (2060 for temperature)
5	Soutpansberg	Drought, heat	Discernible drying in DJF quarter (summer). Lifting of the cloud base, resulting in loss of mist interception in the cloud forest. Fewer rain days. Later beginning and earlier end to rain season. Rainfalls decrease by 20–30%. Significant warming reaching 2.5–3°C by 2060, especially during spring.
6	Pafuri triangle	Irregular rainfall, drought, heat	Discernible drying in DJF quarter (summer). Fewer rain days but more likely to be affected by tropical cyclones making landfall on the Mozambican coastline. Later beginning and earlier end to rain season. Fairly strong warming reaching 2 °C by 2060, especially during spring.
7	Lebowa – Middle Olifants	Drought, heat, water resources demand-supply	Discernible drying in DJF quarter (summer). Lifting of the cloud base, resulting in loss of mist interception in the cloud forest. Fewer rain days. Later beginning and earlier end to rain season. Rainfalls decrease by 20%. Fairly strong warming reaching 2.5–3 °C by 2060, especially during spring.
8	Lower Limpopo–Chokwe	Floods, cyclones	Discernible drying in DJF quarter (summer), especially February. SD modeling shows likely wetting. Later beginning and earlier end to rain season. Moderate warming reaching 1.5 °C by 2060. Possibly fewer tropical cyclones making landfall, but possibly more intense and capable of causing significant damage from floods. Droughts more frequent. Sea level rise (global range of possibilities).

4.3 Development futures

4.3.1 Background

What are development futures? The impacts of a changed future climate on human wellbeing cannot be examined on the basis of the current status of socio-economic development: future climate impacts must be examined in the context of the likely future socio-economic conditions. These future conditions will look different from what they are now. However, the evolution of changes and trajectory into the future will be driven by the local context, its resource base, its population dynamics, its supporting infrastructure and its connectivity into a larger socio-economic system. These we call development futures. Obviously these are not the same everywhere.

4.3.2 Upper Limpopo: Botswana–South Africa border

Urban centers in Soputh Africa are located in the Ramotshere Moila Local municipal area and include Zeerust, Groot Marico, Swartruggens and other smaller settlements and communities. The combined population of the area is 151,000 people, with an estimated growth rate of 0.92%.yr^{-1} and the unemployment is at 36%, with youth unemployment even higher at 45%. Most are located in the arc of these towns, from west of Rustenburg in the east towards the Botswana border and Gaborone (Local Government Handbook and Census 2011, Municipal Fact Sheet). Education levels are low, 21% have no schooling. Connection to water borne sanitation is 22%. Forty six percent of households are headed by women. In the south, where much of the water production originates in the dolomites, the population density is low and is farming and game ranch/ecotourism community. This is a Government Water Controlled Area, meaning there is a limit on the use of water for economic development such as irrigation beyond what is already being extracted from the water resource systems. This situation is unlikely to change substantially over the medium term, as water is key constraint to growth.

By comparison, in Botswana a total of 85,014 people live in the South East District, on the border of South Africa. Compared with the South African side, the unemployment rate is considerably lower, at roughly 18.5% for 2009/2010 and education levels relatively higher, with 86.1% of the population having attended primary school, and a literacy rate of 84.2%.

4.3.3 Pretoria North–Moretele

This is a region of villages that have grown and joined to make large sprawling settlements, without visible and facilitating or supporting infrastructure such as tar/asphalt roads, sanitation, lighting, schools, agricultural production and the like. The settlement is unplanned. The probability of an economic development that will take the inhabitants out of poverty is not high, as there are few reasons to locate significant economic development in this area. The potential for further agricultural development is very limited. Government spending on infrastructure and services may bring some improved human development indicators but it is likely to remain an area greatly in need of development.

4.3.4 Shashe–Limpopo confluence

This area of the Shashe–Limpopo River confluence is relatively sparsely populated. Further developments in the abstraction of water, especially via boreholes alongside the Limpopo River, are possible in the future, as envisaged by various land users. Other water developments include the demand from further coking coal mining activities for coal washing and processing. The Transfrontier Conservation Area (TFCA) is the dominant focus of governance, but is in conflict with the pressures for mining activities. Conflicts over water and ecological functioning between ecotourism and mining will be a dominant feature.

4.3.5 Upper Umzingwane

The upper Umzingwane area is a resource catchment for the larger Bulawayo urban aggregation. Small towns include Gwanda Town and Esibomvu, Esigodini, West Nicholson and Colleen Bawn. Given the poor and unreliable rainfall, little more than further livestock farming and small holder plots in terms of agricultural development will take place, especially in the south where people in communal farming lands will continue to struggle with sustaining livelihoods. Ecosystem resources are likely to come under pressure in the former commercial farming area and degrade as more people move onto that land. The water resources in the upper catchment are tied to the development and growth of Bulawayo, which extracts water from that region. The economic future of Bulawayo is poorly defined; the city is unlikely to grow within the short to medium term. More water might be extracted to supply a growing urban population.

4.3.6 Soutpansberg

The Soutpansberg mountain and the high rainfall received there is a key driver of the region's productivity, especially in the Levuvhu River valley. This is bounded by old homeland settlements and the extended villages of Venda, most of which are degraded through overgrazing and deforestation. The key urban center is Makhado, the economy of which is mostly driven by the agricultural activity of the surrounding countryside. Population growth will continue in the region and is likely to increase land use pressure on the commercial farms and water resources. The upper catchments will continue to underscore their vital contribution to regional water resources by maintaining high-quality runoff, but diminished by increasing temperatures and a lower trending rainfall.

4.3.7 Pafuri triangle

There is extensive low density livestock grazing in all three countries. Settlements are sparse and the area has a low population density. The region is a source of border control issues, with people moving between South Africa, Zimbabwe and Mozambique.

4.3.8 Lebowa–Middle Olifants

This region does not have a particular attraction as an area for a concentration of economic growth. On its boundary, in the Sekhukune mountains, mining remains extremely important; this area is part of the platinum belt of the Bushveld Igneous Complex. Other mineral deposits are likely to be extracted in this area at some stage in the future, putting pressure on the unique biodiversity of this mountainous area. Within the core of the Middle Olifants / Lebowa area, a business-as-usual approach will see the area continue to degrade environmentally. Population pressures in urban centers such as Jane Furse and Lebowakgomo will continue growing, but remain relatively poor, not being centers of manufacture and business development.

4.3.9 Lower Limpopo–Chokwe

The urban centers of Gaza are growing at differential rates. The population of Chokwe is increasing at about 0.6% a year, while that of Xai-Xai is more than double at 1.5%.yr^{-}, and Bilene-Macia about 2.7%.yr^{-}. There is a general coastal movement of people. The driver of this movement is likely the impact of regional flooding along the Limpopo River flood plain.

4.4 Scenarios

This section presents the description of each hotspot area according to a best and a worst case scenario. These are based on the preceding analysis of climate and development futures. They are intended to represent the 'envelope' or range of plausible climate and development drivers of future socio-economic and ecological well-being.

4.4.1 Upper Limpopo: Botswana–South Africa border

Scenario 1 (best case):

- Ten percent wetting (summer rainfall), warming 2.5 °C with moderate increases in maxima.
- Population growth rate remains below 1% p.a.; steady transition towards stronger secondary and tertiary economy; water supply and demand (including groundwater) can be reconciled without harming agriculture or the ecological reserve.

Scenario 2 (worst case):

- No change in annual rainfall, more intense summer convective rainfall, fewer rain days and shorter growth season, warming 3.5 °C with more extreme increases in maxima.
- Population growth rate rises; weak economic growth and lack of diversification; persistent poverty; significant constraints on water supply including groundwater – ecological reserve ignored and degradation ensues.

4.4.2 Pretoria North–Moretele

Scenario 1 (best case):

- Ten percent wetting (annual rainfall), warming 2 °C with moderate increases in maxima.
- Economic and social development linked to improved infrastructure and services; water transfer and return schemes ensure adequate and safe water supply.

Scenario 2 (worst case):

- Ten percent drying (annual rainfall), more intense summer convective rainfall, warming 3 °C with more extreme increases in maxima.
- Weak economic and social development due to failure of infrastructure and service delivery; continued decline of mining sector; significant constraints on supply of safe water.

4.4.3 Shashe-Limpopo confluence

Scenario 1 (best case):

- Ten percent drying (especially summer), warming 2 °C with moderate increases in maxima.
- Shared platform for joint discussions of land and water use planning is in place between the three riparian countries; growth of eco-tourism; sustainable development of aquifer-fed irrigated agriculture.

Scenario 2 (worst case):

- Thirty percent drying (annual rainfall), warming 3 °C with more extreme increases in maxima.
- Long-term lack of a shared platform for joint discussions on land and water use planning by three riparian countries; decline in eco-tourism; unsustainable development of aquifer-fed irrigated agriculture.

4.4.4 Upper Umzingwane

Scenario 1 (best case):

- Ten percent drying (especially summer), warming 2 °C with moderate increases in maxima.
- Local economic development based on sustainable management of natural resources; diversification of livelihood options.

Scenario 2 (worst case):

- Thirty percent drying (annual rainfall), warming 3 °C with more extreme increases in maxima.
- Stagnation due to unsustainable management of natural resources; persistent poverty traps (low productivity of smallholder farming, informal gold panning).

4.4.5 Soutpansberg

Scenario 1 (best case):

- Ten percent drying (especially summer), warming 2°C with moderate increases in maxima
- Local economic development goes hand in hand with good management of watershed ecosystem services; development of diversified livelihoods

Scenario 2 (worst case):

- Thirty percent drying (annual rainfall), warming 3 °C with more extreme increases in maxima.
- Unplanned resource-based development that undermines good watershed management; no alternatives to unviable livelihoods.

4.4.6 Pafuri triangle

Scenario 1 (best case):

- Ten percent drying (especially summer), warming 1 °C with moderate increases in maxima.
- Shared platform for joint discussions of land and water use planning is in place between the three riparian countries growth of eco-tourism; development of viable and diversified land use and livelihoods.

Scenario 2 (worst case):

- Thirty percent drying (annual rainfall), warming 2 °C with more extreme increases in maxima.
- Long-term lack of a shared platform for joint discussions on land and water use planning by three riparian countries; decline in eco-tourism; no alternatives to unviable livelihoods.

4.4.7 Lebowa–Middle Olifants

Scenario 1 (best case):

- Ten percent drying (especially summer), warming 2 °C with moderate increases in maxima.
- Best practice land and water management and governance of natural resources; development of diversified livelihoods.

Scenario 2 (worst case):

- Thirty percent drying (annual rainfall), warming 3°C with more extreme increases in maxima.
- Continued degradation of land and water resources; weak governance; no alternatives to unviable livelihoods.

4.4.8 Lower Limpopo–Chokwe

Scenario 1 (best case):

- Ten percent wetting (especially late summer), warming 1 °C with moderate increases in maxima, moderate sea level rise, no change in cyclone dynamics.
- Agricultural development based on good resource management; growth in tourism; success in controlling malaria, HIV, cholera.

Scenario 2 (worst case):

- Twenty percent drying (especially late summer), warming 1.5 °C with more extreme increases in maxima; significant sea level rise; either less frequent or more intense cyclones.
- Poor resource management of productive agricultural land; decline in tourism; losing battle against malaria, HIV, cholera.

4.5 First to Fourth Order Impact Assessments

This section presents the impact scenarios for each hotspot as developed through the application of the First to Fourth Order Impact Framework. In each case the assessment for the current situation is given first, highlighting the key drivers of risk and the pathways by which these cascade through the four Orders. Next, the assessment for the two future scenarios is presented, showing how future changes in climate and development could lead to shifts in drivers, impacts and socio-economic outcomes. The intention is to weave a 'story' identifying dynamic impact pathways, that can then be subjected to critical stakeholder and expert scrutiny and lead to a final set of validated 'futures'. From these will emerge a process of identifying and prioritizing possible adaptive responses with the greatest possible chance of success.

4.5.1 Hotspot 1: Upper Limpopo: Botswana–South Africa Border

Protecting the Eyes*

*In South African hydrological terminology, an eye is a large spring, in this case from dolomitic aquifers

Key Messages

- This highly sensitive ecosystem at the source of the Limpopo River straddles two countries (Botswana and South Africa). Water resources, including the shared alluvial aquifer and dam-to-dam transfers between the countries, are constrained yet key to current livelihoods and future development in both countries. Specifically, this part of Botswana is a 'food basket' which supplies greater Gaborone. Bilateral discussions around water resource use and management, within the context of downstream implications for the whole basin, will become increasingly important.

- The dolomitic 'eyes', the springs and associated wetland systems fed by groundwater that form the upper catchment of the Groot Marico River, are of great conservation significance and are highly sensitive to groundwater abstraction elsewhere in the interlinked groundwater/surface water system.
- Geographical isolation has led to high levels of speciation and adaptation to local environmental conditions. The Upper Groot Marico River is the last remaining free-flowing river in the entire north-western regions of South Africa. All threats to water quantity, quality and biodiversity must be dealt with to protect this important system.
- Climate change is expected to significantly increase heat stress and warming-related increases in evaporation and transpiration, thus reducing groundwater infiltration, surface runoff, soil moisture, and 'green water' in plants (even if rainfall increases somewhat as projected by some).
- Land use systems, based on irrigated crop farming, livestock farming, and game farming (with associated tourism) may undergo transitions to adjust to the gradual aridification.
- Some population groups suffer high rates of unemployment, poverty and lack of access to basic services. Development is, however, severely constrained by the scarcity of water resources. Meeting the water needs of growing towns and settlements will have future implications for irrigated agriculture and the maintenance of the ecological reserve.

Background

This hotspot covers an area extending from South-Eastern Botswana, south of the capital city Gaborone, towards the east and the small town of Groot Marico in South Africa, and a roughly equivalent diameter to the north and south. The east-west road is an important transport corridor for the movement of people and goods between Botswana (especially Gaborone and its satellite towns) and Gauteng, and the large mines en route. Two sub-catchments of the Limpopo basin are of importance: the Notwane sub-catchment in Botswana and the Groot Marico sub-catchment in South Africa.

The Notwane River arises on the edge of the Kalahari sandveld of south-eastern Botswana and flows northeastwards through the most densely populated area of Botswana, before joining the Limpopo River on the border with South Africa, 50 km downstream of the confluence with the Marico River. The river and its tributaries are ephemeral and flow only seasonally after sufficient rainfall. During droughts the river may cease to flow altogether, but it can also experience flash floods after heavy thunderstorms in the catchment. The Gaborone Dam (144 million m^3 capacity) is situated on the Notwane River and supplies water to the city of Gaborone and surrounding settlements; other smaller dams (about 200) in the catchment provide water mainly for livestock. More than 30% of Botswana's population lives in the Notwane Basin, accounting for the considerable water demand for household use. Gaborone alone consumes 50% of water for urban use, and rapid urbanization is expected to raise this demand significantly for at least the next decade or two. In order to make up the water deficit in this catchment and to redress current inequalities of water abstraction across this transboundary area, South Africa has started to transfer water from the Marico Water Management Area (Molatedi Dam) to Gaborone Dam. This will reach 124 million m^3 per year. Additional large transfers are planned from the Shashe Dam near Francistown to Gaborone.

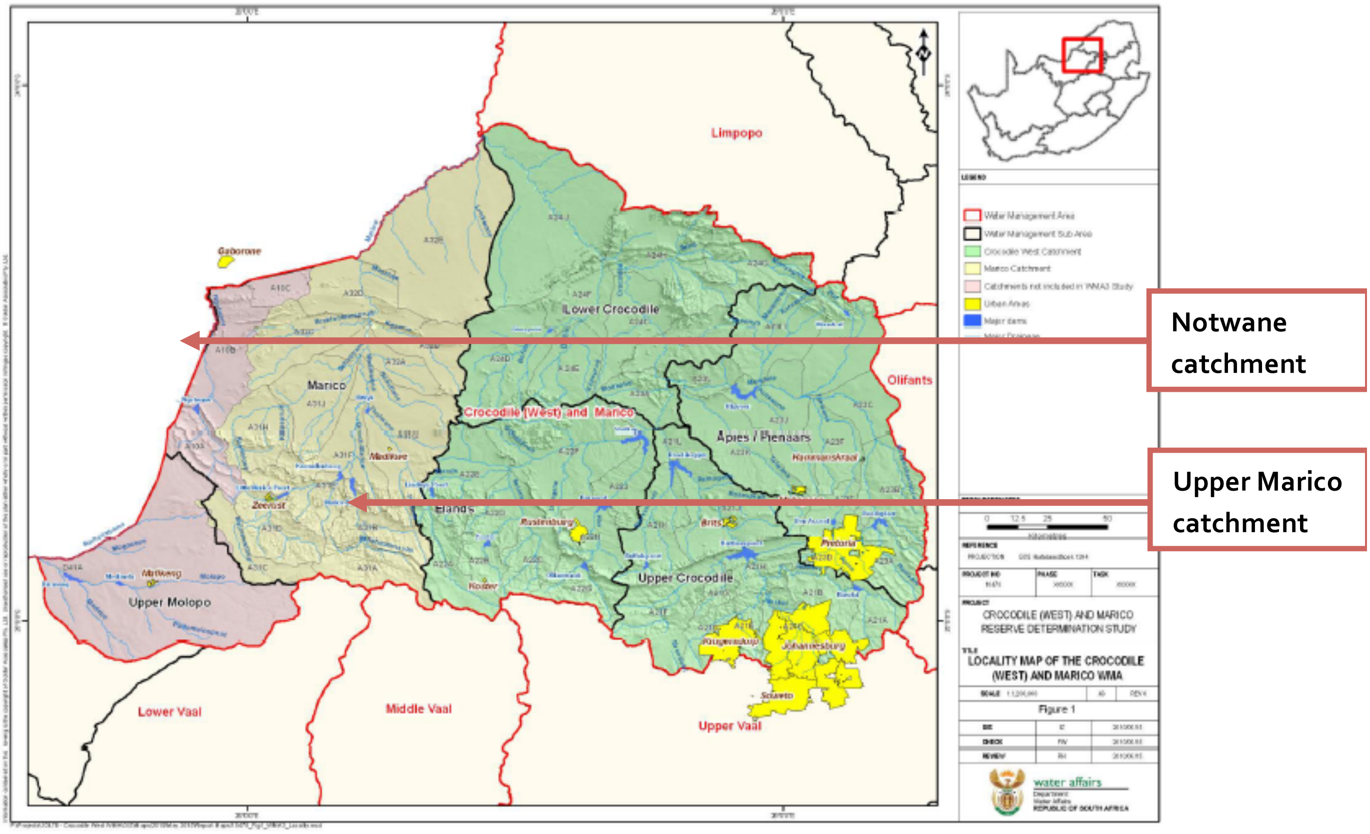

Figure 11 Map showing the spatial extent of the Marico Water Management Area (in brown). The Notwane sub-catchment lies to the west (in purple and extending into Botswana - Gaborone). Source: Directorate Water Resource Classification (2012).

The Marico River arises in the southwestern-most part of the Limpopo Basin, south-east of the town Zeerust in the Swartruggens area of South Africa. It is perennially fed by a number of dolomitic springs ('eyes') and surrounding wetlands, underlain by a large dolomitic aquifer system with high groundwater recharge (Skelton et al., 1994). This system is interlinked with surface water systems over a large area and is highly sensitive to surface and groundwater abstraction even at some distance from the eyes. The larger Groot Marico River is joined by the smaller Klein Marico

River and flows northwards where it forms the border between South Africa and Botswana. It is then joined by the Crocodile River from the east to become the Limpopo River. Two large dams, the Marico Bosveld and Molatedi, occur in the middle and downstream sections.

The Upper Groot Marico River is the last remaining free-flowing river in the entire north-western regions of South Africa. It enjoys flagship 'free-flowing river' and fish sanctuary status under the National Freshwater Ecosystem Priority Areas (NFEPA) Project of South Africa (Nel et al., 2011), with high levels of speciation. It is the lifeblood of communities and economic activities in an otherwise semi-arid region. What happens to this hotspot clearly has implications for the local ecology and economy, as well as for the downstream Limpopo River. All threats to water quantity, quality and biodiversity must be dealt with to protect this still relatively healthy ecosystem (River Health Programme, 2005) and thereby support resilience to climate change.

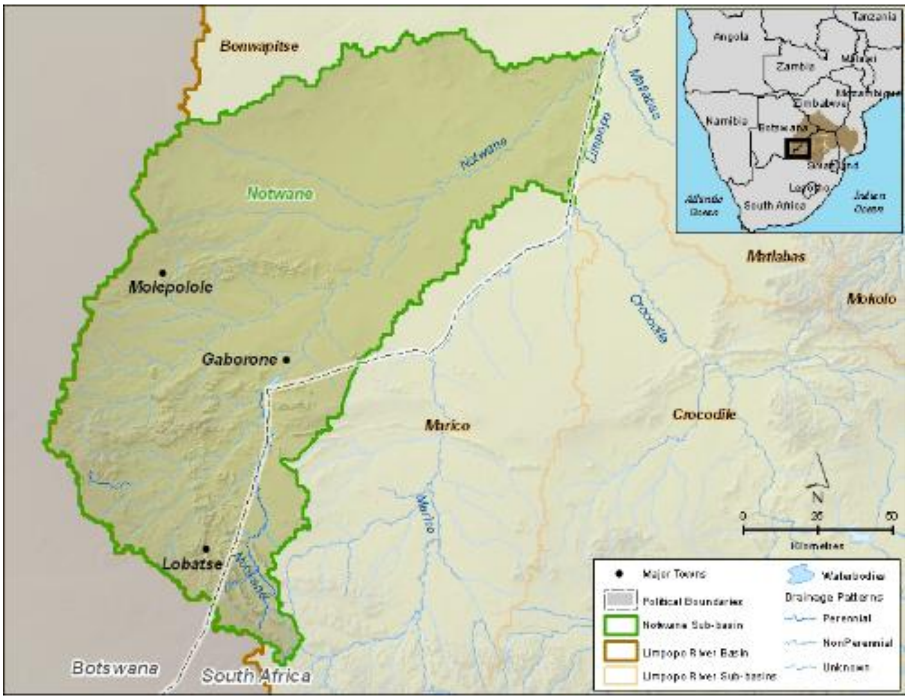

Figure 12 The Notwane sub-catchment of the Limpopo River Basin

The primary land uses and income-generating activities in this region are livestock and game farming, game reserves and ecotourism, and limited crop farming, much of it under irrigation. In South Africa, crops include maize and irrigated wheat, sunflower seeds, groundnuts, citrus and tobacco. In South Africa, commercial livestock farming is practiced with beef and dairy cattle, sheep, boer goats and poultry, but many farmers have shifted to game farming. In Botswana there is a high density of cattle, goats and sheep to supply meat and dairy products to the nearby urban markets.

The drivers of change in the Notwane and Marico sub-catchments are diverse and include the impacts of flow regulating structures (dams and weirs), water abstraction for irrigation and livestock, and threats relating to mining and pollution (River Health Programme, 2005). Recently, proposed anthracite mining along the Groot Marico River was thwarted following concerted efforts by concerned local landowners and other interested parties. This is a Government Water Controlled Area, meaning there is a limit on the use of water for economic development such as irrigation beyond what is already being extracted from the water resource systems. Also, agreements between Botswana and South Africa exist for the amount of abstraction allowed on the South African side, thus intending to ensure a fair allocation to Botswana.

The livelihood zone within the Botswana hotspot area is classified as 'Central-Southern Livestock, Upland Crops and Non-Farm Income' (Rethman & Muhangi, 2009). The rural inhabitants practice mixed farming with livestock (cattle and small livestock) and crops. Agro-climatic conditions are relatively favorable for farming (in the national context) and the bushveld vegetation is particularly suited to livestock. The proximity to mines, industries and commercial centers has attracted large numbers of people and there is a high demand for food.

On the South African side (Ramotshere Moiloa Local Municipality), agriculture and mining are the primary economic sectors (Ngaka Modiri Molema District Municipality, 2012). Alternative livelihood opportunities are very limited. A large proportion of the inhabitants (36%) are unemployed, with youth unemployment even higher at 45% (Local Government Handbook and Census 2011 Municipal Fact Sheet). Education levels are low, with 21% having had no schooling. Connection to water-borne sanitation is only 22%. Forty six percent of households are headed by women.

The growing populations, especially in the west (Botswana) and east (Bushveld mining areas) and dire need for provision of safe water and sanitation are increasing the demands made on scarce water resources, and pose risks through pollution of streams and rivers. Water planning information (DWA Reconciliation Strategy) shows that the Zeerust cluster will run into a water deficit in the next ten years. Rural water supply is heavily reliant on groundwater resources (Ngaka Modiri Molema District Municipality, 2012) but this cannot be over utilized. Clearly, economic and social development is severely constrained by the availability of water. Current water resources are in future likely to be re-allocated away from farming/irrigation use towards domestic needs. In Botswana, new transfer schemes are planned to alleviate shortages.

Figure 13 Gaborone Dam (Source: Unknown)

First to Fourth Order Impact Assessment: Current

Order	Current features and threats	Current impacts
1st	• Low rainfall, mostly in summer, semi-arid • Hot and moderately humid summers, dry cool winters • Cold winter nights and risk of severe frost in low-lying areas • Rainfall variability and drought • Strong desiccating winds in spring/early summer	The rainfall of this area is highly seasonal and highly variable. Droughts occur at regular intervals. Heat stress and frost can have significant localized impacts. This creates a high-risk environment for ecological and human systems. However, these systems are currently still well adapted to the climatic rigors.
2nd	• High rate of evapotranspiration, low soil moisture, tributaries are ephemeral • Headwaters of Groot Marico (SA) and Notwane (Botswana), larger dams (Marico Bosveld, Klein Marico, Gaborone) as well as smaller dams • Towns are supplied with water from both dams and boreholes, major threat is increasing abstraction of water and particularly uncontrolled use of groundwater • Upper catchments are still free-flowing and in good ecological condition • Landfills and effluent at the towns are a potential threat to water quality • Fairly good soils • Short growth season • Wildfire risk	This system represents that farthest source of the Limpopo River. Although the Groot Marico and Notwane rivers flow permanently, sustained from numerous dolomitic springs, many of their feeder streams are ephemeral. This is a highly sensitive environment. However, current impacts are low. In SA, water abstractions are controlled by the government, and the quality of water in the springs is monitored regularly. Inter-basin transfers occur from the Marico system (SA) to Gaborone Dam (Botswana). Current threats to water supply appear to be managed but pressure is increasing and the water supply is at risk of running into deficit as early as ten years' time. Botswana has similar imminent pressures on water supply exacerbated by a high population density and in-migration. The annual variation in fire risk is determined by the previous rainfall season and subsequent grassland biomass production, which varies spatially and in time. Impacts of wildfires tend to be severe but localized, and recovery depends on rainfall conditions during the ensuing period. The fire risk is lower than expected because of the transformation of the landscape by agriculture and human settlement.
3rd	• Low potential rainfed productivity of natural and agricultural systems • High variability of production of natural and agricultural systems • Irrigated cropping on both sides, intensive on SA side but small area • Important source of food for Gaborone and livestock keeping (Botswana side) • Predominance of livestock/ game farming and eco-tourism on SA side • Aquatic and wetland biodiversity is high in the upper reaches of the spring-fed headwaters	The productive potential of the soils is fairly good, but production is limited by aridity and a short growth season, and unpredictability of rainfall. Commercial yields of crops are attainable only under irrigation. Both Botswana and SA farmers use irrigation but in SA it is more intensive. Supply of irrigation water is manageable for now, but is sensitive to a serious drought and escalating demand from growing settlements, both in Botswana and east along the Bushveld mining areas. This is imposing increasing effects on the water systems through abstraction and pollution from waste streams. Re-allocation of water from agriculture to domestic needs is not yet a threat but is projected. The grazing potential of the bushveld vegetation is good and extensively utilized. Carrying capacity is limited by aridity, erratic rainfall and droughts. Grazing is at risk of being destroyed by wildfires but can recover quickly following good rains. Game farming is eminently suitable

Order	Current features and threats	Current impacts
	• A very low density of large woody invasive species at the climatic limits of invasion, only along rivers, grasslands may be invaded by other species • Low level or urbanization but growing (SA: around Zeerust, Groot Marico), high level of peri-urbanization (Botswana: area south of Gaborone)	and well adapted to the conditions, linked with tourism, e.g. safaris/hunting. Game is usually hardier than livestock under climatic stress and fluctuations in rangeland productivity. The biggest threats are a major drought, or a major livestock/game disease, or a devastating wildfire. Ecosystem services are of key importance in the Groot Marico sub-catchment, namely the provisioning of water, regulation of water quality, and the value of high levels of biodiversity. The system is currently still in a healthy condition and has been identified as both sensitive and a conservation priority. Other parts of the greater region have had their ecosystems classified as threatened and approaching critical thresholds, making the Groot Marico an even greater priority.
4th	• Corridor for movement of people between Botswana, the mining belt and Gauteng • Low level of human development and access to basic services • Localized high levels of unemployment and poverty • Extensive small-scale mining of chrome, andalusite, diamond (kimberlite), fluorspar, dimension stone, with substantial prospecting of vanadium, manganese, lead – mostly related to the Bushveld Complex. There are also mines for dolomites and limestone (cement manufacture)	Cross-border migration is driven by the employment opportunities provided in South African cities and in the mines. Farming is important but offers limited potential for growth. Alternative livelihoods are highly limited in this hotspot. Mining is currently conducted at a small scale and does not provide many opportunities. The impacts on natural resources (water, biodiversity) are currently low to medium-low in the case of the chrome mines on the edge of the Bushveld Complex. Hexavalent chrome pollution is of concern. Plans for a nickel mine along the Groot Marico River have been abandoned following strong public opposition. Low human development (education, health issues) and poor access to services renders people vulnerable to shocks, both climatic and non-climatic. The most important limitation and impact are through inadequate access to safe water and sanitation, both of which are severely constrained by the finite water resources of the area. Impacts of water quality shocks (e.g. sewerage spills) are also much more severe on the poorer parts of the population.

First to Fourth Order Impact Assessment: Future Scenario 1

- Ten percent wetting (summer rainfall), warming 2.5 °C with moderate increases in maxima.
- Population growth rate remains below 1% p.a.; steady transition towards stronger secondary and tertiary economy; water supply and demand (including groundwater) can be reconciled without harming agriculture or the ecological reserve

Order	Future features and threats	Future impacts
1st	• Slightly higher summer rainfall, but retains its semi-arid status. • Hotter summers, warmer winters. • Warmer winter nights and lower risk of severe frost. • Rainfall variability and risk of drought remain. • Changes in wind strength as yet undetermined. • Higher concentration of atmospheric CO_2.	The risks and impacts of variable rainfall and drought remain. Rainfall increases could improve the situation but could be negated by higher temperatures, through increased evapotranspiration. Higher maximum temperatures will increase the risk of heat stress in humans, plants and animals. Reductions in frequency and intensity of frost could be beneficial for life and productivity, but could also lead to increased risks of pests and diseases. Overall, ecological and human systems will not be much worse off than they are now.
2nd	• Hydrological systems could become more intense through higher rainfall but also higher rates of evapotranspiration. • Runoff into the major dams and smaller farm dams could increase marginally, but higher temperatures and evapotranspiration could negate these gains. • Water quality is affected. • The growth season is extended. • Wildfire risk increases.	Soil moisture and groundwater could improve for short periods but also dry out more rapidly between rainfall events. Some ephemeral tributaries could flow more often, but depending on timing between rainfall events. Water management associations will have time to put into place long-term strategies for water supply and demand management, as well as water quality monitoring. Sustainable use of groundwater is achievable but good monitoring becomes critical. Landfills and effluent at the towns are still a potential threat to water quality. Rising temperatures could increase risks to the provisioning of safe water, especially if organic effluent gets into the system. The fire risk increases through increased rainfed rangeland productivity (grass and shrub/tree biomass) and higher temperatures.

Order	Future features and threats	Future impacts
3rd	• Rainfed productivity of natural and agricultural systems remains low. • Variability of production of natural and agricultural systems remains problematic. • Irrigated cropping on both sides remains viable, subject to heat stress impacts. • Livestock/game farming and eco-tourism remain viable. • The risk of bush encroachment increases through increased soil moisture, a longer growth season and rising CO_2, but this is counteracted by more frequent and intense wildfires.	The potential productivity of agricultural systems could increase as conditions become less arid, the growth season is extended, and dam levels increase at times. However, increasing heat stress of crops could reduce yields. Supply of irrigation water remains manageable but is still sensitive to a serious drought and increasing demand from growing settlements. Settlement growth is, however, at a low rate and well planned. Re-allocation of water from agriculture to human needs is not yet a threat but remains a future threat. The grazing potential of the area remains good although still limited by aridity, erratic rainfall and droughts. The impacts of wildfires increase leading to loss of grazing and animals. The biggest threats remain the same: a major drought, a major livestock/game disease, or a devastating wildfire. Biodiversity, habitat diversity and ecosystem services in the Groot Marico sub-catchment could be threatened by increasing temperatures. Aquatic species are particularly sensitive to changing temperatures.
4th	• Migration between Botswana and SA continues but at a lower rate. • Human development gains and improved access to basic services reduce vulnerability. • Small-scale mining continues.	Cross-border migration continues although people on both sides are better off. Farming is still important but secondary and tertiary jobs offer more opportunities. People are more resilient to climatic and non-climatic shocks. However, development draws on scarce water resources (better supply of safe household water and sanitation) and water-saving technologies and behaviors are required in order to balance supply and demand. The impacts of mining remain low.

First to Fourth Order Impact Assessment: Future Scenario 2

- No change in annual rainfall, more intense summer convective rainfall, fewer rain days and shorter growth season, warming 3.5°C with more extreme increases in maxima
- Population growth rate rises, weak economic growth and lack of diversification, persistent poverty, significant constraints on water supply including groundwater – ecological reserve ignored and degradation ensues

Order	Future features and threats	Future impacts
1st	• No change in annual rainfall. • Far hotter summers, far warmer winters. • Far warmer winter nights and no or very few frost events. • Rainfall variability and risk of drought remain, intensity of droughts increases. • Changes in wind strength as yet undetermined.	Significant increases in potential evapotranspiration through high levels of warming, with no change in rainfall, lead to significant losses of water and moisture in the groundwater, surface water bodies and streams, soil and vegetation. The risks and impacts of variable rainfall and drought remain but the impacts of drought are magnified by the general aridification. The system is at risk of transitioning from semi-arid to arid. Far higher maximum temperatures become a regular occurrence and cause severe heat stress in humans, plants and animals. Frost does not occur, and together with the heat. This increases the risks associated with pests and diseases, which now have better conditions for survival and reproduction. Ecological and human systems are placed under severe strain.
2nd	• Reduced water runoff. • Reduced groundwater infiltration. • Increased evapotranspiration • Water quality is affected. • The growth season is reduced. • Wildfire risk decreases.	Runoff into the major dams and smaller farm dams decreases, and higher evaporation from these structures reduces water resources further. Groundwater resources will come under severe pressure as water users tap into this supply. The ecological reserve will be threatened as humans seek other sources of water. 'Green water' is also reduced through significant increases in transpiration through plant leaves. A larger proportion of streams and tributaries become ephemeral, and some permanent rivers could become dry at times. Water quality is at high risk due to low levels in rivers and impoundments, together with high temperatures that favor bacterial and algal growth. Water quality problems will be experienced more often. The management and supply of water to agriculture and settlements will become challenging. Ecosystems are threatened by aridification. The fire risk decreases through decreased rainfed rangeland productivity (grass and shrub/tree biomass), arid systems are less prone to burning.

Order	Future features and threats	Future impacts
3rd	• Rainfed productivity of natural and agricultural systems is further reduced. • Variability of production of natural and agricultural systems is worsened. • Irrigated cropping on both sides becomes limited by scarce water resources and competing needs, as well as significant heat stress impacts. • Livestock/game farming and ecotourism become less productive but still viable with adjusted management. • Species and habitat diversity suffer declines.	The system becomes arid and unsuited to crop farming even under irrigation. Heat stress becomes a major limitation. Supply of irrigation water is reduced by re-allocation of dwindling resources to other needs, particularly the growing settlements. The grazing potential of the area is reduced and carrying capacity has to be adjusted downwards. Animals suffer from heat stress causing mortality, reduced reproductive success, reduced growth rates and production of milk. Droughts have a greater impact on top of an already stressed system. Biodiversity, habitat diversity and ecosystem services in the Groot Marico sub-catchment become significantly threatened by the reduction in spring flow from groundwater (the dolomitic eyes which feed the source of the Limpopo). This, together with large temperature increases, reduces the wetland habitats. Aquatic and other species are lost due to a combination of habitat loss and significantly higher temperatures.
4th	• Migration between Botswana and SA increases. • Poor progress in development and deteriorating conditions increase vulnerability. • Mining development is supported.	Persistent poverty and unemployment fuels increasing cross-border migration, placing severe pressure on areas en route. Some of the migrants settle en route. However, opportunities in this area are not good, and many people compete for dwindling resources. Water scarcity and quality problems exceed the ability of the water management associations to balance supply and demand and provide safe water at all times. Financial resources are low and options limited. The impacts of mining increase as this sector is developed in the interests of job creation and economic growth.

Adaptation Approaches and Options

- Rigorous monitoring of climate trends, water resources supply and water abstraction, both groundwater and surface water seasonal quantities and quality, in SA and Botswana, and particularly monitoring of the 'eyes' and associated wetlands (in SA).
- Careful and flexible/adaptive water resources supply and demand management, linked tightly to development planning (both countries), with no compromises on the ecological reserve.
- Best practice waste and sewerage management to ensure no accidental spills into water bodies (both countries).
- High level of conservation protection for the Upper Groot Marico ecosystem, and a moratorium on any new impoundments or mining activities along this river (SA).

- Maintenance of bilateral discussions and binding agreements on flexible and adaptive use and management of shared water resources.
- Promotion of sustainable and climate-adapted land use systems.

Key References

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4.5.2 Hotspot 2: Pretoria North–Moretele

Vulnerable homes

Key messages

- The people of Moretele experience hardship as a result of weak past investment in infrastructure and basic services. Lack of town and spatial planning and poor building standards combine with a drainage system of numerous rivers and wetlands to create high risks of flooding and loss of homes and assets after heavy rains in the upper catchments. This situation could be aggravated by more intense downpours linked to climate change.
- Decades of high-density stocking has led to high levels of land degradation. Frequent fires destroy grazing land and even homes, and fire-fighting services are hampered by lack of resourcing and infrastructure. Fire risk could increase with climate change.
- The water flowing through this hotspot is highly polluted through urban and industrial effluent (originating in Tshwane) and return flows pumped from the Vaal system further south. It is not safe for consumption and provision of safe water to households by the District Municipality is problematic. Downstream intensive agriculture in the Crocodile sub-basin is placed at risk. Further pollution is linked to the lack of waste removal services.
- High levels of unemployment, competition for meager informal trade opportunities, poverty and a weakened social fabric render many inhabitants very vulnerable to shocks. Livelihood options are severely limited due to a lack of access to productive natural resources and poor transport infrastructure.
- Declining employment opportunities for people in the mining industry would have dire consequences for the surrounding areas of the Bojanala Platinum District Municipality, and would also affect Moretele.

Background

In the northeastern corner of North-West Province of South Africa there is a sprawling rural area of low-density settlements that is deceptively close to the industrial and wealthy heartland of Gauteng, yet suffers from severe developmental deprivation. The Moretele Local Municipality (LM) is the smallest and poorest LM within the Bojanala Platinum District Municipality. The most important sector of the economy of this region and source of employment is mining, which is concentrated in a band (the Merensky Reef) stretching from west of Pilansberg eastwards towards Brits, south of Moretele. Mining is the life-blood of Bojanala and continues to attract migrants in search of work, although recently at a diminishing rate. Intensive irrigated agriculture is a feature of the area around Brits. Moretele, however, provides few livelihood opportunities. As part of the Bantustan Bophuthatswana, a scattered patchwork of six enclaves, no investment was made in the provision of infrastructure and basic services, a situation which has only marginally improved since its incorporation into a democratic South Africa.

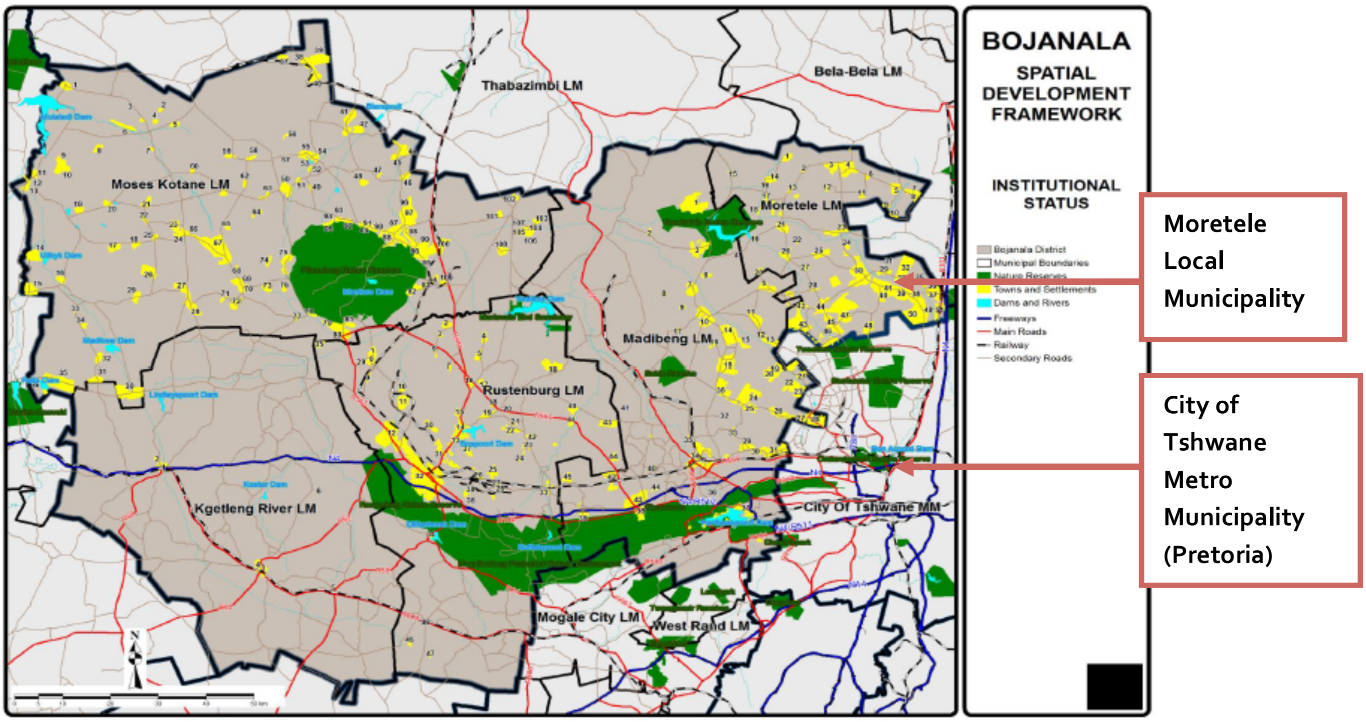

Figure 14 Bojanala Platinum District Municipality Settlements Pattern. Source: Bojanala DM Integrated Development Plan, 2012

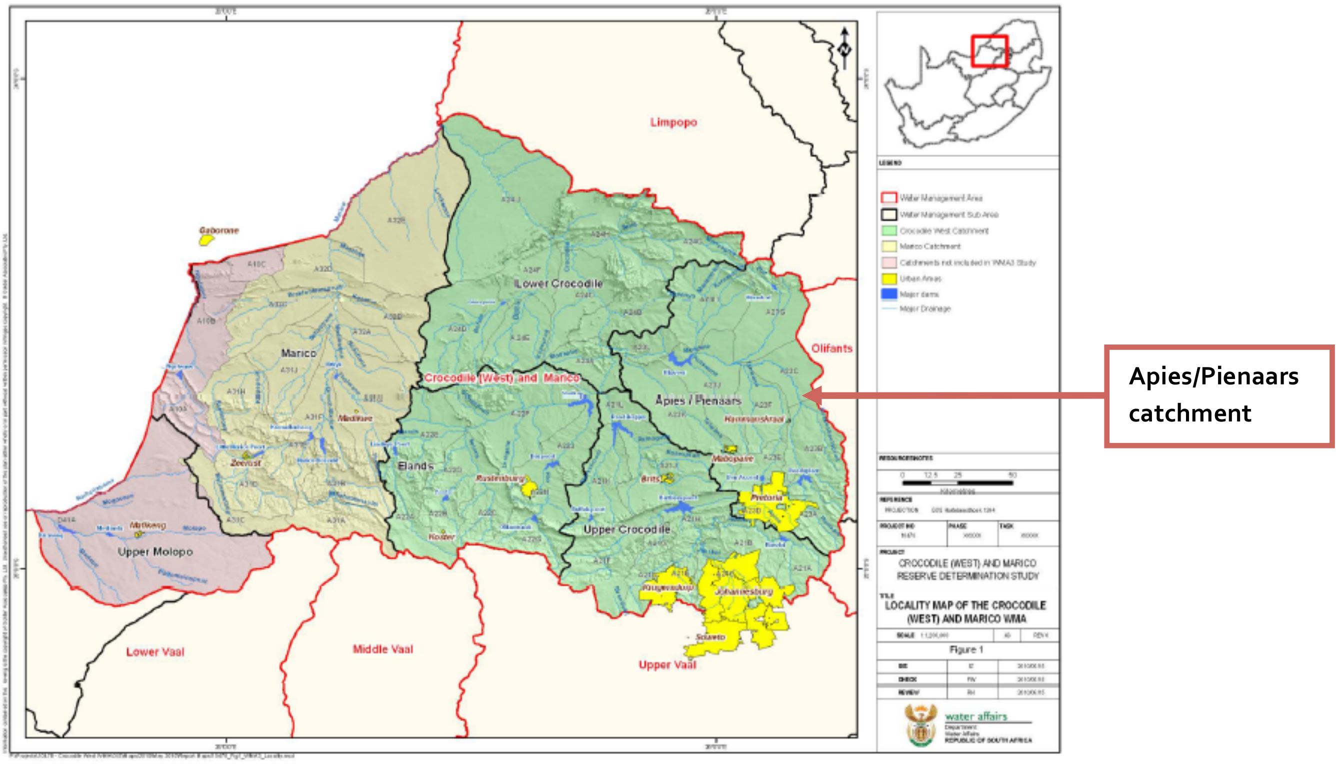

Figure 15 Map showing the spatial extent of the Apies/Pienaars catchment within the Crocodile (West) Water Management Area (in green). Source: Directorate Water Resource Classification (2012).

Moretele has a temperate sub-tropical climate, with hot summers characterized by rainfall occurring mainly as summer thunderstorms. Winters are dry and clear, and nighttime temperatures often drop to freezing point. Frosts are common.

The area is traversed by the Apies and Pienaar Rivers which, together with some smaller tributaries, flow to the confluence with the Crocodile River which then winds its way north-west to the confluence with the main stem of the Limpopo River on the border between South Africa and Botswana. The Apies and Pienaar Rivers drain the densely populated area from Pretoria northwards (Tshwane Metro Municipality) towards Bela-Bela. Roodeplaat Dam and Klipvoor Dam (in Moretele LM) are the major dams in the sub-catchment, the latter surrounded by a small game park, the Borakolalo Reserve. The larger rivers flow permanently, but have highly seasonal flow rates.

The flows in these rivers are supplemented by substantial discharges of treated domestic and industrial effluent, enhanced by water transfers (around 50% of the total water use) from the Vaal River system south of Johannesburg. By the time they reach Moretele they suffer from significant pollution and water quality is very poor.

Moretele has extensive wetlands on stream channels, partly as a result of substantial clay formations, which are prone to periodic flooding. Poor location and planning of settlements due to lack of access to suitable land, and a lack of storm water drainage means that poorly built houses are at high risk of inundation and destruction. In addition, the expanding/shrinking clays play havoc on structures and some houses are seriously damaged and become dangerous for habitation. For the same reason, engineering projects are challenging.

Settlements suffer from poor provision of safe water for domestic use, and dependence on the District Municipality for water and sanitation services. There are numerous boreholes but a high proportion of boreholes (~29%) yield water of poor quality.

No waste collection or disposal services are available, and the people bring their waste to two public landfills, or, more often, burn their waste or discard it in an unsafe manner. The potential environmental and health impacts are significant. Health services, transport infrastructure and services, telecommunication facilities and access to clean energy are also inadequate, although slowly improving.

Most of the land of Moretele (73%) belongs to the Traditional Authority. In this typical bushveld region, around 41% of the land is classified as degraded (both soil erosion and deforestation are high) and the productive capacity of the area is low. Communal livestock are grazed on unfenced lands, much of it overgrazed, and disease management is challenging. Veld fires are also a potential threat that can destroy large areas of grazing, especially under dry conditions. Fires also ravage the informal settlements, with poor availability of fire-fighting services.

The social fabric of this area is fragile. The high rates of unemployment are particularly concerning in light of the very youthful population. In 2010 the poverty rate was 47.2%, and women head many indigent households. Many people rely on very low incomes generated from informal trade conducted from their houses or backyards, and this contributes 30% to the local economy (Bojanala Platinum District Municipality IDP, 2012/17). Most commonly, they sell basic food, drinks and household commodities such as washing and cleaning agents. This satisfies only basic daily needs, supplemented with social grants and remittances from husbands or relatives working elsewhere. Many of those who can find employment travel to Pretoria on a daily basis, and half the households spend more than 10% o their income on travel costs.

Future water demand for domestic use will increase. Current planning makes provision for the continued importing of water from the Orange and Vaal River system and greater reuse of return flows in the Crocodile River could create surplus water in the Crocodile River. However, these return flows affect the quality of the water, and it becomes increasingly important to manage the resulting water quantity and quality in an integrated way in order to prevent environmental impacts and to ensure compliance with other water user requirements.

Figure 16 Flooding in Moretele. Source: Nakedi, D. (2011) New Age newspaper Issue date: 14/01/2011.

First to Fourth Order Impact Assessments: Current

Order	Current features and threats	Current impacts
1st	• Moderate rainfall mostly in summer. • Hot and moderately humid summers, dry cool winters. • Cold winter nights and risk of severe frost in low-lying areas. • Rainfall variability and drought. • Intense summer thunderstorms. • Strong desiccating winds in spring/early summer.	Semi-arid; rainfall is moderately low (600-650mm per year), seasonal and variable; Intense summer thunderstorms; hot humid summers, dry cool winters; summer heat waves; cold winter nights and risk of frost; desiccating winds in spring/early summer; Regular droughts.
2nd	• A significant clay component in the soils leads to poor drainage and waterlogging when water is abundant, and cracking under dry conditions. • Numerous streams and rivers (Apies and Pienaars) traverse area (with associated wetlands) and flow into Klipvoor Dam on western boundary. • Significant risk of flooding along the rivers and wetlands. • Surface water resources are highly polluted by domestic and industrial effluent, mostly from sources outside the area but exacerbated by local pollution caused by lack of waste removal. • Groundwater is utilized but is often of poor quality. • Significant wildfire risk.	Numerous streams, rivers and wetlands; Poorly drained clayey soils lead to waterlogging/flooding and cracking when dry; High rate of evapotranspiration; One major dam (Klipvoor Dam); surface water is highly polluted by upstream domestic and industrial effluent, made worse by local pollution (sewage, landfills); Dependence on groundwater but quality is often poor; High risk of wildfires.
3rd	• High levels of land degradation and poor productivity of grazing lands. • Low levels of biodiversity and poor ecological status. • High off take of firewood. • Little own food production. • High risk of livestock diseases.	Bushveld (savanna); high levels of land degradation and low livestock productivity resulting from overstocking and poor management; Livestock farming also at risk of wildfires, droughts and diseases (low access to veterinary services); Very little cropping (limited to households); agriculture hindered by lack of access to land and productive natural resources; Lack of safe water for irrigation; Excessive removal of firewood has led to denudation and energy shortages.

Order	Current features and threats	Current impacts
4th	• Very poor level of infrastructure and access to basic services. • High levels of unemployment and poverty. • High proportion of vulnerable female-headed households.	High past population growth rate; very poor level of infrastructure and access to basic services; high levels of unemployment and poverty; high proportion of vulnerable female-headed households; Poor transport infrastructure and poverty limits access to jobs in surrounding centers; very few local livelihood options; Flooding, droughts and fires put people, livestock, homes and other assets at risk; It is very difficult to recover from shocks; High exposure to health risks compromises family health and resources are lacking for adequate health care and the provision of a safer environment.

First to Fourth Order Impact Assessment: Future Scenario 1

- Ten percent wetting (annual rainfall), warming 2 °C with moderate increases in maxima.
- Economic and social development linked to improved infrastructure and services, water transfer and return schemes ensure adequate and safe domestic water supply.

Order	Future features and threats	Future impacts
1st	• Slightly higher summer rainfall. • Hotter summers, warmer winters. • Warmer winter nights and lower risk of severe frost. • Risk of drought remains. • Increased concentration of atmospheric CO_2.	Remains semi-arid; 10% increase in annual rainfall (mainly summer); small increase in mean number of rain days; earlier beginning and later end of rain season; small increase in number of convective rainfalls (thunderstorms); Warming by 2.5°C, highest in spring; moderate increases in heat extremes; with some additional heat stress to living organisms; warmer nights and fewer frosts; Risk of drought remains.
2nd	• Wetter conditions will increase the risk of waterlogging and flooding. Soil moisture and groundwater could improve for short periods but also dry out more rapidly between rainfall events. • Deteriorating water quality due to rising temperatures that stimulate bacterial and algal growth. • The growth season is extended. • Wildfire risk increases.	Slightly increased runoff throughout Apies-Pienaars catchment; wetlands retain moisture longer with more frequent waterlogging/flooding; increased rate of evapotranspiration; greater fluctuations in soil moisture; Water levels in Klipvoor Dam may rise in summer but greater evaporation may reduce gains; Groundwater levels maintained or increased but more variable; water quality further reduced due to warming which stimulates bacterial/algal growth; Risk of wildfires increases due to greater biomass (fuel) and temperatures; Increased risk of flash floods from thunderstorms.
3rd	• Productivity of grazing lands remains low. • Small positive changes linked to moister conditions at times are not sufficient to counteract environmental problems. • Increased risk of livestock diseases.	Productivity of grazing land remains low and conditions become more variable; Livestock farming at increased risk of wildfires, pests/diseases and possibly droughts; Demand for firewood overrides potential increases in woody biomass; Non-climate-related constraints on agriculture and problems of land degradation remain and override small potential gains from higher rainfall.
4th	• Improved infrastructure, settlement planning and building codes. • Human development gains and improved access to basic services.	Population stabilized but demand for resources and services, especially clean water and sanitation remains; Investments in improved infrastructure (including transport, bulk water, health), settlement planning and building codes, human development and support to the vulnerable, disaster risk management and secondary/tertiary economic development, and pollution control have significantly greater impacts than climate change trends.

First to Fourth Order Impact Assessment: Future Scenario 2

- Ten percent drying (annual rainfall), more intense summer convective rainfall, warming 3 °C with more extreme increases in maxima.
- Weak economic and social development due to failure of infrastructure and service delivery, continued decline of mining sector, significant constraints on supply of safe water.

Order	Future features and threats	Future impacts
1st	• Slightly reduced summer rainfall. • Far hotter summers; far warmer winters. • Far warmer winter nights and no or very few frost events. • Rainfall variability and risk of drought remain; intensity of droughts increases. • Intense thunderstorms in summer.	Remains semi-arid; 10% decrease in annual rainfall; small reduction in mean number of rain days; more frequent and more intense convective rainfalls (thunderstorms); Warming by 3°C, highest in spring; strong increases in heat extremes; with significant additional heat stress to living organisms; warmer nights and fewer/no frosts; Risk of droughts remains.
2nd	• Reduced water runoff. • Reduced infiltration to groundwater. • Increased evapotranspiration. • The growth season is reduced. • Wildfire risk decreases.	Reduced runoff throughout Apies-Pienaars catchment; wetlands dry out more rapidly but periods of waterlogging/flooding and flash flooding remain after heavy rainfall; Significantly increased rate of evapotranspiration; severe fluctuations in soil moisture; Water levels in Klipvoor Dam reduced due to lower flows and evaporation; Groundwater levels reduced and more variable and some may run dry more often; Water quality at high risk due to warming and lower flows which stimulates bacterial/algal growth; Risk of wildfires decreases due to lower biomass (fuel); impacts of droughts magnified by aridification.
3rd	• Productivity of grazing lands becomes much lower. • Increased frequency of intense rainfall (thunderstorms) leads to further erosion and degradation of the grazing lands. • Increased risk of livestock diseases.	Heavy rainfall combined with general aridification increases erosion and land degradation; Grazing potential is significantly reduced and conditions highly variable; livestock farming at increased risk of pests/diseases and droughts; Potential of game reserve around Klipvoor Dam (Borakolalo Reserve) reduced; demand for firewood far greater than supply; However, previous wetlands become available for productive purposes although still at risk of seasonal flooding; Non-climate-related constraints on agriculture and problems of land degradation gain in importance as barriers to development.
4th	• Living conditions and infrastructure	Population stabilized but demand for water-dependent services, especially clean water and

	remain poor.	sanitation, cannot be met from Apies-Pienaars sub-basin; Demands on water transfers from other sub-basins increase significantly, and may not be met; Flash flooding occurs more frequently with high impacts on houses, infrastructure and health; Increasing vulnerability.

Adaptation Approaches and Options

- Measures are taken to restore the degraded lands used for grazing, and to instill best practice livestock herd management and grazing systems.
- Measures are taken to monitor and reduce the levels of pollution in the surface water.
- Groundwater levels are carefully monitored and water abstraction regulated.
- Proper spatial planning is conducted, infrastructure and services put in place, and building codes laid down and enforced. Existing services are strengthened e.g. veterinary services, fire-fighting services.
- The area is economically connected to Johannesburg-Tshwane and alternative economic / livelihood options explored.

Key References

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4.5.3 Hotspot 3: Shashe–Limpopo Confluence

Heritage matters

Key messages

- This is a hotspot where three countries meet: Botswana, Zimbabwe and South Africa. Large-scale efforts to achieve transboundary conservation of a unique natural and cultural heritage, with benefits to the divergent peoples of all three countries, will require good communication and collaborative governance to succeed.
- The area has a particularly harsh, arid climate, with very low rainfall and intense summer heat. The habitats of the Limpopo and Shashe Rivers and their tributaries provide a refuge for many species that are currently adapted to these conditions.
- The hotspot's economy depends heavily on water resources (including the shared alluvial aquifer used for crop irrigation) and mining resources. Increased utilization of resources for economic development, including further mining and irrigated agriculture along the river, needs to be sensitive to the ecological fragility of the area and scarce water resources, and possible implications of climate change.
- The potential for further development of ecotourism (game farms and reserves and related tourism) and cultural/historical tourism (Mapungubwe and other sites) is large. The conservation of the rich species and habitat diversity is a priority.

Background

This hotspot covers three countries (Botswana, Zimbabwe and South Africa) extending around the confluence of the Shashe–Limpopo River. This arid zone contains beautiful landscapes, abundant game and wildlife, and a rich cultural history with much potential for tourism.

Most economic activity in the region is centered on mining, eco- and cultural tourism (game farms and lodges) and irrigation agriculture. Mining consists of opencast coal extraction (started 8 km east of the Mapungubwe Heritage Site) and diamonds (Venetia diamond pipe) 26 km south of the border between South Africa and Zimbabwe. Irrigated agriculture is located on both banks of the Limpopo, i.e. on either side of the border. Extensive (low density) livestock grazing is practiced in all three countries.

The Shashe area is relatively sparsely populated. The major urban center is Musina, +70 km to the east. Musina is growing rapidly as a border town at around $5.5\%.yr^{-1}$. The region is a source of border control issues, exemplified by the practice of driving cattle across from Zimbabwe and Botswana to graze in the Mapungubwe National Park. It is therefore a region of potential animal disease as pathways exists and veterinary controls are apparently defunct. Elephant and cattle browsing and grazing pressure on the vegetation are high in places. Further developments that include extensive abstraction of water, especially via boreholes alongside the Limpopo River, are possible in the future, as envisaged by various land users. Other water-related developments include the demand from further coking coal mining activities for coal washing and processing. The coal resource base is several hundreds of millions of tons. The Transfrontier Conservation Area (TFCA) is the dominant focus of governance, but in conflict with the pressures for mining activities. It is unlikely to be a zone of future urban settlement and will continue to be a semi-desert zone dominated by resource extraction and legislatively constrained agriculture and mining activities.

There is some development potential upstream in the Selibi Pikwe area on the Motloutse River tributary, such as construction of the Letsibogo Dam, which could supply primarily Francistown. The existing Shashe Dam does not have the storage or mean inflow to sustainably supply that urban center. In the Francistown area there are also about 146 small dams that are used for stock watering. This level of water abstraction and future intentions points to possible water flow issues further downstream, at the confluence of the Shashe and Limpopo rivers.

Water developments are especially being sought from the Botswana side of the border for economic reasons, with tentative sites for dams being identified along the Limpopo River mainstem at Pont Drift, Martin's Drift and the so called Cumberland Dam. (GOB-MFDB, 1997). Building of these dams would initially require substantial negotiation at a high level, precisely the sort of thorny issue that a body such as LIMCOM would need to process.

This hotspot also incorporates much of the proposed area of The Greater Mapungubwe Transfrontier Conservation Area (TFCA). The total proposed park extends over the international boundary around the Shashe-Limpopo confluence between South Africa (53%), the western border of Botswana (28%) and southern eastern portion of Zimbabwe (19%).

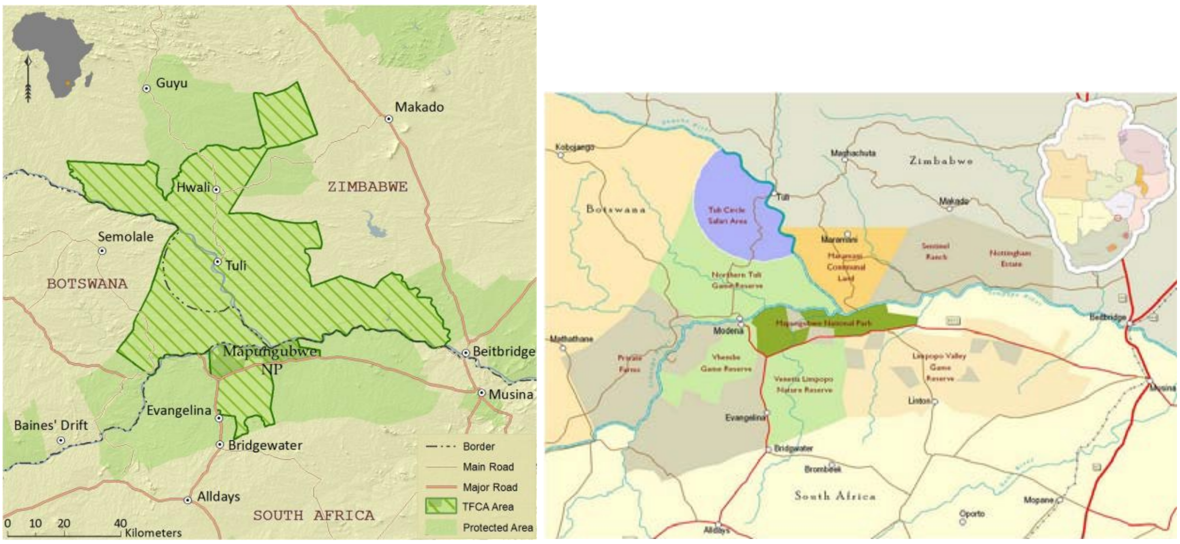

Figure 17 Actual area and proposed area of the of The Greater Mapungubwe Transfrontier Conservation Area (TFCA).

The TFCA includes a diverse group of private landowners, the Northern Tuli Game Reserve, South Africa's Mapungubwe National Park, The Tuli Circle Safari Area, Sentinel Ranch, Nottingham Estate, Maramani Communal Land and the Machachuta, Masera and River Ranch Resettlement Areas. The area has the potential for the further development of a viable tourism industry.

In the South African portion the hotspot falls mainly within the Musina Local Municipality in the Vhembe District. This municipality has huge opportunities for tourism activities and includes the Mapungubwe National Park that has scenic beauty, great diversity, big game and a rich cultural heritage with archeological sites that attest to a wealthy and highly sophisticated civilization around 1200 AD.

Figure 18 The gold rhino found near Mapungubwe

The only town within this municipality is Musina and the majority of the rural population resides in clustered rural settlements mainly in the eastern section of this municipality.

Half of the employed population works in the agricultural sector, which contributes approximately 35% to the local economy. Commercial irrigated crops are grown mainly along the Limpopo River. Rangeland is used for cattle and game farming, while crops include maize, wheat, sugarcane, cotton (all mostly irrigated), vegetables, oranges, mopani worms, and macadamia nuts. Emerging farmers suffer from lack of funding and capacity constraints and unreliable freight transport. The unemployment is 25% and highest amongst the youth. The natural resource base and economy does not have the capacity to support the total population many of whom seek employment further afield.

Mining and quarrying is currently a declining sector within the municipality. Coal of Africa's Vele colliery has had some setbacks and Venetia is the only active diamond mine. Land claims are a major factor influencing development and more than a third (36%) of the municipality is subject to land claims.

The Botswana portion of this hotspot incorporates the Tuli block on the confluence of the Limpopo and the Shashe rivers in the easternmost corner of Botswana. The Northern Tuli Game Reserve (NTGR) is the collective name for several privately owned game reserves and covers a thin strip of land (approximately 10–20 km wide and 350 km long) north of the Limpopo River. Spectacular scenery with towering sandstone cliffs, basalt formations and diverse wilderness, dry riverbeds and savannah plains as well as an abundance of wildlife make this an attractive tourist area providing some income opportunities.

This area is dry for most of the year with most rain in the hot and humid December. Rainfalls decline steadily towards the west and south, reaching some 350–400 mm per annum at the Shashe–Limpopo junction. Apart from game reserves, land use is primarily livestock farming of mostly goats and donkeys with small irrigation areas along the rivers. Invasive cactus species are problematic.

In Zimbabwe, the hotspot includes the western part of the Lower Umzingwane Catchment area that extends to Botswana and is a major catchment for the Limpopo River Basin. This zone stretches from Beit Bridge through to the southwestern lowveld communal land along the south of the country on the border with South Africa and Botswana.

The annual rainfall is very low and the communal areas are considered to be semi-arid agro-pastoral zones. Farming is mainly subsistence with communal livestock farming cattle, goats, sheep, donkeys (south-western lowveld, Maramani community). Arable land for crop cultivation is generally small and the main cereals grown in this zone are sorghum, millet (pearl and finger) and maize. Intensive commercial agriculture occurs downstream of the confluence where there are large irrigation schemes, with smaller ones on the Shashe River before the confluence. Water used for irrigation is from groundwater (alluvial aquifers). In Zimbabwe, 90% of rural households consume untreated water (Hoko, 2005) so any reduction in water quality has a major impact on the community.

The majority of households own some animals, and cash is supplemented by sorghum cropping, mopane worm sales, gold panning and remittances from seasonal or migrant work. There has been an increase in the number of people crossing the border to look for work in South Africa or Botswana and border security is an issue.

Livestock diseases are problems that occur periodically. There are constant veterinary concerns arising from movement of livestock and game across these borders. The interactions at the interface between animal health, ecosystem services and human health need to be better understood.

First to Fourth Order Impact Assessment: Current

Order	Current features and threats	Current impacts
1st	• Hot and uniformly very dry throughout the year, high evaporative demand • Relatively high wind speeds, especially in spring and summer when temperatures are highest • Classed as hot semi-arid climate - rainfall very low at 350-450 mm/yr.	Arid; rainfall is low in the hotspot (350-400mm per year) and slightly higher in the Shashe and Mogalakwena sub-basins (450-550 mm), highly variable rainfall with a long dry season; intense summer thunderstorms; Hot summers, dry winters; extreme maximum temperatures in summer; Relatively high wind speeds, especially in spring and summer when temperatures are highest; Regular droughts; occasional floods
2nd	• Rivers flow ephemerally (summer months) and episodically and arise primarily in Zimbabwe but include the headwaters beyond Francistown and the tributary Motloutse that arises north-west of Selebi-Phikwe • Low rainfalls and high variability and high evaporation mean very low runoff • High fire risk in lowland areas • Saline soils	Most streams and rivers are ephemeral, except the main stem of the Limpopo; water flows episodically following sufficient summer rainfalls; flash floods can occur; Very high rate of evapotranspiration and very low runoff; low soil moisture; Numerous smaller dams in sub-catchments; extensive use of groundwater from boreholes and wells; floods are required to periodically replenish alluvial aquifers; High risk of wildfires in lowland areas; Saline soils – salinization risks from irrigation.
3rd	• Rangeland and livestock production • Overuse of groundwater a risk.	Open savanna and riparian forests; high levels of biodiversity; Dominance of livestock and game farming/reserves (safari/hunting tourism); low rangeland productivity with variable grazing depending on summer rainfall quantities; mixed game ranching also utilizes browse availability; Not suited to rainfed crop farming; short growth period; irrigated farming (cotton, citrus) close to the Limpopo and Shashe Rivers using the alluvial aquifer; Risks of droughts and animal diseases are significant; Fires can destroy grazing in some areas; Wildlife-livestock-human conflict; Cross-border animal movements cause veterinary problems.
4th	• Socioeconomic enterprises depending on water • Copper, gold, nickel and arsenic (including bismuth) from small mines, many closed, in the greenstone belts. Alluvial (artisanal) mining in Zimbabwe. • Coal, nickel and copper mining in the Moloutse sub-catchment.	Botswana and South Africa: commercial farming/tourism; Zimbabwe: commercial farming/tourism and communal farming; Very low population densities; Significant mining in some parts impacts on water resources; both small/artisanal mining (Zimbabwe) and large commercial mining: diamond (Venetia) and coal (Vele) mining in South Africa; In SA 27% of land is under land claim; Greater Mapungube Transfrontier Conservation Area across

		3 countries; rich cultural/archaeological heritage; Water scarcity constrains economic development; Conflict between conservation/ecotourism and mining; Considerable cross-border migration in search of work (much of it illegal).

First to Fourth Order Impact Assessment: Future Scenario 1

- Ten percent drying (especially summer), warming 2°C with moderate to strong increases in maxima.
- Shared platform for joint discussions of land and water use planning is in place between the three riparian countries; growth of eco-tourism; sustainable development of aquifer-fed irrigated agriculture

Order	Current features and threats	Current impacts
1st	• Hot and uniformly very dry throughout the year, high evaporative demand • Relatively high wind speeds, especially in spring and summer when temperatures are highest • Classed as hot semi-arid climate - rainfall very low at ~335 mm/yr.	Remains arid; 10% decrease in annual rainfall (mainly summer); small reduction in mean number of rain days; later beginning and earlier end to rain season; Warming by 2°C, highest in spring; increases in heat extremes; additional heat stress to living organisms; Risk of droughts and floods remain.
2nd	• Rivers flow ephemerally (summer months) and episodically and arise primarily in Zimbabwe but include the headwaters beyond Francistown and the tributary Motloutse that arises north-west of Selebi-Phikwe • Low rainfalls and high variability and high evaporation mean very low runoff • High fire risk in lowland areas • Saline soils	Ephemeral streams and rivers flow less often with longer dry periods; reduced flow in main stem of the Limpopo; water flows are more variable with flash floods still occurring; Further increases in already very high rates of evapotranspiration; further reductions in soil moisture; Water levels in dams and groundwater levels more variable and generally decreasing; alluvial aquifer recharge less frequent; Increased risk of wildfires at times (sufficient fuel + heat).
3rd	• Rangeland and livestock production is the chief land use, this includes game farms • Overuse of groundwater a risk where it is extracted within the alluvial aquifers for the irrigation schemes in the near the river.	Vegetation cover decreases and biodiversity at increasing risk (especially birds and aquatic species); Continued dominance of livestock and game farming/reserves (safari/hunting tourism) but with increasingly variable conditions and rising risks; some sensitive animals suffer heat stress; reduced grazing and browse; Irrigated farming at risk of water supply insecurity and crop heat stress; small-scale farming in Zimbabwe at greater risk; Risk of over-abstraction of alluvial aquifer; Increasing impacts of droughts, animal diseases and fires; Increased wildlife-livestock-human conflict; Increased cross-border animal movements and veterinary problems as animals seek food and water.
4th	• Socioeconomic activity is restricted to pastoralism, game farms, mining and ecotourism. Those people with a subsistence livelihood at small scale are greatly challenged by the environmental conditions and must	Farming systems remain but with higher risks and lower production; Low population growth; Pressure on agricultural livelihoods; Mining impacts on water resources become more

	have multiple sources of income. • Copper, gold, nickel and arsenic (including bismuth) from small mines, many closed, in the greenstone belts. Alluvial (artisanal) mining in Zimbabwe. • Coal, nickel and copper mining in the Moloutse sub-catchment.	important; Greater Mapungube Transfrontier Conservation Area and other tourism areas at risk of reduced tourist numbers due to lower animal densities, heat stress and increasing water scarcity; Increasing water-related constraints on economic and social development; Increasing conflict between conservation/ ecotourism and mining; Increasing cross-border migration in search of work.

First to Fourth Order Impact Assessment: Future Scenario 2

Scenario 2 (worst case):

- Thirty percent drying (annual rainfall), warming 3 °C with more extreme increases in maxima.
- Long-term lack of a shared platform for joint discussions on land and water use planning by three riparian countries; decline in eco-tourism; unsustainable development of aquifer-fed irrigated agriculture.

Order	Future features and threats	Future impacts
1st	• Increase in temperature – extremely dry throughout the year, higher evaporative demand • High wind speeds, potential dust storms • Rainfall reduced • Temperature extremes increased	Transition to even more arid climate; 30% decrease in annual rainfall (mainly summer); significant reduction in mean number of rain days; much shorter rain season; warming by 3°C, highest in spring; increases in very high heat extremes; significant additional heat stress to living organisms; risk of droughts and floods remains and impacts increase.
2nd	• Rivers flow reduced to ephemeral rivers and drying of tributaries • Lower rainfall impacts heavily on semi-arid area • Higher concentration of salinity	Many ephemeral streams and rivers stop flowing; perennial flows become ephemeral; significantly reduced flow in main stem of the Limpopo; water flows are much more variable with flash floods still occurring; Extremely high rate of evapotranspiration; large reductions in soil moisture; water levels in dams and groundwater levels much more variable and significantly decreasing; alluvial aquifer recharge much less frequent; Reduced risk of wildfires due to much lower grass/shrub cover.
3rd	• Rangeland and livestock production reduced • Overuse of groundwater	Much reduced vegetation cover and high risks to biodiversity (most groups); large-scale tree mortality due to reduced groundwater and heat; Livestock and game farming/reserves (safari/hunting tourism) become marginal and unviable in some areas; sensitive animals suffer heat stress; All crop farming (including irrigation farming) becomes

		unviable due to heat stress and lack of water; Very high risk of over-abstraction of alluvial aquifer; Significantly increased wildlife-livestock-human conflict; Significantly increased cross-border animal movements and veterinary problems as animals seek food and water.
4th	• Socioeconomic impacts • Reduced water has impacts for all	Transition in land use systems and water resources leads to reduced economy and jobs/livelihoods; negative population trends as people migrate in search of work; crop farming at all scales fails and all food is imported into the area; Threats to water quantity and quality become critical; Greater Mapungube Transfrontier Conservation Area and other tourism areas require significant adaptation and new strategies to survive economically/ecologically; Water is a major constraint on economic and social development; Mining gains upper hand over weakened conservation/tourism and becomes primary economic sector.

Adaptation Approaches and Options

- Maintain the area as a center for cultural and eco-tourism and wildlife concentration.
- Focus on the restoration of river flow and prevent degradation of water quality.
- Monitor and control groundwater extraction from alluvial aquifers and well fields (that supply mining activities).
- Manage conflicts with mining demands for water and conversion of landscapes.
- Maintain/improve vegetation cover, particularly riverine forest, and prevent overgrazing from uncontrolled domestic animal movement and concentration of animal population density.
- Improve transboundary relationships of national governments, particularly with respect to movement of animals and people across borders, which could prove a pathway for diseases vectors

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4.5.4 Hotspot 4: Upper Umzingwane

Soil water conservation in drought prone Umzingwane

Key messages

- Drought and erratic rainfall are key features of the Umzingwane catchment, which falls in some of the driest and hottest parts of southwestern Zimbabwe. The area is marginal for rainfed agriculture, the primary livelihood. Climate change is likely to reduce surface runoff from the Upper Umzingwane catchment, further constraining the production potential of this hotspot.
- Sustainable land and water use and diversified livelihood options offering better security are critical for the area.
- Catchment management is complicated by the high number of small dams, many of which are not functional or suffer from siltation. Strong governance of the critical water resource and its associated infrastructure is needed, taking into account the climate change projections for this sub-basin.

Background

Generating an estimated quarter of the Limpopo Basin runoff (Love et al., 2005), the Umzingwane catchment is an important component of the management of basin water resources. Divided into four sub-catchments, Shashe, Upper Umzingwane, Lower Umzingwane and Mwenezi, the catchment has three major seasonal rivers: the Shashe, Umzingwane and Mwenezi. The majority of the runoff is generated within Upper Umzingwane and Shashe (Love et al., 2005). All the rivers flow into the Limpopo River in a southeasterly direction. While the rivers do not flow in winter, the thick sandy alluvial soils in the riverbeds provide enormous water storage capacity. The catchment remains susceptible to drying, however, as the mean annual potential evapotranspiration, at estimated rates of 1 800 mm, are higher than the annual rainfall average of 465 mm.

In Zimbabwe's climate categorizations, the Umzingwane catchment falls within regions IV and V. Upper Umzingwane is slightly better than the rest of the catchment within region IV, receiving slightly more rain than the rest at estimates of 450–650 mm per annum. Upper Umzingwane is also the source of the majority of the runoff from the entire catchment. The catchment is one of the driest in the country and receives some of the least rain in a year. In 2002–2003, just four years after another drought in 1998, the catchment area experienced what was regarded as the worst drought in many years.

The catchment is characterized by extreme weather and climate conditions. The catchment is generally water scarce and characterized by droughts and low and erratic rainfalls. The situation is compounded by the fact that these predominantly rural areas do not have access to blue water, which is normally used for irrigation (Love et al., 2005). Rain falls mainly in the summer months from October to April. Temperatures fluctuate between a mean minimum of 5 °C and a maximum mean of 30 °C.

In terms of geology, the Umzingwane catchment consists of the Zimbabwe craton, mostly greenstone belts and granitic terrain. Soils are categorized into four groups:

- soils derived from the granites and Limpopo gneisses are moderately shallow, course grained kaolinitic sands
- soils formed from the greenstone belts are clays and loams that are shallow to moderately shallow
- shallow sands are derived from basalts.

The Umzingwane catchment strategy 2010–2015 (Umzingwane Catchment Council 2010) indicates gender and population statistics that need to be taken into consideration in the management of the catchment resources. The population is composed predominantly of youths in the age group 6–24 years. In the districts constituting the catchment, there are more women than men, but this could very well be because most men migrate to South Africa and Botswana in search of jobs. Migrant labor is a key source of livelihoods in the area.

Three main forms of land tenure characterize the districts in Umzingwane. They are communal tenure, lease and resettlement. These forms of tenure are mostly supported on small sized plots ranging from an average of 2–5 acres, with implications for the main form of asset ownership – livestock rearing – that normally requires larger plot sizes to be viable. The other form of farming practiced in the catchment area, crop farming, is threatened by low rainfall and unfavorable climatic conditions.

Food security is precariously insecure in the area, with implications for the number of meals residents have in a day, dietary diversity being low and nutrition among children being poor. Residents engage in multiple livelihood strategies to mitigate the impacts of food insecurity. These include livestock sales, collecting and eating wild fruits, cross-border trading, prostitution and foreign currency exchange. In areas where there is still wildlife, such as Mwenezi district, residents engage in illegal hunting of game. Some mines operate within the catchment area, and many local people are employed at the mines.

As well as mines operating in the area, there is increased activity in gold panning, with major implications for water resources management as it involves the digging of river beds and banks as well as the use of chemicals such as mercury (Phiri, 2011). This poses a big problem for siltation of rivers and mercury pollution (Love et al., 2005). Gold panning is also not just an activity practiced by the local residents but has led to in-migration of panners who settle along rivers. Newspaper reports have also cited incidences of localized conflicts between gold panners and local farmers.

In terms of governance, the catchment is under a variety of institutions. For water resources management, the Umzingwane Catchment Council manages the catchment. Love et al. note that the catchment management is largely dominated by the powerful farmers, and not the communal farmers whose representation is through the Rural District Councils. This presents a challenge as the catchment falls under different provinces and districts, often requiring that greater coordination of activities and interests be undertaken.

Good soil water management techniques are important in sustaining rainfed agricultural-dependent livelihoods, and mitigating some of the impacts of high evapotranspiration in this drought-prone and low rainfall area (Mupangwa et al., 2005). The low rainfall and the general lack of surface water resources mean that groundwater resources are more important. Given the importance of groundwater resources, Love et al. see an untapped potential to increase crop yields through improved soil and water resources management. Pilot conservation agriculture initiatives in Umzingwane district have resulted in increased yields in the area. Other interventions to improve water supply and support irrigation have been plagued by governance problems. For instance, infrastructure development in the form of dams has not been completed in some of the projects. Where it has been completed, such as the Mtshabezi Dam, the process of construction has often been contested by local people who felt excluded from decision-making.

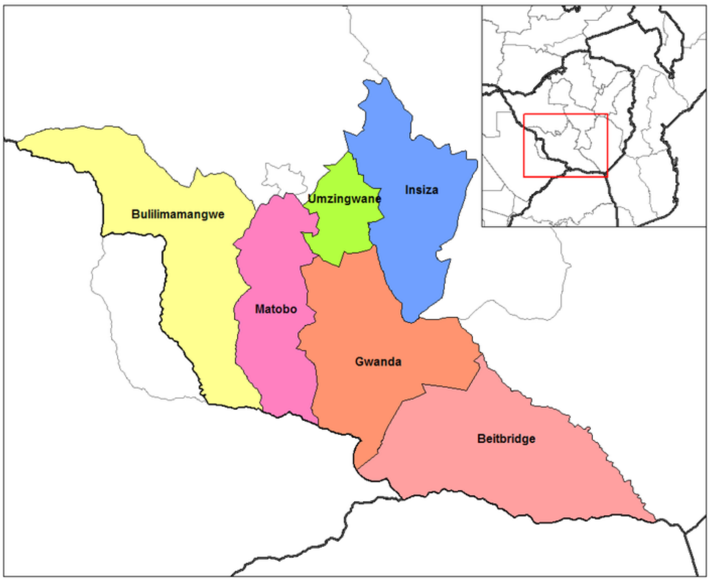

Figure 19 Administrative districts of the Upper Umzingwane

Upper Umzingwane falls mostly in the districts of Umzingwane and Insisa but the actual hydrological boundaries do not necessarily coincide with the administrative districts. The administrative map above only shows the districts that are within Matabeleland South, but not the other districts to the east that fall in Masvingo Province. The lack of a fit between administrative and hydrological boundaries presents a challenge for governance of the water resources.

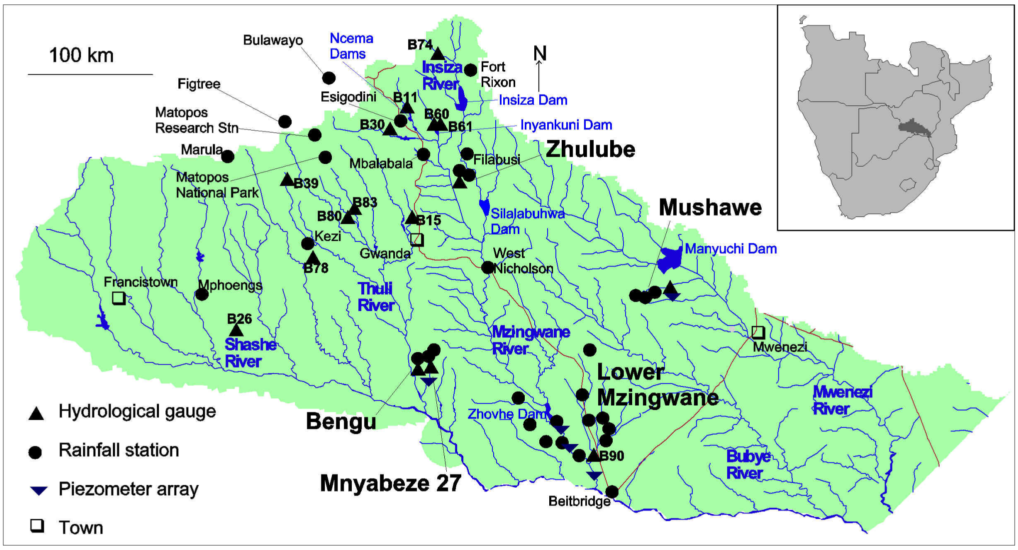

Figure 20 Position of hydrological gauges, rainfall stations, piezometer arrays and towns of the Umzingwane

Figure 21 The Mzingwana River near West Nicholson. Source: http://en.wikipedia.org/wiki/West_Nicholson

First to Fourth Order Impact Assessment: Current

Order	Current features and threats	Current impacts
1st	• Hot and dry, high evaporative demand. • Relatively high wind speeds, especially in late spring and summer when temperatures are highest. • Classed as semi-arid.	Semi-arid; rainfall is moderately low (500-650mm per year); Highly variable rainfall with a long dry season; hot humid summers, dry cooler winters; summer heat waves and extended dry spells; frequent droughts; Occasional frost in winter.
2nd	• River flow is highly variable. • Rivers and streams are ephemeral. • Alluvial aquifers are important sources of water. High lateral flows of water in the soils. • Single flood events are sufficient to recharge them – high infiltration rates given the sandy nature of the soils. • Wildfires are unrecorded. Grass fires are common in late winter/spring where a fire can be carried.	Most streams and rivers are ephemeral, except the upper reaches and main stem of the Umzingwane; water flows episodically following sufficient summer rainfalls; Very high rate of evapotranspiration; Large number of farm and small-scheme dams with high levels of sedimentation; Relatively benign grass fires are common in late winter/spring; Potential for acid mine drainage from the cobalt, gold and larger nickel operations; arsenic loading possible from larger gold mines; very little monitoring of mining impacts on water quality.
3rd	• Savanna/woodland; • Crops. • Livestock. • Invasion of riparian zones and aquatic systems by exotic fish.	Dominance of low-intensity pastoralism; low rangeland productivity with variable grazing depending on summer rainfall quantities; Some small scale crop production for subsistence purposes, but yields are very low and highly variable - mostly of millet, sorghum (both adapted to dry climates) and maize; Irrigation infrastructure exists but is mostly underutilized and poorly maintained, and some dams are full of sediment; risks of droughts and animal diseases are significant.
4th	• Socioeconomic. • Mining: small operations in the eastern part of the Gwanda and the Filabusi Greenstone Belts. Asbestos, aventurine, barites, clay, cobalt, emerald, feldspar, garnet, gold, limestone, nickel and tungsten have been mined at one stage or another. Gold mines are in operation, including artisanal alluvial operations. • Explorations have taken place for nickel, gold, copper, lead, tungsten, cobalt, silver, diamond, platinum, and arsenic.	Subsistence farming (pastoralism and some crops) is the primary livelihood; Relatively high population densities; Employment in formal and artisanal mining; most heavily mined area of Limpopo basin in Zimbabwe; high levels of poverty and lack of formal employment; Water scarcity and variability constrains economic development; Considerable cross-border migration in search of work (much of it illegal).

First to Fourth Order Impact Assessment: Future Scenario 1

- Ten percent drying (especially summer), warming 2°C with moderate to strong increases in maxima.
- Local economic development based on sustainable management of natural resources; diversification of livelihood options

Order	Future features and threats	Future impacts
1st	• Increased temperatures. • Shorter rainy seasons, late start and early ending. • Decreased rainfall. • Increased climate extremes (droughts). • Increased rainfall variability.	Remains semi-arid; 10% decrease in annual rainfall (mainly summer); small reduction in mean number of rain days; later beginning and earlier end to rain season; Warming by 2°C, highest in spring; increases in heat extremes; additional heat stress to living organisms; Risk of droughts and floods remains.
2nd	• Increased evapotranspiration. • Decreased soil water moisture. • Increased droughts.	Ephemeral streams and rivers flow less often with longer dry periods; reduced and more variable flow in main stem of the Umzingwane; Dam levels and alluvial aquifer recharge are more variable and generally decreasing; Further increases in rates of evapotranspiration; further reductions in soil moisture; higher rates of evaporation from small dams; Increased risk of wildfires at times (sufficient fuel + heat); Increasing importance of risks to water quality e.g. acid mine drainage and siltation.
3rd	• Decreased livestock productivity. • Decreased crop production. • Increased land degradation. • Decreased water quality.	Grass and shrub/tree cover decreases; Continued dominance of low-intensity pastoralism but with increasingly variable conditions, lower productivity and rising risks; increased land degradation; Rainfed subsistence crop production increasingly less viable and more variable; maize becomes marginal; Irrigation potential decreases due to more variable dam levels and decreasing water quality; Risk of over-abstraction of alluvial aquifer to meet animal and human demand; Increasing impacts of droughts and animal diseases.
4th	• Increased poverty. • Decreased livestock numbers. • Risk of land degradation through increased gold panning activities.	Farming systems remain but with higher risks and lower production (lower carrying capacity) and possible loss of maize; pressure on agriculture-based livelihoods; reduced food security from own production; Growth in formal and artisanal mining to boost economy and employment; increasing impacts of mining on river systems and siltation/sedimentation; Increasing levels of poverty and lower resilience (with links to lower livestock numbers); Increasing water-related constraints on economic and social development;

		Increasing cross-border migration in search of work; Loss of runoff from Umzingwane catchment has negative impacts downstream to the Limpopo confluence and beyond, with hydropolitical impacts.

First to Fourth Order Impact Assessment: Future Scenario 2

- Thirty percent drying (annual rainfall), warming 3°C with more extreme increases in maxima
- Stagnation due to unsustainable management of natural resources; persistent poverty traps (low productivity of smallholder farming, informal gold panning)

Order	Future features and threats	Future impacts
1st	• Highly reduced summer rainfall • Increased intensity of droughts • Far hotter summers and warming winters	• Remains semi-arid but with increased aridity; 30% decrease in annual rainfall (mainly summer); significant reduction in mean number of rain days; much shorter rain season; warming by 3°C, highest in spring; increases in very high heat extremes; significant additional heat stress to living organisms; risk of droughts and floods remains and impacts increase.
2nd	• Reduced groundwater infiltration • Reduced growth season • Reduced river runoff	• Many ephemeral streams and rivers stop flowing; perennial flows become ephemeral; significantly reduced flow in main stem of the Umzingwane; inflows into dams and alluvial aquifer recharge are much more variable and significantly decreasing; some boreholes and wells dry up; extremely high rate of evapotranspiration; large reductions in soil moisture; very high rates of evaporation from small dams; very high risks to water quality e.g. acid mine drainage and siltation owing to low quantities; reduced risk of wildfires due to much lower grass/shrub cover.
3rd	• Further reduction in crop and livestock productivity • Decreased land productivity • Increased land degradation	• Much reduced cover of grass and shrubs/trees; large-scale tree mortality due to reduced groundwater and heat; low-intensity pastoralism becomes marginal and unviable in some areas; severe land degradation as stock owners try to retain stock; sensitive animals suffer frequent heat stress; rainfed subsistence crop farming becomes unviable; irrigation crop farming becomes increasingly limited by water quantity and quality and crop suitability to heat conditions; alluvial aquifers can no longer meet demand from animals and humans; significantly increased conflict over grazing lands as animals seek food and water.
4th	• Increased poverty • Infrastructure is further affected	• Transition in land use /farming systems and water resources leads to reduced economy and jobs/livelihoods and rising poverty; pressure on agriculture-based livelihoods keenly felt, particularly the reductions in livestock and other productive assets; crop farming at all scales fails and all food is imported into the area; significantly reduced food security as lack of income limits food purchases; high

		dependence on informal and artisanal mining to provide income with high impacts on the environment; unsustainable livelihood approaches negatively affect land and water management; further increases in cross-border migration escalate transboundary tensions; loss of runoff from Umzingwane catchment has negative impacts downstream to the Limpopo confluence and beyond, with hydropolitical impacts.

Adaptation Approaches and Options

- Adaptation approaches should premise mostly on soil water conservation. This will tap largely into the water storage capacity of the soils in the catchment.
- The dry areas of the Limpopo River Basin have shown viability for wildlife farms. This is a potential development in the area and can generate valuable livelihoods for communal areas.

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4.5.5 Hotspot 5: Soutpansberg

Water catchment in the mountain of salt

Key messages

- The Soutpansberg is an important 'water tower' in the otherwise semi-arid surrounding environment of the northern Limpopo Province. It is critical to preserve a healthy water catchment (water quantity and quality) through best practice catchment management in order to maintain vital ecosystem services and water flow into the Limpopo River. One example is the urgent need to remove alien invasives that significantly reduce water runoff.
- This hotspot is central to the Vhembe Biosphere, a region of known high species endemism and conservation priority. The current climate varies widely from lower elevations (the densely populated hot and drier valleys) to the high elevation unpopulated mist forests. This range could well provide important refugia for species under climate change
- Sustainable land and water use practices in the populated valleys, together with areas of high biodiversity and scenic beauty, can provide the basis for the development of sustainable and diversified resource-based livelihood systems, for example a through a mixture of broad-based agriculture and ecotourism.

Background

The Soutpansberg mountains, rich in biodiversity, have a cultural heritage and ancient ruins spanning centuries. The high misty mountain provides a good catchment area for rivers (Luvuvhu and Nzhelele) that feed into the Limpopo River, while the fertile valleys below produce a variety of agricultural products. This contrasts with the rural population who subsist with poor services and infrastructure and increasing pressure from the surrounding overpopulated areas. Anthropomorphic activities are progressively placing stress on the catchment areas, compounded by alien vegetation infestation. These factors threaten to seriously alter the ecological services provided by the rivers.

The Soutpansberg, or *Tha vhani ya muno* (Mountain of Salt), is the northernmost mountain range of South Africa, spanning approximately 200 km in an east-west direction. The Soutpansberg fall mainly in the Makhado Local Municipality, a rural municipality located in the northern part of Limpopo province and part of the Vhembe District Municipality adjacent to the Musina, Mutale and Thulamela Local Municipalities. The altitude ranges from 250 m above sea level to Letjuma at 1,748 m (the highest peak). The highest points and steepest slopes are situated in the upper portion of the Luvuvhu catchment where the Luvuvhu River and some of its tributaries rise. Here there is significantly higher rainfall which affects the hydrology of the rest of the catchment. The Luvuvhu River flows for about 200 km before it joins the Limpopo River.

This area is strategically located next to both the N1 highway and the railway passage, which is the main access going north to Zimbabwe. Makhado has a population of approximately 606,633 people and a population density of 67 persons/km², with the majority residing in the rural areas. Scattered villages function only as residential areas having no economic base, and much of the population depends on social grants. There are approximately 10,478 farms, and the areas between settlements are also being farmed, providing an increasing threat of environmental degradation. Development has largely taken place in reaction to specific needs resulting in large disparities between the different communities. The very productive commercial agriculture includes citrus and sub-tropical fruits, wine grapes, nuts, flowers, forestry products, maize, wheat, lucerne, tobacco and a range of vegetables, as well as dairy and beef cattle, sheep, boer goats, pigs, chickens, game and animal products.

Invasive alien plants occur mostly in high altitude mountain humid habitats of Limpopo Province along the riparian zones. The impact of these invasive plants (mostly trees) is particularly heavy in the upper Nzhlele and Luvuvhu catchments consuming +30% MAR. The forest biome is most heavily invaded by *Eucalyptus* and *Pinus* species (le Maitre et al., 2013). There is extreme fire risk on higher land during late winter/spring with less of a risk in the lowland areas.

The surrounding areas of the Soutpansberg have large rural settlements in the Upper Nzhelele Valley that in the past were classified as the 'Venda homeland'. Here unemployment and an increasing population, searching for grazing and wood for fuel, is already beginning to impact on the natural resources.

There is a huge service infrastructure backlog. The roads are poor and often impassable after rains making transportation, which is both limited and expensive, problematic. A large proportion (>48%) of the population is unemployed, mostly women, and out of approximately 30,000 households about 30% do not have basic access to water, and 28% have below basic access to electricity.

This hotspot provides us with a dichotomy: it is a biologically diverse ecosystem with fertile soils and productive commercial agriculture on the one hand, whilst on the other hand are the small scale farmers with little land ownership and lack of basic services and infrastructure, and the pressure of increasing population in the surrounding areas. This dichotomy threatens to challenge the ability to maintain healthy water catchment areas in order to maintain sustainable ecosystem services.

One solution is to begin intensive alien clearing programmes which can provide jobs and dramatically increase the water flow.

Box 2: Institutional arrangements

The Integrated Development Plan of Makhado Municipality (2013–2016) reflects a good grasp of both the enormous problems and the potential of the area. There is a crucial link between land allocations and water allocations, making the issues around claims and land ownership a priority.

Land in the rural areas is held in trust by government for the traditional authorities. In these areas traditional leaders have been responsible for the implementation of customary laws for sustainable water management. Current legislation makes private land ownership in these rural areas almost impossible, and the common form of land ownership is the Permission to Occupy (PTO).

Some legislation has been delegated to the municipality, but most of the former homeland legislation is still assigned to the province, making it extremely difficult to control land use. Illegal water usage and theft of remote pumps pose a huge problem.

At this point in time, low to very low impacts exist in the Soutpansberg mountains as a direct result of climate change. It is felt, however, that major problems are beginning to emerge from the tensions that result at the interface between the human population and biodiversity.

Climate and variability depend on the location in the Soutpansberg. The mountain climate generally has a substantially different climate from that of the area north of the mountain towards the Limpopo River. The mountain area has a hot humid climate with mean minimum temperatures > 4.4 °C, mean maximum temperatures of < 29 °C, Mean RH 52 < > 71, and a predominantly summer rainfall with wind > 2.7 m.s-1 during summer. Transpiration has Eto 5.2mm.d-1 in summer 2.6 mm.d-1 in winter. Due to the east-west orientation of the Soutpansberg, large amounts of rain are discharged onto the southern slopes driven by the prevailing south-easterly winds. The total rainfall is strongly influenced by this topography, with the orographic rainfall due to moisture-laden air from the Indian Ocean. The mean annual precipitation (MAP)[4] varies from 1,800 mm in the mountainous areas to 300 mm at the Limpopo River. The mountainous areas of the Entabeni forest receive an annual rainfall of 1,874 mm, but orographic mist along this southern slope may increase annual precipitation to 3,233 mm (Hahn 2002, Olivier & Rautenbach 2002). Evaporation increases gradually from about 1,400 mm/a in the west to about 1,900 mm/a in the east. About 60% of the evaporation occurs during the six months from October to March. There is extreme fire risk on higher land during late winter to spring, with a medium fire risk in lowland areas (Forsyth et al., 2010).

The lowveld is warm and dry and classed as semi-arid at low altitudes. There is relatively high evaporative demand and high wind speeds, > 2.7 m.s-1 during October and summer when temperatures are highest. The mean minimum temperatures are 11 °C, mean maximum temperatures are 32 °C, and the mean RH 51 < > 60. The transpiration has an Eto 6 mm.d-1 in summer and 3 mm.d-1 in winter. Total rainfall ~ 335 mm.yr-1 which differs substantially from the area north of the mountain towards the Limpopo River. Frost is possible on low-lying ground but is rare.

Given that climate change does not pose an immediate threat, what are the major current issues facing the Soutpansberg? The main and most crucial issue is the importance of conserving the upper catchment areas of the Soutpansberg, especially where the impacts of human activities and alien vegetation invasion are being felt. A healthy water catchment is essential to maintaining the ecosystem services that ultimately affect the water downstream. The quality of the headwaters in the upper reaches of the Luvuvhu and the Nzhlele rivers has generally been found to be healthy, but already the impact of invasive woody plants (trees) has reduced flow by approximately +30% MAR. This disturbingly large number of alien species occurs mostly in humid high altitude habitats along riparian zones. Forests are the most heavily invaded with *Pinus* and *Eucalyptus* species (le Maitre et al., 2013).

The Soutpansberg rivers provide water to the fertile valleys at the foothills of the Soutpansberg, where predominantly Venda speaking communities use the valley for extensive agricultural activity. There is an abundance of perennial streams with tributary streams, including the Nzhelele, Sand, Tshipise and Luvuvhu, with ecologically important wetland areas. Although the high rainfall provides a large water resource in the catchment area, the water requirements are dominated by irrigation required for agriculture mainly in the valley, and irrigation for agriculture has started to exceed the available resource. Irrigation is possible close to rivers but boreholes supply a significant proportion of water away from the rivers. Large dams and numerous small farm dams provide irrigation to farmers but dams are often not used effectively and boreholes are drying up. In some areas there is a great deal of unauthorized water connection as well as high and unmonitored groundwater use. Continual vandalism (e.g. remote water pumps) and theft of electrical infrastructure also impact on water supply.

Most rural communities do not have basic access to water at household level. The illegal dumping of waste and lack of adequate sanitation contributes to the contamination of ground water which in some areas shows high levels of nitrates. Other problems associated with anthropogenic water use include: poor infrastructure (e.g. dirt roads), where it exists, leads to erosion and sediment in the river, overgrazing and trampling, vegetation cutting, washing, excessive fishing, sand mining, and intensive and extensive agricultural use along the over-utilized riparian zone. The largest threat to this region is not the lack of water but poor governance and a lack of financial resources.

Probably the greatest source of biodiversity loss is from habitat loss, due either to alien vegetation infestation or as a result of human activities. At present there are many attempts to conserve the rich biodiversity of Soutpansberg, which involves the formation of two conservancies, nature reserves, natural heritage sites and the inclusion in the Vhembe Biosphere Reserve. The benefits of conservation are numerous, but conservation will be ineffective unless these benefits are apparent to all stakeholders, particularly the local communities, which is difficult to demonstrate in the short term. As this region experiences high levels of poverty and unemployment and low levels of literacy (31% of the total local population is illiterate), it is likely that the general response will be 'it will only stay if it can pay'.

At present the major hazards relating to this region, apart from the implications of the scarcity of water resources, are veld fires, structural fires, floods, epidemics, transport related incidents (road and rail), aircraft accidents, droughts and extreme weather. Veld fires, floods, droughts and extreme weather would all increase with climate change.

Reduced rainfall will cause decreased agricultural production in the valleys of the Soutpansberg, where irrigation is not possible, unless drought-resistant crops such as sorghum are planted. Current crops such as maize are sensitive to higher temperatures and decreased rainfall, especially in the main growing period. This increase in potential evapotranspiration of 6–8%, with the largest increase taking place from September to November (when local heating takes place, wind velocity picks up but rainfall season has not yet started) will increase the potential for fire, already a natural hazard in the area.

The lifting of the cloud base, resulting in loss of mist interception in the cloud forest, has important implications for biodiversity as the vegetation patterns in the plant communities largely relate to the availability of soil moisture and the rate of environmental desiccation (Bond et al., 2003). Plant species needing a cooler climate will move to cooler elevations and those species at the highest elevations may be lost. As alien vegetation invasion can be managed, the implications will depend on both the intensity and area of alien vegetation in the catchment area. At high altitudes in the water catchment, where the rainfall-runoff ratio is the highest, runoff production will be reduced with implications for reduced runoff downstream. This has major implications for the Limpopo Basin where rivers such as the Luvuvhu flow two hundred kilometers into the Limpopo River and where perennial rivers could become ephemeral. Reduced flow will affect dam storage and irrigation water supply, having implications for agriculture and food security.

Some models project wetting of the north-eastern portion of South Africa in the Limpopo River Basin. As population pressure increases, erosion and land degradation is likely to increase and a wetter climate would probably increase flooding, damaging infrastructure, homes and livelihoods and causing further erosion to compromised eroded areas. Increased rainfall could increase agricultural production but this would depend on the rain intensity and temperature. Higher rainfall would increase the cloud base, increasing mist interception and resulting in higher rainfall in the cloud forest. At high altitudes where the rainfall-runoff ratio is the highest, runoff production would increase, resulting in increased flow. This will result in fuller dams and more water available for irrigation, provided that a good quality of water is maintained. Alien vegetation infestation would again be a question of management. A wetter Soutpansberg would possibly have a lesser effect on biodiversity loss than a drier climate but this would depend on loss of habitat and preceding biodiversity loss.

Many problems that currently exist will be exacerbated by climate change. The low level of formal education, lack of economic opportunities, high poverty rates as well as environmental degradation and little environmental awareness make this an area in dire need of good governance. However, the natural potential of the Soutpansberg has not been fully realized and given the right support, many eco-tourism opportunities could exist in to the future.

First to Fourth Order Impact Assessment: Current

Order	Current features and threats	Current impacts
1st	• High temporal variability of rainfall: irregular climatic cycles, periodic stochastic events. • High spatial variability of rainfall and temperature and other climatic features linked to topography – pronounced localized climate patterns. • Soutspansberg mountain area has a substantially different climate to the area north of the mountain descending towards the Limpopo River. • Mountain climate: total rainfall ~ dependent on location. As high as 2,000 mm (3,200 mm.yr^{-1} if fog collections are included) (Olivier and Rautenbach, 2002). • Lowveld climate: Total rainfall ~ 450 - 650 mm.yr^{-1}.	Ranges from semi-arid (450-500 mm per year) in the Nzhelele sub-basin on the northern slopes of the mountains, to mildly semi-arid (600-650 mm) in the Levuvhu sub-basin and the southern slopes, but as high as 2000 mm in the cloud forest or 3200 mm if fog collections are included; High spatial variability of rainfall and temperature – pronounced micro-climates; Irregular climatic cycles and periodic stochastic events (drought, flood); hot humid summers, dry cooler winters; frosts possible on low-lying ground; Relatively high wind speeds, especially in spring and early summer when temperatures are highest.
2nd	• Nzhelele, Sand, Tshipise, Luvuvhu Rivers, ephemeral. Tributary streams episodic after rainfall. • Thermal spring at Tshipise. • Risk of floods in the lower areas. • Soil erosion and severe land degradation. • Water quality problems – untreated effluent. • Pollution of rivers downstream. • Extreme fire risk on higher land during late winter, spring. Medium fire risk in lowland areas. (Forsyth et al., 2010).	The Luvuvhu River and its tributaries are perennial; the Nzhelele R. is perennial in the upper reaches but some tributaries are ephemeral; Several large and smaller dams regulate surface water flows; further dams are planned; boreholes supply a significant proportion of water away from the rivers; groundwater is overexploited in some areas; Levuvhu water resources are slightly overcommitted; High rate of evapotranspiration; soil erosion and severe land degradation; Water quality problems from untreated effluent; pollution of rivers downstream; Extreme fire risk on higher land during late winter and spring; Risk of floods in lower-lying areas.

Order	Current features and threats	Current impacts
3rd	• Agriculture. • Forestry. • Invasive alien plants occur mostly in high altitude mountain humid habitats of Limpopo Province (A), along riparian zones, elsewhere are almost non-existent. • Wetland biodiversity and productivity. • Loss of and damage to productive assets.	Wide range of habitats and vegetation types; high levels of speciation and endemism in the natural forests, wetlands and rivers (Vhembe Biosphere); Southern slopes support highly productive diverse commercial irrigated agriculture (citrus and sub-tropical fruits, nuts and tea); Livestock farming (large and small stock, poultry and game); rainfed low level subsistence cropping and livestock in some areas; Water quality risks for agriculture; Upper slopes support productive commercial forestry (pines, eucalyptus); Invasive alien woody plants occur in high altitude habitats along riparian zones of the upper catchments, consuming +30% of annual rainfall; Poor land use practices cause erosion and sedimentation in places.
4th	• Low/stalled economic growth. Increasingly poor as villages expand and link up with one another, loss of arable land, and migration to cities but population growth in these areas keeps population dense. • Socio-economic disruption to livelihoods dependent on agriculture. • Water security and quality. • Nickel, lead mines (closed), pegmatites, coal (Tshikondeni coal mine in Luvuvhu catchment), alluvial diamond prospecting along the Limpopo River flood plain terraces.	Economy driven by services, trade and agriculture ('dual' agricultural economy); Rural areas of ex-'homeland' Venda characterized by high population density, sprawling settlements with low levels of services and infrastructure, high unemployment and poverty, and land tenure problems; villages are expanding and merging with increasing use of and impacts on natural resources; Erosion and degradation of arable land; Risk of biodiversity loss from habitat loss linked to alien vegetation infestation and human activities; Migration to cities but continuing population growth; Low economic growth and poor development planning; High proportion of youth and women; Low level current and planned coal mining.

First to Fourth Order Impact Assessment: Future Scenario 1

- Ten percent drying (especially summer), warming 2°C with moderate to strong increases in maxima.
- Local economic development goes hand in hand with good management of watershed ecosystem services; development of diversified livelihoods.
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Order	Future features and threats	Future impacts
1st	• Rainfall variability increases as a general condition – fewer extreme rainfalls and fewer rain days; • Increased rainfall intensity for the heavy rainfall events • Shifts in rainfall seasonality. • Increased temperature.	10% decrease in annual rainfall (mainly summer); small reduction in mean number of rain days; later beginning and earlier end to rain season; Northern slopes and lowlands could transition to arid, southern slopes remain semi-arid; increased rainfall intensity for the heavy rainfall events; Warming by 2°C, highest in spring; increases in heat extremes; additional heat stress to living organisms; higher temperatures result in lifting of the cloud base with reduced rainfall/mist interception of the cloud forest; Risk of droughts and floods remain; Fewer frosts.
2nd	• Streamflow from the upland areas decreases • Increased soil erosion and land degradation. • Reduced ephemeral water flows. • Decreased water quality (untreated). • Increased pollution of rivers downstream.	Ephemeral streams and rivers on northern slopes flow less often with longer dry periods; reduced and more variable runoff and flow in perennial streams and rivers; Increasing importance of cloud forest rainfall/mist interception; Some loss of ecosystem services including reduction in wet season storage of water for later release; Dam and groundwater levels more variable and generally decreasing; Increased rate of evapotranspiration and reductions in soil moisture; increased soil erosion and land degradation from heavy rainfall following dry periods; increased siltation of watercourses and dams; water quality problems exacerbated by lower flows; Increased risk of fire at times.
3rd	• Some loss of ecosystem services ensues, including loss of wet season storage of water for later release • Increased habitat loss from alien invasives and population pressure; biodiversity loss. • Increased alien infestations affecting water catchment. • Overgrazing exacerbates erosion and land degradation in some catchments, especially those heavily populated.	Aridification of high altitude moist habitats impacts on species (birds, invertebrates) and ecosystem services; changes in species ranges (e.g. up-slope) at local scales; Wetlands dry out more quickly and may contract; alien infestations account for increasing relative water losses; Rangeland productive capacity decreases and if stock are not reduced this leads to further land degradation in heavily utilized areas; Commercial agriculture is exposed to risk of insufficient water supply to meet demand and re-allocation to other uses; rainfed low level subsistence cropping experiences lower and more variable yields; commercial forestry experiences greater variability of production and risks.

		Water quality risks increase due to lower flows;
4th	• The variable climate and limited productivity of the land restricts the levels of food production in the densely populated areas. • Human health is challenged by the increasingly poor • Biodiversity is affected by the changed hydrological regime, especially with regard to the increase of the condensation level and increasing marginality of the cloud forest..	Subsistence agriculture-based livelihoods become more difficult; increasing poverty and food insecurity; economically active males continue to leave, with remaining women, elderly and youth progressively less able to support their livelihoods; Lower resilience linked to decreasing livestock numbers; Alternative livelihoods (e.g. ecotourism) become more difficult to develop due to pressure on water and habitats/biodiversity; Growth in commercial agriculture stalls due to more variable climate and yields and reduced water resources and quality; Loss of runoff from Soutpansberg "water tower" has negative impacts downstream to the Limpopo confluence and beyond, with hydropolitical impacts.

First to Fourth Order Impact Assessment: Future Scenario 2

- Thirty percent drying (annual rainfall), warming 3°C with more extreme increases in maxima.
- Unplanned resource-based development that undermines good watershed management; no alternatives to unviable livelihoods.

Order	Future features and threats	Future impacts
1st	• Shifts in rainfall seasonality. • Decreased rainfall with more extreme temperatures • Increased rainfall intensity. • Increased temperature • Lifting of cloud base resulting in loss of mist interception	30% decrease in annual rainfall (mainly summer); large reduction in mean number of rain days; later beginning and earlier end to rain season; Northern slopes, valleys and lowlands transition to arid, southern slopes remain semi-arid; increased rainfall intensity for the heavy rainfall events; Warming by 3°C, highest in spring; significant increases in heat extremes; significant additional heat stress to living organisms; Lifting of the cloud base results in large reductions in rainfall/mist interception of the cloud forest; Risk of droughts and floods remain; no frosts.
2nd	• Flooding in lower region, but at a reduced frequency • Increased soil erosion and severe land degradation with rising population pressures. • Loss of ecosystem services on high altitude areas . • Reduced ephemeral water flows. • Decreased water quality (untreated). • Increased pollution of rivers downstream. • Reduction in catchment area.	Ephemeral streams and rivers on northern slopes stop flowing; perennial flows become ephemeral; significantly reduced flow in main stems of rivers; Loss of cloud forest rainfall/mist interception has high impact on runoff; significant loss of ecosystem services; high variability of flow and risk of flash floods after heavy rain; Dam and groundwater levels highly variable and reduced with less frequent aquifer recharge; Extremely high rate of evapotranspiration; large reductions in soil moisture; further land degradation, siltation and risks to water quality; Reduced risk of wildfires in acidified areas due to much lower grass/shrub cover; Increased fire risk to previously moist forests.
3rd	• Increased habitat loss from alien invasive plants and population pressure; biodiversity loss. • Increased alien infestations affecting water catchment. • Increased loss of and damage to stressed infrastructure. • Decreased crop production. • Possibility of fires increase	Further aridification of high altitude moist habitats; Large impacts on biodiversity (all groups) and ecosystem services; reduced forest cover; increase in xeric shrubs and grasses; changes in species ranges and local species extinction; Significant contraction of wetlands; Significant reduction in rangeland productive capacity; animals and crops suffer heat stress; Contraction of commercial agriculture as scarce water is re-allocated to human needs; changes in crop suitability; rainfed low level subsistence cropping becomes unviable in places; contraction of areas suitable for commercial forestry

		and reductions in production.
4th	• Decreases in subsistence and commercial food production. • Increases in poverty and food insecurity. • Deterioration in human health (HIV, Aids, diarrhea, respiratory diseases and water borne diseases e.g. cholera.) • Loss of life. • Socio-economic disruption. • Agriculture-based livelihoods shift towards harvesting of natural resources in biodiverse/conserved areas. • Decreased maintenance of culture/traditions, migrations to cities.	Subsistence agriculture-based livelihoods become marginal/unviable; large-scale poverty and food insecurity; rural economy collapses; local crime rate soars; Potential for ecotourism greatly reduced due to landscape transitions, loss of biodiversity and water scarcity; Commercial agriculture survives only where water rights are still held and crops/farming systems are adjusted; high variability of yield due to drought and heat stress; Significant loss of runoff from Soutpansberg "water tower" has large impacts downstream to the Limpopo confluence and beyond, with larger hydropolitical impacts.

Adaptation Approaches and Options

- The top priority here, and in all high altitude mountainous areas in the Limpopo River basin, that contain cloud forest, amongst other biodiversity, is to maintain the ecosystem in as pristine a condition as possible, in order to maintain river flows off the slopes. Degradation of the slopes and vegetation should be prevented at all costs. The highest rainfall and the highest rainfall/runoff conversion ratio occurs in this area and is crucial for water production.
- Remove alien invasive woody species that utilize a substantial proportion of runoff where they occur.
- Focus on diversifying the local economy so that the population pressure does not being to impinge on the ecosystem resources of the Soutpansberg mountain area.

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4.5.6 Hotspot 6: Pauli Triangle

A Three-cornered Problem

Key messages

- Droughts are the main driving force at Pafuri for all the countries involved: Mozambique, South Africa and Zimbabwe. The area receives low and erratic rains and the temperatures are high. In the recent flood incidences, crops and livestock have also been damaged leading to food insecurity and loss of assets.
- Governance issues, given the different administrative arrangements in the three countries are central.
- Land use is a key factor considering the multiple and competing interests in the area. Land use has implications for water resources allocation, in particular between mining, ecosystems and local livelihoods (crop and livestock production).

Background

Significantly, the Pafuri corner is the last stretch of the Limpopo River that is not a political boundary marker and flows solely into Mozambique. But it is also the second point where three of the four basin countries (after the Shashe–Limpopo confluence further upstream) share a common point, making the assessment of collaborative governance of water and biodiversity a critical one.

The key rivers in the area are the Levubu (the headwaters of which are in the Soutpansberg) and the Mutale that originates at the legendary Lake Fundudzi. Compared to other areas of the basin, the Pafuri triangle has a relatively small population, with an average exclusively rural population density of 2.3 people per square kilometer (Malbender et al., 2006).

The history of the Pafuri triangle is significant for governance and prevailing land tenure systems today. During the consolidation of homelands South Africa during the 1960s, the Makuleke Community was forcefully removed from the Pafuri area in 1969 but returned after a successful land claim. Their neighboring Venda villages were also forcibly removed from along the Limpopo River and settled further inland. Both communities have claimed pieces of land within the triangle but also stretching into other areas. The Makuleke people's land has since been restituted and they have agreed to incorporate it into the Kruger National Park, while the neighboring Venda have their land on paper but it is still occupied by the South Africa National Defense Force (SANDF).

The high wildlife numbers and the prevalence of malaria have influenced the types of land use in the area. In 1969 when the Makuleke were forcibly moved, the Kruger National Park was extended to reach the borders of Zimbabwe. To the west, the Venda were removed to establish a military zone that was later partly converted into the Matshakatini Nature Reserve. The Pafuri corner under the Makuleke land has been included in the Great Limpopo Transfrontier Park (GLTP), while the Madimbo corridor is intended to become part of a larger transfrontier conservation area. The GLTP includes the Kruger NP in South Africa, Limpopo NP in Mozambique, Gonarezhou NP, Manjinji Pan Sanctuary and Malipati Safari Area in Zimbabwe. The transfrontier conservation area includes Sengwe Communal lands in Zimbabwe and villages in the Pafuri administrative post in Mozambique. Clearly the main form of land use in the area is conservation, but there are also competing interests. Among the local people there are differing perspectives on land use, with some opting for livestock and crop production while others are in favor of conservation-driven tourism (Whande, 2007).

The main hazard that occurs in this livelihood zone is the chronic lack of rain, reducing the potential for satisfactory crop yields. Factors that damage crops and livestock every year are crop pests, some livestock diseases, violent storms and wild animals. As regards intermittent or periodic hazards, there are years when the red-billed sparrow descends on crops in unusually large numbers. In some years there are particularly bad attacks from rodents and/or grasshoppers. Periodically also there is an upsurge in ticks and skin disease in cattle.

In Zimbabwe, this lowveld zone forms a long thin strip along the south of the country. These communal lands are classified as Natural Region V. Annual rainfall is very low, averaging less than 475 mm. Rivers, along with disused mines, provide opportunities for gold panning. Livelihoods are characterized as primarily agro-pastoral. Small grains are mainly grown as well as cotton in some parts of the zone, particularly in Chiredzi District, due to the drier weather pattern. Food and cash income from animal husbandry is supplemented by income from seasonal work on the nearby A2 and large-scale commercial farms or by migratory work in South Africa. Animal holdings are generally larger in this zone compared with other parts of the country, especially around Beitbridge, as land there is more suited to grazing. Arable land for crop cultivation is generally small. Cereals are sold to the Grain Marketing Board (GMB) and private buyers. Cotton is the major cash crop in Chiredzi District and is sold to cotton companies such as Cotco, Terafin and Olam. There is a relatively lively cross-border exchange of goods and currency.

In South Africa, subsistence farming for communities south of the Madimbo corridor and on the edge of the Pafuri plays an important role in sustaining livelihoods. There is minimal beef cattle farming outside the Park, and small-scale egg farming. The Local Municipality has very small production of tomatoes, oranges, bananas and mangoes.

On the Mozambique side there is subsistence farming in areas outside Park. The main crops are maize, sorghum, millet, vegetables and melons. Harvesting of natural resources is predominantly mopane worms for household consumption and selling. Cattle are mainly sold to local traders who come to the villages and purchase animals for resale to butcheries or abattoirs in town. Own farm produce such as melons and sweet cane are sold to travelers along the tarmac roads or in urban centers.

Mostly for Mozambique and Zimbabwe, migrating across political boundaries is a key source of livelihoods. Local jobs can be found either doing piecemeal work for better-off farmers or working casually on A2 and large scale commercial farms in the zone. More lucrative job opportunities are found across the border in South Africa as well as in major urban centers within Zimbabwe. Such work opportunities are chiefly exploited by better-off households.

Governance is complicated by the fact that the area joins three countries with different administrative systems. Incidences of cattle theft across boundaries and transboundary grazing of livestock with no clear agreement makes this a difficult situation to govern. While there is a transboundary agreement for biodiversity conservation through transfrontier parks and conservation areas, this does not necessarily extend to water resources and human relations. In particular, the local government systems do not as yet have a system of jointly managing common resources and resolving local disputes such as cattle rustling.

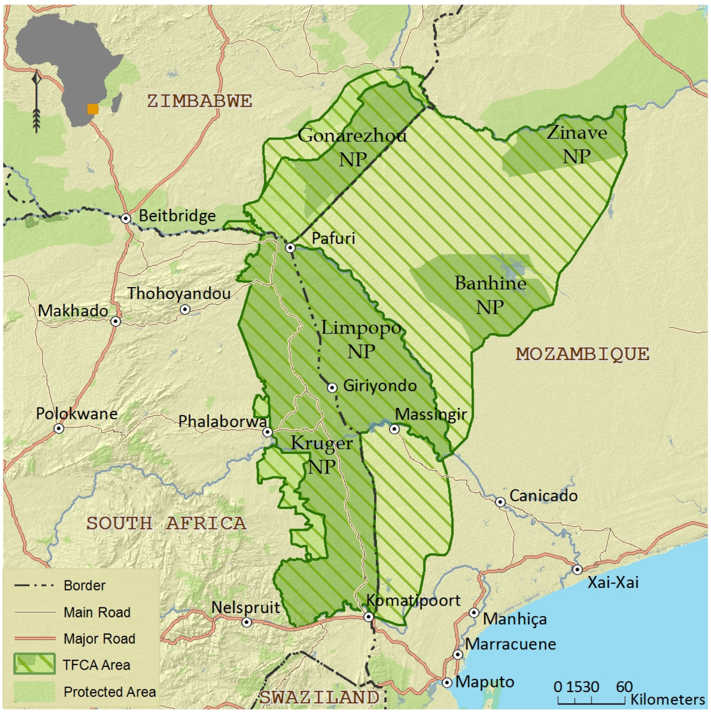

Figure 22 Great Limpopo Transfrontier Park. Source: Peace Parks
http://www.peaceparks.co.za/story.php?pid=1005&mid=1048

First to Fourth Order Impact Assessment: Current

Order	Current features and threats	Current impacts
1st	• Hot semi-arid climate, highly seasonal with a short rainfall season. Annual rainfall is about 450–650 mm. • Intense rainfalls occur through warm-cored low-pressure systems, or cyclones making landfall over the Mozambican coastlines. • Relatively high wind speeds, especially in spring and summer when temperatures are highest.	Annual rainfall is 450–470 mm per year at Pafuri; Levuvhu sub-basin (South Africa) receives 600-650 mm per year; Bubi sub-basin (Zimbabwe) receives 550-600 mm per year; Semi-arid climate; highly variable rainfall with a long dry season; intense summer thunderstorms; hot summers, dry winters; extreme maximum temperatures in summer; regular droughts; occasional floods.
2nd	• Permanent surface water flows only from the Mutale–Levuvhu River system. Elsewhere flows are ephemeral (summer flows) and episodic (after heavy rainfalls). • Limpopo River at this point is often dry during the winter months.	The Luvuvhu River and its tributaries are perennial; the Bubi R. and its tributaries are ephemeral; flow in the Limpopo River at Pafuri is highly seasonal and the river can run dry in the dry season; Episodic strong flows and occasional floods occur after heavy rainfall in the Upper/Middle Limpopo basin; High dependence on groundwater (boreholes) away from the rivers; The important Levuvhu water resources are highly exploited and flows have decreased recently; High rate of evapotranspiration; low soil moisture; Makuleke wetlands between Levuvhu and Limpopo Rivers.

Order	Current features and threats	Current impacts
3rd	• Rangeland productivity is severely limited by the short growing season, high temperatures and poor soils. • Low and variable rangeland productivity based on grassland and biomass production dependent on seasonal rainfall, which is variable and semi-arid. • Soils are sodic and dispersive and therefore prone to erosion. • Water for irrigation is in short supply given that the Limpopo River may be dry for substantial periods throughout the year. Irrigation off-takes would also be highly vulnerable to the occasional floods. There are some alluvial aquifers that could be exploited.	Dry savanna and open woodlands; high aquatic biodiversity especially in lower reaches of Levuvhu sub-basin; high terrestrial biodiversity across protected areas (Great Limpopo Transfrontier Park including Kruger National Park and Limpopo National Park); Almost no commercial agriculture except some game ranching; low rangeland productivity with variable grazing and browse depending on summer rainfall quantities; High risk of drought and heat; Wildlife-livestock-human conflict over resources; Rainfed low level crop farming with hardy small grains, vegetables/melons, and cotton (Zimbabwe).
4th	• Food production is at a very small scale and environmental challenges is one reason for the relatively sparse population and limited livelihood options. • The variable climate and limited productivity of the land restricts the levels of income. • Human health is challenged by the hot climate, poor nutrition and trans-humance of people through the area • An area of high biodiversity, given the abundant riparian ecosystems.	Primary economic activity is ecotourism; also communal agro-pastoralism; Very low population densities; very few formal employment opportunities; sporadic food insecurity; Commercial coal mining (SA) and artisanal gold panning (Zima); Makuleke land claims in SA have been successfully dealt with; High levels of livestock/game and human (e.g. malaria) diseases; cross-border animal disease issues; Great Limpopo Transfrontier Park across 3 countries; Rich natural and cultural/archaeological heritage; water scarcity, heat and disease constrains economic development; Considerable cross-border migration and small trade (much of it illegal); significant poaching and cattle rustling problems; Collaborative governance of natural resources and security is important.

First to Fourth Order Impact Assessment: Future Scenario 1

- Ten percent drying (especially summer), warming 1°C with moderate increases in maxima.
- Shared platform for joint discussions of land and water use planning is in place between the three riparian countries growth of eco-tourism; development of viable and diversified land use and livelihoods.

Order	Future features and threats	Future impacts
1st.	• Decrease in rainfall extremes. • More severe droughts.	Remains arid to semi-arid with possible transition to arid only especially in Zimbabwe and Mozambique section; 10% decrease in annual rainfall (mainly summer); small reduction in mean number of rain days; later beginning and earlier end to rain season; rainfall changes strongly influenced by changes in cyclones from Indian Ocean (possibly more intense, possibly less frequent); Warming by 1°C, highest in spring; increases in heat extremes; additional heat stress to living organisms; risks of droughts and floods remains.
2nd. .	• Decrease in flood events. • Increase in severe droughts in the region.	Water flows in the Luvuvhu River are more variable with longer periods of low flows; ephemeral Bubi River and its tributaries flow less often with longer dry periods; reduced and more variable inflows into the Limpopo River at Pafuri and the river runs dry more frequently; Episodic strong flows and flash floods still occur after heavy rainfall; Further increases in already very high rates of evapotranspiration; further reductions in soil moisture; groundwater levels more variable and generally decreasing; alluvial aquifer recharge less frequent; Makuleke wetlands show drying and possible contraction in area.
3rd.	• Decrease in rangeland productivity is likely. • Decrease in cropping cycles (i.e. shortened by the shorter rainfall seasons). • Decrease in crop types. • More limited cropping patterns	Vegetation cover decreases and species ranges change; certain types of ecotourism are impacted (e.g. birding); productivity of grazing and browse reduced and livestock/game production becomes more variable and at higher risk of drought; Groundwater less available for humans and livestock; changes in livestock/game and human diseases can be expected; Increased wildlife-livestock-human conflict over resources; increased cross-border animal movements and veterinary problems as animals seek food and water; Rainfed crop yields become lower and even more variable.

Order	Future features and threats	Future impacts
4th.	• Decrease in food production. • Increase in poverty. • Decrease in human health. • Decrease in biodiversity and natural resources	Farming systems remain but with higher risks and lower production; agricultural livelihoods become marginal; Low population growth; Ecotourism remains important but tourist number start to decline due to lower animal densities and range changes, heat stress and water scarcity; No growth in formal employment opportunities; increasing food insecurity; increasing water scarcity, heat and disease constrains economic and social development; Continued high levels of cross-border migration and small trade, poaching and cattle rustling; Collaborative governance of natural resources and security becomes even more important.

First to Fourth Order Impact Assessment: Future Scenario 2

- Thirty percent drying (annual rainfall), warming 2°C with more extreme increases in maxima.
- Long-term lack of a shared platform for joint discussions on land and water use planning by three riparian countries; decline in eco-tourism; no alternatives to unviable livelihoods.

Order	Future features and threats	Future impacts
1st.	• Highly reduced summer rainfall • Increased intensity of droughts • Far hotter summers and warming winters	High possibility of transition to arid climate over the whole area; 30% decrease in annual rainfall (mainly summer); significant reduction in mean number of rain days; much shorter rain season; Changes in cyclone intensity (possible increase) and frequency (possible decrease) have major influence on rainfall; Warming by 2°C, highest in spring; increases in very high heat extremes; significant additional heat stress to living organisms; Risk of droughts and floods remains and impacts increase.
2nd.	• Reduced groundwater infiltration • Reduced growth season • Reduced runoff in the Limpopo tributaries • Increased land surface heat reflection	Significant decrease in flow of Levuvhu River and its discharge into the Limpopo; Bubi sub-catchment dry most of the time; main stem of the Limpopo has low flows and is frequently dry; Flash floods still occur after heavy rains causing land degradation; extremely high rate of evapotranspiration; Large reductions in soil moisture; groundwater levels much more variable and significantly decreasing; alluvial aquifer recharge much less frequent; Makuleke wetlands show significant drying and contraction.
3rd.	• Further reduction in crop and livestock productivity • Decreased land productivity • Increased land degradation	Much reduced vegetation cover; large-scale tree mortality along watercourses and elsewhere; large changes in species ranges and possible local extinctions – loss of biodiversity; Livestock and game suffer serious declines in productivity and some species become unviable in some areas; Groundwater becomes scarce;

		All crop farming becomes unviable due to heat stress and lack of water. Significant changes in livestock/game and human diseases with serious cross-border disease control problems; Wide-spread conflict between wildlife-livestock-humans;
4th.	• Increased poverty • Conditions not conducive for livestock production but might slight improve for wildlife • Infrastructure is further affected	Transition in habitats and biodiversity, land use and water resources leads to reduced economy and jobs/livelihoods; Crop farming fails and all food is imported into the area; impoverished communities suffer severe food insecurity and abandon their rural livelihoods; Ecotourism requires significant adaptation and new strategies to survive economically and ecologically; tourist numbers under pressure from changes in biodiversity, heat stress and water scarcity; Mining development increasingly allowed to bolster economy leading to conflict with conservation and water resources; Cross-border security challenges become critical.

Adaptation Approaches and Options

This area is conducive for wildlife and a consideration for the future are game reserves and increased tourism opportunities.

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4.5.7 Hotspot 7: Lebowa – Middle Limpopo

The land and water is bitter

Key messages

- A high population density, with inappropriate agricultural and specifically governance arrangements stemming from its history (e.g. issues of land tenure), has led to reduced ecosystem productivity and resilience, widespread poverty and poor health outcomes for people of this area. Drier and hotter conditions in future add to existing stresses on insecure agriculture-based livelihoods.
- The higher-lying catchments, such as the Wolkberg, generate a high proportion of surface runoff into the Olifants sub-basin, one of the largest contributors of water into the Limpopo River system. Increased climate-related risks to this sub-basin would have significant impacts on the water resources reaching downstream Mozambique.
- The Olifants River water quality is poor and verges on the toxic, with high acidity and heavy metal concentrations arising from the coal mines and industry on the Highveld and Gauteng. River water becomes increasingly acid during seasonal low flows and droughts, and these conditions are expected to increase in frequency under climate change. Metals precipitating into river sediments will be released during floods and transported downstream.
- Unsustainable land use management in this hotspot relates directly to the high levels of land degradation and requires remedial actions in order to bring this potentially productive area back into optimal productivity. This would also confer greater resilience to climate variability and climate change.

Background

The Lebowa–Middle Olifants is an area bounded in the east by the rim of the Bushveld Igneous Complex mountains and in a rough line in the west from the Loskop dam in the south to Mokopane further north. The small towns of Marble Hall and Roedtan are on the periphery. Within the hotspot, urban centers are exemplified by Lebowakgomo and Jane Furse. This is a region defined by a high population density, rural poverty and degraded and denuded land. People live in extended villages in simple, single-storey houses in poorly serviced clusters. It is an area in which the welfare-dependent population outnumbers the population of small famers. Its hotspot status stems from the impact the high population density has had on residual biomass and the land degradation that has taken place. Normalized Difference Vegetation Indices (NDVI) show similar values to those in far more arid areas further to the west in the Kalahari Desert (Gibson, 2006), although during summer it has a grass and scrub cover.

The high density of population is due to the declaration of the area as a self-governing homeland during South African apartheid and the subsequent concentration of people there (according to cultural and language affiliations). The people living there have not been able to develop a sustainable agriculture. Living from subsistence agriculture alone became impossible and remains so. Out-migration of people to the major urban centers such as Gauteng is occurring but a residual population growth remains.

Land use is communal and governance is through the local tribal authority. This means that everyone, more or less, has access to the same resources, which is a factor in its state of degradation. While the soil and vegetation maps do not show a particular reason or evidence of an inherent vulnerability, the high demand for ecosystem resources has inevitably led to landscape degradation. Because of the intense use of biomass, there is now a fuelwood crisis in the region (Scholes et al., 2004). Few large trees remain and most of the woody plants are scrub.

The solution is to improve supporting infrastructure, provide farmer extension support, invest in erosion control measures and perhaps introduce sustainable technologies such as conservation agriculture, which will also require extensive education and behavioral change.

The water availability aspect provides a different view. The Olifants River, which flows through this region, drains part of the South African industrial heartland of Gauteng. Coal mining and industrial activities within the catchment s of the Wilge, Bronkhorstspruit and Klein Olifants tributaries, as well as the Olifants River headwaters, leads to contamination by acid leachates, high levels of nitrates, sulfates, fecal contaminants and ammonia (Aurecon, 2011). Heavy metals are also a major problem, including Cu, Fe, Zn, Cr, Pb, Ni and V (Wepener, 1997). Water quality is now a major problem in the Olifants River, to the extent there has been a major die-off of crocodiles in the river, especially in the Loskop dam just upstream of the Lebowa area. The current trend indicates a worsening problem (Aurecon, 2011). Dabrowski and de Klerk (2013) indicate that the acidic tributaries contribute proportionally more water than neutral rivers during winter months, intensifying acidity during the dry months. The implications are that droughts bring greater acidification and that a future with more droughts and dryer climate, which is what is projected, will bring even greater acidity and metal concentration. This will forestall attempts to reallocate water into the former Lebowa area as a means of improving agricultural production. The metals are also deposited into river channel sediments. Intense rainfalls and resulting flood disturbance will release them into the flood water for transport downstream (Dabrowksi and de Klerk, 2013). The problem then becomes a transboundary one.

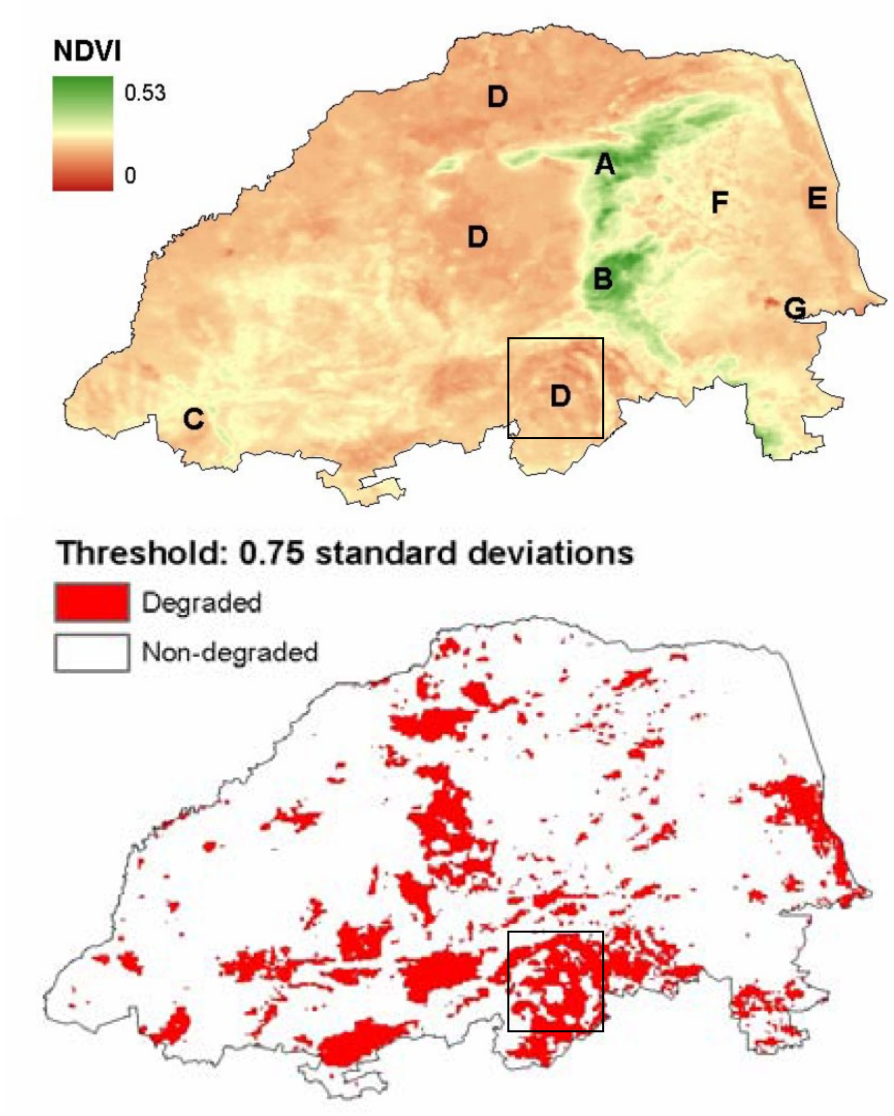

Figure 23 A Normalized Difference Vegetation Index (NDVI) map of the South African portion of the Limpopo River catchment from Gibson 2006). The southern-most letter D represents the middle Olifants–Lebowa region. The dark red hues indicate the low levels of biomass in that region.

Figure 24 A settlement in the Steelpoort River valley, eastern limit of the Lebowa–Mid Olifants river section indicating the mountainous terrain, extended settlements and denuded state of the land. Source: http://www.fao.org/ag/agp/agpc/doc/show/safri/sapaper/photo9.htm, photograph by J.E. Victor.

Figure 25 Severe erosion in the Middle Olifants–Lebowa region as a result of inappropriate land uses. Source: http://www.fao.org/ag/agp/agpc/doc/show/safrica/sapaper/photo9.htm, photograph by J.E. Victor.

First to Fourth Order Impact Assessment: Current

Order	Current features and threats	Current impacts
1st	• Total rainfall ~ 450 $mm.yr^{-1}$. The area is classified as arid. • Heavy rainfalls and drought are frequent. • Mean min temperatures > 4.4 °C but frost occurs. • Wind > 2.7 $m.s^{-1}$ during summer.	A highly seasonal climate with relatively short rainfall season, which is a reason why this area is a savannah biome. Droughts occur relatively frequently and constrain dryland crop production. Most rainfall is based on convective systems, with intense rainfalls. The rainfall concentration index is above 60%. A long dry season (savanna grassland). Experiences a relatively high evaporative demand and high wind speeds are possible, especially in late spring (November) and summer when temperatures are highest. Frosts are possible on low-lying ground during winter.
2nd	• Runoff is ephemeral in the smaller tributaries and prone to flash flooding during intense storms. • Water erosion is prevalent; some wind erosion has been reported.	Water storage for human habitation is required for sustainable water supply. There are few, if any, run-of-river extractions. Boreholes are also required to service human settlements. Erosion control methods are used, but their application has been sparse and therefore not effective. High sediment loads are observed in the streams as a result of erosive overland flows. Deposited metals in the Olifants River sediments are re-suspended during floods and transported downstream where they are newly deposited or are taken up into the biota. Very significant impacts of acidic water and metal ecotoxicology are being experienced in the main stem of the river.
3rd	• Rangeland productivity is limited by the short growing cycle and increasingly poor soils.	High populations and failing productivity push people into other livelihood patterns. Low and variable rangeland productivity based on grassland and biomass production dependent on seasonal rainfall , which is variable and semi-arid. Crops mostly restricted to maize on a larger scale, with small market and subsistence gardens elsewhere, not irrigated.
4th	• Food production has become severely limited • Increases in poverty as the population grows without increases in productivity. • Human health challenges as a result of poverty, poor infrastructure and declining productivity, • Degrading ecosystem and biodiversity resources as through overuse.	High food insecurity. Lack of production based on other cultural factors and environmental conditions other than climate (eroding, over-used soils which have lost A-horizon and litter layer). Biodiversity and natural resources highly degraded in the highly populated areas, but relatively intact in the Sekhukune mountain land. Poverty is widespread and extreme. The region is dependent on government grants and unlikely to turn around in the short term. Human health is in crisis, with very high levels of HIV, Aids and tuberculosis. Recognized by the TB hospital at Jane Furse, which has a good reputation. The poverty, difficult livelihood conditions and high population density lead to high levels of interpersonal violence.

First to Fourth Order Impact Assessment: Future Scenario 1

- Ten percent drying (especially summer), warming 2°C with moderate increases in maxima.
- Best practice land and water management and governance of natural resources; development of diversified livelihoods.

Order	Future features and threats	Future impacts
1st	• Decrease in rainfall extremes. • Increase in severe droughts.	Frequency of drought increases. Discernible drying in DJF quarter, especially Feb. Fewer rain days. Later beginning and earlier end to rain season. Fewer convection storms in the rainfall season. Fewer convection cells and fewer storms in the South West Indian Ocean region bringing torrential rains. Higher temperatures, fewer cool nights.
2nd	• Decrease in flood events. • Runoff declines generally in rivers . • Higher temperatures increase evapotranspiration	Water resource availability becomes increasingly difficult in the region More heat waves, with temperature spikes and duration driven by poor surface cover and degraded nature of land (feedback from 3rd order). .
3rd	• Decrease in rangeland productivity. • Decrease in cropping cycles (i.e. shorten). • Decrease in crop types. • Decrease in cropping pattern.	Rainfall has a strong influence on rangeland productivity, less rainfall means poorer productivity. Soil temperatures increase, making it harder for establishment of sprouting – more frequent loss of crop plantings. Growing season shortens. Fewer crop types practically possible in the warming climate. Feedback from 4th order, poverty and subsistence nature of livelihoods has negative effects on rangeland productivity and environmental conditions. Water quality declines even further and acidity and toxicity of water in the Olifants increases without interventions.
4th	• Decrease in food production. • Increase in poverty. • Decrease in human health. • Decrease in biodiversity and natural resources.	Poverty increases with declining farm productivity and increasing food insecurity. Increased disease burden and levels of inter-personal violence. Higher temperatures in the tropics or sub-tropics invariably means poorer health outcomes due to increased pathways and vectors for disease, poorer nutrition, worse water quality. It is generally accepted that higher temperatures and a dryer atmosphere has a negative influence on biodiversity intactness. Supporting ecosystems decline, but the Sekhukune mountain land biodiversity hotspot (in the positive sense) remains relatively intact and is a useful attractant for ecotourism.

First to Fourth Order Impact Assessment: Future Scenario 2

- Thirty percent drying (annual rainfall), warming 3°C with more extreme increases in maxima.
- Continued degradation of land and water resources; weak governance; no alternatives to unviable livelihoods are currently being considered at local or national government levels because of a lack of resources and the size of the problem.
-

Order	Future features and threats	Future impacts
1st	• Significant decrease in rainfall extremes. • Increase in severe droughts.	Frequency of drought increases substantially. Strong drying in DJF quarter, especially Feb. Fewer rain days. Later beginning and earlier end to rain season. Fewer convection storms in the rainfall season. Higher temperatures, fewer cool nights.
2nd	• Decrease in floods frequency and all rainfall days. • Increase in severe droughts.	Fewer convection cells on the Highveld of South Africa and fewer storms in the South West Indian Ocean region bringing torrential rains reduce flood frequency, leading to changes in dam and reservoir operation rules. More heat waves, with temperature spikes and duration driven by poor surface cover and reinforcing the degraded nature of land (feedback from 3rd order). Water resource availability becomes increasingly difficult in the region.
3rd	• Decrease in rangeland productivity. • Decrease in cropping cycles (i.e. shorten). • Decrease in crop types that are tolerant for the new environmental conditions. • Decrease in cropping pattern.	Higher rainfall and less rainfall has a strong negative influence on rangeland productivity. Temperatures increase, making the early stages of plant and crop growth more difficult, especially on bare soil. Growing season shortens. Fewer crop types practically possible in the warming climate. Feedback from 4th order, poverty and subsistence nature of livelihoods has negative effects on rangeland productivity and environmental conditions through increasing utilization and degradation from overuse Water quality declines even further and acidity and toxicity of water in the Olifants increases without interventions, accelerated by the higher temperatures. Microsystins in the water (from blue-green algae in eutrophic waters affects potable qualities and is toxic to livestock.
4th	• Overall, decreases in food production increase from their current low levels. • Increases in poverty ensue. • Decrease in human health. • Decrease in biodiversity and natural resources.	The higher temperatures and less rainfall reduce crop productivity further . Poverty increases with declining farm productivity and increasing food insecurity. Increased disease burden and levels of inter-personal violence. Higher temperatures in the tropics or sub-tropics invariably mean poorer health outcomes due to increased pathways and vectors for disease, poorer nutrition, along with worsening water quality. It is generally accepted that higher temperatures and a dryer atmosphere has a negative influence on biodiversity intactness. Supporting ecosystems decline, but the Sekhukune mountain land

		biodiversity hotspot (in the positive sense) remains relatively intact and is a useful attractant for ecotourism.

Adaptation Approaches and Options

- Extensive changes are needed in the agricultural and pastoral systems. Re-establishment of organic matter in the soil is required, improved erosion controls are required, greater protection of the soil in-situ, more application of essential fertilizers and other methods of increasing productivity along with conservation of resources
- Most importantly, changes in governance is required in that the negative aspects of communal ownership, and the effects that has on investment and productivity, is negated.
- The whole region exhibits an opportunity for conservation agriculture on a very large scale.
- Clean rivers and a highly diverse aquatic biota are indicative of good quality fresh water, ready for irrigation.
- Expansion of irrigation opportunities.

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4.5.8 Hotspot 8: Lower Limpopo–Chokwe

<u>Flood plain agriculture: Living with extremes</u>

Key messages

- Frequent flooding driven by coastal tropical cyclones and sometimes by heavy rainfall upstream, has encouraged people to move away from the floodplain settlements, further south to higher ground.
- The projected climate trends are uncertain, with some projections indicating less rainfall and fewer tropical cyclones, while others project the opposite. Flooding is likely to remain an important climate stressor. The frequency of drought is expected to increase. Both irrigated and non-irrigated flood plain agriculture will become more challenging.
- Coastal livelihoods, including the high dependence on tourism, are already severely impacted by tropical cyclones and coastal storm action. Potentially more frequent and/or more intense cyclones, combined with coastal erosion brought about by sea level rise, place future coastal tourism at high risk.
- Flooding and rising temperatures, combined with poor infrastructure such as drainage, bridges, waste removal and poorly constructed houses, increase the risks of cholera, malaria and diarrhea. The health impacts of climate change have wider implications for economic growth.
- There are some important caveats and uncertainties in the climate modeling for this hotspot and a nuanced view of what these are and how to deal with the meaning of this uncertainty is called for.

Background

The lower Limpopo region, from the Chokwe through the Guija district down to the coast of Mozambique at Xai-Xai, is dominated by the Limpopo River flood plain and is a region of low-lying loamy and sandy soils with a meandering river channel. The flood plain is used intensively for agriculture, from just above Chokwe, where sufficient drainage of soils can be obtained, all the way down to Xai- Xai, over a total distance of about 110 km. Chokwe itself is the site a major irrigation scheme, which is partly functional. Downstream, towards Xai-Xai, the soils are more waterlogged and the flood plain tends to a large wetland, with a meandering main channel defining the river.

The main livelihoods are crop and livestock production, casual labor and self-employment (manufacturing or harvesting ecosystem goods for sale). 60% of people are poor or very poor (according to the Household Economy Classification system). The major determinant of wealth is the ownership of livestock, which are cattle, pigs, goats and poultry. The poor and very poor own an insignificant proportion of the livestock. The next determinant is the quantity of produce from irrigation agriculture, which includes maize, beans, cowpeas, groundnuts and pumpkins as annuals and cashews, banana, mango, citrus and guavas, amongst others, as perennials. Many people also own land in the *alto* area, which is the higher ground away from the floodplain, and farm cassava and sweet potatoes. All members of families are involved in some aspect of production. Yields are substantially affected by diseases and pests, both crops and livestock (which may also be attacked by predators, particularly crocodiles). Two crop seasons are possible annually.

The system of vulnerability is determined by the human occupancy of this floodplain and the urban centers of high population density on the banks of the floodplain, from Chokwe down to Chibuto at the confluence of the Changane tributary, and with many small settlements on marginally higher ground, down to Xai-Xai. Some smaller settlements occur right within the defined flood plain and along the infrequent roads. Settlements on the southern bank appear to be wealthier than those on the north bank.

Major floods are caused by tropical cyclones making landfall from the Mozambique Channel, or warm closed low pressure systems at the edge of the Inter-tropic Convergence Zone (ITCZ) causing intense rainfall in the mid and even upper Limpopo and Changane catchments, generating large floods that cause water levels to rise markedly. The flood waves move relatively slowly, about 25 $km.day^{-1}$, so that it takes three or four days for a flood wave to reach Xai-Xai from Chokwe. The flooded width expands to 20 km and more, inundating towns such as Chokwe to roof level, covering a total area of 1,500–2,000 km^2. People are drowned, hundreds of thousands are displaced, crops inundated, and infrastructure and livestock is destroyed. Outbreaks of water-borne disease such as cholera immediately follow and hundreds of cases result.

Some people are moving out permanently, to Xai-Xai and beyond, which is indicated by the differential rates of population growth in these centers. The population of Chokwe is increasing at about 0.6% a year, while that of Xai-Xai is more than double at $1.5\%.yr^{-1}$ and Bilene-Macia to the south-west is about $2.7\%.yr^{-1}$. There is a general movement of people towards the coast. This movement and concentration of people has its own negative effects, such as the increasing deforestation around these zones of increasing population density.

Uniquely, the area undergoes significant periods of drought, and inhabitants therefore suffer the worst of both worlds: flooding and drought. Making a livelihood in this region is particularly difficult. Despite the rich soils of the flood plain, people are generally poor, and those who have few resources are left in desperate states when inclement weather goes against them.

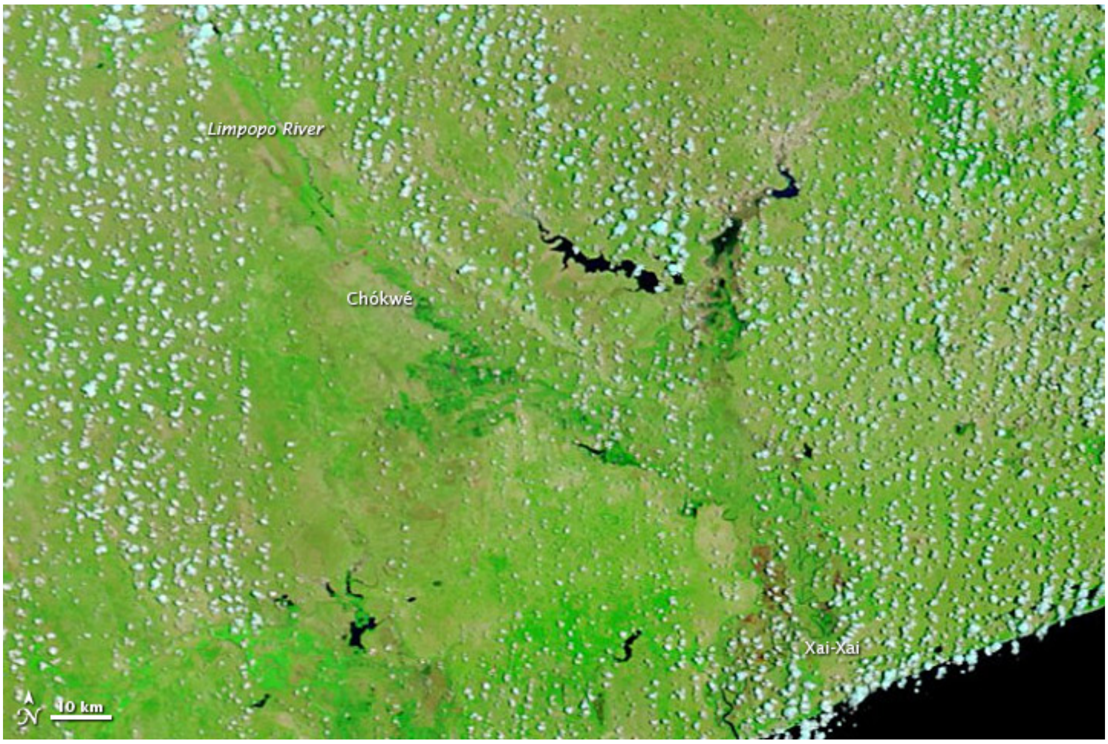

Figure 26 The lower Limpopo River Basin on 9 January 2013 (Image aquired by NASA Earth Observatory), normal summer condition (Source:Nasa, 2013).

Figure 27 A flooding lower Limpopo River Basin on 25 January 2013 (Image aquired by NASA Earth Observatory), a result of torrential rains deposited by a warm-cored low-pressure system from 15-17 January over the mid Limpopo River Basin. The blue colors represent open water surface (Source:Nasa, 2013).

First to Fourth Order Impact Assessment: Current

Order	Current features and threats	Current impacts
1st	• Rainfall extremes as a result of tropical cyclones and intense convection cells. • High variability of rainfall; driving severe droughts in Gaza Province.	Annual rainfall ranges from 600 mm (interior) to 1000 mm (coast) per year; Rainfall in Chokwé averages 623 mm per year; semi-arid to sub-humid climate; Summer rainfall in the interior with rainfall over the coastal region possible throughout the year; Heavy rainfall accompanies tropical storms (cyclones) making landfall from the southern Indian Ocean; Hot summers; occasional droughts in the interior, linked to sea surface temperature cycles; stochastic severe floods; coastal storm surges
2nd	• Severe flooding of the lower Limpopo Flood plain are a common feature that result from intense storms. • Severe droughts in the region.	The Limpopo River usually flows perennially in its lower reaches, but with highly variable seasonal flow; episodic strong flows and floods of various magnitudes (some extremely severe) occur after heavy rainfall in the upper/middle basin or after intense rainfall accompanying tropical cyclones; Large-scale abstractions occur for irrigated agriculture - Chokwé Irrigation Scheme and smaller schemes around Xai-Xai; High dependence on groundwater (boreholes) away from the river; Moderately high rate of evapotranspiration; generally good soils but high risk of salinization under irrigation; The estuary is a very large wetland area with a meandering river channel.
3rd	• Rangeland productivity. • Cropping cycles. • Crop types. • Cropping pattern.	River floodplain vegetation, grassland and savanna; highly transformed in many areas; mix of commercial irrigated agriculture (sugar, maize, sub-tropical fruit and nuts; vegetables) and small-scale flood recession/irrigated or rainfed crop production; Livestock also important – cattle, pigs, goats, poultry; Fertile land but access becomes more difficult in highly populated areas closer to the coast; Considerable loss of arable land due to salinization; high levels of crop/ livestock and human (e.g. malaria) diseases constrain productivity; Crops, livestock and land destroyed by large floods; water-borne diseases (e.g. cholera) proliferate following floods; Significant deforestation caused by high demand for firewood.

Order	Current features and threats	Current impacts
4th	• Food production declines, during both floods (from inundation and destruction), as well as drought • Poverty increases, especially for those not able to secure • Human health. • Biodiversity and natural resources.	Agriculture-based economy around Chokwé, transitioning to higher dependence on services, trade and tourism towards the built-up areas on the coast; Very high population densities in some areas; few formal employment opportunities and high levels of poverty and food insecurity; Floods and cyclones damage and destroy agricultural and other infrastructure e.g. tourism; inability to recover from multiple or sequential shocks; Lack of human and financial resources, health issues, and frequent climate-related shocks constrain economic and social development; Considerable cross-border migration into South Africa.

First to Fourth Order Impact Assessment: Future Scenario 1

- Ten percent wetting (especially late summer), warming 1°C with moderate increases in maxima, moderate sea level rise, no change in cyclone dynamics.
- Agricultural development based on good resource management; growth in tourism; success in controlling malaria/HIV/cholera.

Order	Future features and threats	Future impacts
1st	• Decrease in rainfall extremes. • Increase in severe droughts.	Possible transition to sub-humid climate; 10% increase in annual rainfall (mainly summer); Possibly fewer tropical cyclones making landfall, but likely more intense and capable of causing significant damage from floods; Stronger coastal storm surges accompany stronger onshore winds; Droughts likely more frequent especially in the inland area; Sea level rise projected within the global range of probabilities; Moderate warming by 1°C; moderate increases in heat extremes; warmer nights.
2nd	• Decrease in severe flooding of the lower Limpopo flood plain. • Increase in severe droughts in the region.	Increased stochastic flows of water in the Lower Limpopo River with significant risks of severe flooding; Wetland areas around the lower reaches and estuary have seasonally higher water levels and waterlogging spills over into adjacent agricultural lands; Increased rate of evapotranspiration; greater fluctuations in soil moisture; groundwater levels maintained or increased but more variable; Risk of water quality reductions due to warming and more standing water which stimulates bacterial/algal growth; Sufficiency of river water resources for irrigation depends on climate conditions in basin; low level of saline intrusion of rivers/aquifers and salinization of soils; Coastal erosion.
3rd	• Decrease in rangeland productivity. • Decline in cropping cycles (i.e. shorten). • Decrease in crop types. • Decline in cropping pattern	Productivity of commercial irrigated and small-scale agriculture not significantly impacted except at times of flooding and drought; Increased risk of land degradation under more variable climatic conditions and continuing deforestation; Land lost to coastal erosion and salinization; Increased risks of crop/livestock and human diseases; Impacts of large floods remain significant; Non-climate-related constraints on agriculture (e.g. lack of land or credit) remain and override small potential gains from higher rainfall.
4th	• Decrease in food production. • Increase in poverty. • Decline in in human	Agricultural economy shows potential growth given the right policy and financial support but remains highly exposed to droughts and floods; Coastal economy exposed to increasing climate risks;

Order	Future features and threats	Future impacts
	health. • Decline in biodiversity and natural resources	Poverty and food insecurity remain problematic; Greater resources required to prevent and deal with flood and cyclone damage to agriculture and infrastructure; this reduces potential public investment in improved infrastructure (including transport, bulk water, health), settlement planning and building codes, human development and support to the vulnerable, disaster risk management and secondary/tertiary economic development; Continuing cross-border migration into South Africa.

First to Fourth Order Impact Assessment: Future Scenario 2

- Twenty percent drying (especially late summer), warming 1.5°C with more extreme increases in maxima; significant sea level rise; either less frequent or more intense cyclones.
- Poor resource management of productive agricultural land; decline in tourism; losing battle against malaria/HIV/cholera.

Order	Future features and threats	Future impacts
1st	• Decrease in rainfall extremes and frequency of extreme events. • Severe increase in severe droughts and length of dry periods. • Acceleration of sea-level rise to the top-end of the global projections - ~ 1m.	Interior remains semi-arid but sub-humid areas transition to semi-arid; 10% decrease in annual rainfall; small reduction in mean number of rain days; Changes in frequency and intensity of tropical cyclones making landfall are magnified; increased coastal storm surges magnified by continuing sea level rise; Changes in frequency and intensity of droughts are magnified; Warming by 1.5°C; increases in heat extremes; warmer nights.
2nd	• Decrease in severe flooding of the lower Limpopo flood plain. • Increase in severe droughts in the region. • Ocean storms leads to high-energy impacts on the coastline	Changes in cyclonic activity and basin-wide flow changes determine stochastic flows of water in the Lower Limpopo River; Risks of severe flooding likely remain; risk of periods of very low flow and occasional drying of Limpopo River; these dynamics determine the sufficiency of river water resources for irrigation; increased variability of water levels of wetland areas; Further increases in rate of evapotranspiration; large fluctuations in soil moisture; groundwater levels reduced and more variable and some boreholes/wells may run dry more often; Risk of water quality reductions due to warming and lower flows; Impacts of droughts magnified by aridification; sea level rise leads to saline intrusion of rivers and aquifers and salinization of soils.
3rd	• Decrease in rangeland productivity. • Decline in cropping cycles (i.e. shorten). • Decrease in crop types. • Decline in cropping pattern	Agricultural production highly variable and exposed to droughts, low river flows and floods; high risk of land degradation under these climatic conditions; grazing and rainfed cropping potential are significantly reduced and yields highly variable; Large tracts of land lost to coastal erosion and salinization; Severe risks of crop/livestock and human diseases; Impacts of large floods remain significant; Demand for firewood outstrips supply and woodlands are

		denuded; Previous wetlands become available for productive purposes although still at risk of seasonal flooding; Non-climate-related constraints on agriculture (e.g. lack of land or credit) remain and magnify the climate stress.
4th	• Decrease in food production through lower yields brought on by drought. • Increase in poverty as a result of declining agricultural yields. • Decline in in human health as vector-borne diseases increase. • Decline in biodiversity and natural resources	Agricultural economy significantly weakened; increased used of flood-prone land; Coastal economy including tourism at severe risk of cyclones due to coastal erosion and other impacts; coastal aquifers and rivers may become too saline for human use; Increased poverty and food insecurity; Greater resources required to prevent and deal with flood and cyclone damage to agriculture and infrastructure; this reduces potential public investment in improved infrastructure, settlement planning, human development and support to the vulnerable, disaster risk management and secondary/tertiary economic development; High rates of cross-border migration into South Africa and internal migration within Mozambique.

Adaptation Approaches and Options

- Improved irrigation systems, better maintenance, with a strong focus on post-harvest technology and transport systems for moving product quickly is required.
- Early warnings of rising flood waters need to be effective.
- Greater role for women in managing disasters and diversifying livelihood opportunities is required (and is recognized).
- Caveats in climate science include that of understanding the ocean climate. The nature of the ocean climate in the South West Indian Ocean region is not settled, and may become comparatively warmer or cooler. The direction it takes will have a significant effect on the trend of climate over the LRB because sea surface temperatures (SSTs) affect the quantity of moisture in circulation over the LRB interior.
- Greater cognizance is required of how ENSO features in the climate variability of the region, and how ENSO and IOD oscillations will evolve in future climates, which is an area in which current ocean-atmosphere coupled GCMs need to increase skill. The key question is what is the likely trend of the frequency of cyclones and other warm-cored low-pressure systems over the LRB in the future?

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5. Discussion and next steps

There are some conclusions that may be drawn at this stage of the political economy analysis and these inform how we consider the basin's ability and capacity to strengthen resilience and open water flows.

There are many reasons to be optimistic about the future of integrated water management in the LRB. Over the past two decades, progress toward regionally integrated water management in the LRB has gained momentum. National systems of water management have achieved a relatively high level of harmonization. Policies and structures are in place to effectively decentralize and democratize water management. There is a general atmosphere of support and enthusiasm for the embryonic regional institutions, SADC/WD and LIMCOM. Primarily because the region, in the aftermath of civil and cross border wars and conflict, prioritizes peace building and strong neighborly relations, the region has not experienced major cross-border conflicts surrounding water usage in the past 20 years, thereby avoiding tension and bitterness that so often leads to inaction over issues of regional importance.

There are, however, important political and economic dynamics at work in the region that must be acknowledged for meaningful progress to be made. This analysis draws the following conclusions about the current reality of regional water management in the Limpopo.

Historical relationships matter. The apartheid-era dynamic between the four riparians has direct consequences for levels of trust and collaboration in the LRB. Economic dependence on South Africa prevented Botswana from overtly supporting the South African liberation movement. This led to closer cross-border collaboration with South Africa on water management issues beginning in the 1980s. The two countries developed a working relationship that produced the following outputs: (1) the JULBS study created a foundation for uncontested, cohesive data sharing between the two countries to aid in joint decision-making; (2) the JPTC established a precedent for project collaboration and dispute settlement through bilateral channels of communication; and (3) an understanding of the mutual interests that lie in the development of the water and coal resources along the South Africa–Botswana border, the exploitation of which will require joint efforts by both countries. Zimbabwe and Mozambique, on the other hand, supported the South African liberation movement. As a result, they were not a part to the agreement on knowledge or skills sharing and transfer that stemmed from a collaborative relationship, nor were they able to build a foundation of mutual understanding of each nation's interests in the basin. Even though this agreement was entered into during the political isolation of South Africa, it attests to the fact that long standing institutions can result in effective collaboration for shared water resources. There is still a disparity between the water management capabilities in the upstream riparians, South Africa and Botswana, and the downstream riparians, Mozambique and Zimbabwe, evident in existing patterns of communication, information sharing, dispute settlement and underlying level of trust.

Control of information is a reflection of the balance of power. Choices surrounding water management—allocation of water to certain activities, environmental protection measures, approval of resource development projects—involve inputs of information into the decision-making process. How the information is acquired and who determines whether it is accurate has great implications in determining the outcome of the process. Currently, information gathering is controlled and implemented by stakeholders that have both the financial and technical capacity. These stakeholders consist largely of South African and foreign (e.g. German, Swedish, Chinese) state agencies, research institutions, and private companies, limited to specific topics of interest and backed by specific motives. The use of these inputs for basin-wide decision-making will continue to produce outputs that further the interests of South Africa and foreign investors, maintaining the asymmetrical power dynamic in the LRB and deepening an underlying distrust in regional collaborative processes. A basin wide information platform, which would result in skills and technology transfer to riparian countries, is urgently needed if planning and development in the basin is to reflect the respective interests of the member states and a shared approach to the basin's management.

Capacity building is not a panacea. The most glaring conclusion to be drawn from the current state of institutional structures in the basin is the pervasive lack of financial, technical, and personnel capacity. The paucity of funding and skill is at the core of every major issue hindering the success of integrated water management in the basin. However, that is not to say that building capacity and accessing funding will produce a system that functions and functions well. A regional water management system with institutional sophistication, adequate funding, and a staff of highly skilled professionals cannot compensate for a lack of trust between participating states and a continued focus on national development needs ahead of basin wide water allocation and use. There is a critical need to address the fundamental issue of trust within the LRB, an issue that is the product of historical relationships, current power asymmetries, conflicting national interests, and concerns of national sovereignty. Addressing the lack of trust necessarily involves the difficult and complex task of building trust. Building trust requires a commitment to honest communication, collaboration that benefits all and not some, multilateral decision-making, and, most significantly, time to establish a pattern of consistency, cooperation and goodwill between members.

National conflicts have transboundary implications. Most disputes surrounding water allocation in the LRB have remained within national boundaries. Conflicts erupt at a point of intersection between the interests of national development, energy security, environmental conservation, local job creation, international norms, private profit, and water security. However, national conflicts require national solutions. As long as these disputes manage to remain within national boundaries, there is less pressure placed on developing basin-wide conflict resolution mechanisms. Yet it is impossible for the repercussions of national conflicts regarding international river basins to be contained within borders. A dispute in Botswana over expansion of a mine in Selebi-Phikwe will impact the waters that that feed the irrigation schemes of farmers in Chokwe, Mozambique. The transboundary effects of decisions made in locales of intersecting interests need to be recognized within, not just the national water department, but across all departments involved in matters of national development. This position toward issues of water security must be adopted *now* before problems that were once localized within national boundaries become full-blown cross-border issues of competing national development ambitions.

The absence of hostility gives regional institutions like the SADC Water Division (SADC/WD) and Limpopo Watercourse Commission (LIMCOM) an opportunity to build a foundation for equitable and responsible transboundary water management before tensions rise. In order to prevent national development ambitions from outpacing environmental and water use regulations along the path to rapid economic growth, trust and participation in transboundary governance structures must be strengthened. This report hopes to provide an accurate depiction of the political-economic realities of the region so that transboundary water management institutions can make future decisions rooted in a realistic perception of how decisions are made and actions are executed on the ground, not in some normative ideal.

Multilateral cooperation on water resources is typically weak and upstream-downstream conflicts are a latent risk. This is because communities are mostly excluded from decisions in the political economies of water in both basins**,** which are characterized by decoupled national and basin-wide sustainability frameworks on the one hand**,** and national economic growth strategies on the other. This will be further examined in the participatory analysis phase of this work.

Civil society and communities affected by investments in natural resources continue to exert low, if any influence, probably because they persistently question transparency and accountability as well as environmental and social impacts and are therefore seen as obstructive to development. Some international NGOs such as the WWF and the IUCN[1] have mainly been instrumental in knowledge production information sharing, lobbying and capacity building in some riparian countries and may be labeled 'knowledge NGOs'. Other NGOs focus primarily on environmental and social justice campaigns and may be labeled 'advocacy NGOs'[2]. As a knowledge based NGO, the WWF has contributed significantly to the scientific knowledge base in some countries in the LRB.

These early conclusions have a bearing on the various assessments being conducted in the basin under RESILIM and in particular will inform the process for the development of adaptation strategies of scale and ultimately the LIMCOM climate change response strategy.

[1] The IUCN is strictly speaking not an NGO but an international umbrella union of 900+ NGOs and 200+ government organizations world-wide.

[2] The distinction between 'knowledge based' and 'advocacy based' NGOs is for clarity only. Both NGO categories have elements of both knowledge production and advocacy. But for the knowledge based NGOs the priority is for knowledge production of scientific value, knowledge sharing and capacity building. The advocacy based NGOs have as their main objective to advocate for social and environmental justice and are therefore critical of all major infrastructure developments that cause disruption to human livelihoods and ecosystems. At the same time, some advocacy NGOs also develop or help in developing new knowledge on the social and environmental impacts of development. Such knowledge is typically used to support campaigns against unwanted infrastructure developments where hydropower dams are prominent targets. Knowledge based NGOs often have a more pragmatic approach that accepts some comprises between economic development and the preservation of the environment and livelihoods.

Effective institutional arrangements and responding to the limitations and possibilities that exist within the balance of power status quo in the LRB are critical success factors in the implementation of any strategy that intends to result in improved resilience and in the opening of basin water flows. The validation and enhancement of these conclusions is therefore an essential component of the next steps in this work, as is the development of the social economy analysis, and how this intersects—or does not intersect—with the political economy analysis in evaluating basin risk and vulnerability and impact assessments. Specifically, problems in the basin's decision-making processes, a lack of intersection between the political and social economies of the basin and/or a lack of useful information are all examples of factors that can shift a hotspot to tipping point status, placing a sub system or location close to or at a critical threshold, or placed beyond return.

Conclusions may also be drawn from the climate risk and vulnerability hotspot assessment. They illustrate that impacts and responses occur at multiple nested scales, and that the strengthening of resilience at basin level can only succeed if unique and complex local systems are receptive to adaptation and the benefits of local adaptation are able to multiply across larger scales.

Efforts at adaptation in Africa have until recently been fragmented, with numerous actors engaging with communities and introducing interventions aimed at building local resilience. Whilst these efforts have produced a large body of evidence of great value, they have seldom been conducted with larger scales in mind, for example the linkages between specific communities and upstream or downstream regions within a sub-basin or river basin which influence both impact and response options. This difficulty in scaling up is attributable to a number of factors, which will be discussed here in the context of the above study for the Limpopo River Basin.

Every "place" is defined by a unique set of features and dynamics. The basis for climate vulnerability can be wide-ranging, resting on either severe exposure to climate stress, severe sensitivity of natural and human systems to such exposure, or a severe lack of adaptive capacity to deal with the impacts. The hotspots assessed in this study were identified because they all show a combination of at least two of these categories, and a number show a combination of all three. However, the details differ in every case – each area has a unique set of features and dynamics driven by biophysical differences, social and cultural differences, different economic systems, diverging histories, and contrasting governance systems. It is almost impossible to identify multiple "places" with the same features and impose a uniform adaptation strategy on them. One size does not fit all.

The ability to adapt is influenced by the basin-level political economy (as discussed earlier in this section). As is the case at country or basin level, political economy is key to what happens, why, and by whom at local levels. The social economy is also important and as outlined in the introduction to this report, the social economy, and more importantly, the gap between this and the political economy will be further analyzed during the participatory analysis phase. Every "place" (in our case 'hotspot') has a unique history and this combined with cultural diversity and varying socio-economic as well as biophysical conditions means that adaptive capacity is likely to vary between the hotspots, contributing to the likelihood of reaching a 'tipping point' or critical threshold in each.

Drivers of change, including climate, interact in unique ways in different places. The most obvious example of this is the various trajectories that land use change can take. In some cases (particularly in densely populated agricultural areas), land is severely overused and degraded and in a downward spiral of loss of productive potential. In other cases, land use is transitioning from low impact agriculture to conservation and associated lucrative ecotourism. The development of mines in other areas represents a very different driver of change. Superimposed on land use change are other drivers such as demographic changes and migration, political and governance changes, cultural transitions, and urbanization. The complex outcomes of these changes in turn interact with climate change and climate extremes to produce local impacts. Clearly, adaptation requires a keen understanding of this by the locals themselves, and the entities tasked with planning and financing adaptation.

On the other hand, the hotspot assessment also identifies themes, which show how local activities and changes can have impacts across all spatial scales. While the details of what happens at the smallest scale (e.g. a mountain, a cluster of villages, the site of a mine, a national park) differ, they illustrate how impacts multiply upwards. Local climate trends affect not only that "place" but change the situation and ability to adapt for places much farther away, downstream, in some cases all the way to the river mouth.

What happens to local "water towers" has impacts across all scales. "Water towers" are areas (often mountains) with high rates of runoff, which feed the streams, and rivers that eventually form the large regional rivers. They contribute the highest percentages of water to the basin. The LRB has a number of such areas, some of which are described in the hotspot assessment (Upper Mzingwani in Zimbabwe, Soutpansberg in South Africa, and Lebowa in South Africa). These catchments provide critical ecosystem services in the form of runoff and often harbor particularly high levels of biodiversity. Their forests are valuable natural resources. Current threats include high population densities in close proximity with resultant degradation (e.g. soil erosion, siltation, pollution, fire), which compromise the ability of the catchment to deliver high rates of clean water. Some are threatened by alien invasive trees, which reduce runoff by up to 30% (e.g. Soutpansberg). Possible additional stresses from climate change will have significant ramifications for local communities and those further downstream, and will be felt all the way to the mouth of the Limpopo in the form of reduced water flows.

High levels of local pollution have impacts across all scales. Pollution of stream, rivers and groundwater are serious problems in many parts of the LRB. They occur as a result of urbanization and the discharge of domestic and industrial effluent, the processing of water by mines, acid mine drainage (AMD), leaching of agricultural chemicals into groundwater and return flows, dumping of hazardous waste, and spillages of raw sewerage. The Crocodile sub-basin (Pretoria North, urban/industry), the Mzingwani sub-basin (artisanal mining) and the Olifants sub-basin (Lebowa, AMD and agriculture) show some of the highest levels of water pollution in the LRB. Any climate change-related changes in seasonal flows, and particularly periods of low flows and droughts, will increase the negative impacts of pollution as concentrations rise. These impacts cascade all the way downstream. The water entering the Limpopo in Mozambique from the Olifants River is already of such poor quality that planned irrigation schemes in Mozambique could be threatened. This could severely compromise Mozambique's ability to adapt to climate change.

Species migrations and adaptation across larger spatial scales, driven by climate change, are assisted by contiguous conservation areas and corridors. While protection of habitats and species diversity is currently encouraged on the basis of local socioeconomic benefits (e.g. ecotourism, hunting), the future benefits across the region are potentially even greater. Some of the best-protected areas in the LRB harbor species, which are highly adapted to very harsh climates including periodic droughts and excessive heat. This genetic wealth has the potential to migrate to other regions as the climates there become harsher, thus allowing ecosystems to adapt and provide resources for alternative livelihoods in those areas.

In conclusion, any attempt to develop resilience to climate change across the LRB must draw on a deeper local understanding of systems and dynamics, and how these do or do not telescope up to larger scales where they can achieve real transformative change.

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