Options for Adaptations at Scale in the Limpopo River Basin:

A conceptual assessment

15 November 2013

oneWORLD
We build resilient futures

USAID FROM THE AMERICAN PEOPLE | SOUTHERN AFRICA

Options for Adaptations at Scale in the Limpopo River Basin: A conceptual assessment

Type of report:	Technical Report
Project number:	RESILIM
Version:	V2
Authors:	RA Chapman

Submitted by:	Submitted to:
One World Group	RESILIM Management Team
Postal address: PO Box 1777 Cape Town 8001 South Africa **Physical address:** 2nd Floor 4 Church Square Spin Street Cape Town South Africa	**Physical address:** 231 Lange Street Nieuw Muckleneuk Pretoria 0181
Prepared by: OneWorld Sustainable Investments Tel:+ 27 (0)21 8182900 Fax: + 27 (0)21 8182932	**Prepared for:** RESILIM Management Team Tel: +27 12 346 1877

Executive summary

The RESILIM Program of USAID Southern Africa seeks to enhance the resilience of people and ecosystems in the Limpopo River Basin (LRB) by strengthening the capacity of the Limpopo Watercourse Commission (LIMCOM) and its key stakeholders to address issues of climate change adaptation and biodiversity conservation in the context of trans-boundary integrated water resources management (IWRM). Climate change can reduce the resilience of people living in the basin, particularly where natural resource dependencies for development are high.

The LRB is mostly semi-arid, with a highly variable climate, and is periodically exposed to severe droughts and floods. It has widely divergent land-use patterns, ecosystems, social, economic and governance systems. Its water resources are already over-subscribed, it is over-reliant on rainfed agriculture for food production, livelihoods are largely based on climate sensitive natural resources, has large poor rural populations, relatively undiversified economies in some parts, and insufficient public and private resources to deal with poverty and shocks. As a result, the LRB is highly vulnerable to climate-related risks.

In this conceptual assessment 'nexus thinking' was used to examine the different drivers operating in the Limpopo River basin (LRB) system and propose alternative pathways to increasing sustainability. The context, however, is that resolving the drivers of vulnerability requires interventions that are system-wide and not necessarily at the places where they converge, which are hotspots of vulnerability. The assessment focuses on the interrelatedness of water resources, biodiversity and climate change and includes livelihoods (related to land-use), governance and population growth in the interlinked system. System-wide adaptations need to focus on those issues that are not particularly affected by the scale at which they are implemented.

The mean annual runoff per unit area from the upland catchments is 100 times that of the low-lying areas of the LRB. Therefore, the protection of biodiversity and ecosystems, especially along the mountain ranges, results in the most optimal generation of high quality runoff from rainfall – this includes the removal of alien woody vegetation which is invading these well-watered upland catchments. The improvement of water quality in the headwaters of the Olifants and Crocodile catchments should increase water availability across the whole system. Reducing erosion and sediment transfer through improved land-use management and ecosystem conservation has positive benefits for the sustainability of dam and large reservoir storage. Ensuring a vegetated land surface reduces the risk of desertification and can result in cooler temperatures, mitigating climate change effects. Desertification results in local climate changes and this potential coupling of the land surface with the climate has negative effects (declining rainfall, or more intense rainfalls with longer duration dry periods).

Policy reforms being considered in the water sector of South Africa need to reconsider issues such as the proposed acceleration, at all costs, of the mining use of water. Because people in the LRB are vulnerable to extreme events, an improved system of forecasting and early warning, as well as disaster management responses, will reduced vulnerability across the basin. An improvement in governance systems and practices is the over-arching goal that must be achieved, particularly through transboundary cooperation.

Contents

Introduction

The Limpopo River Basin (LRB) sits astride the shared borders of Botswana, South Africa, Zimbabwe and Mozambique. It is home to more than 18 million people, is an important agricultural area, has extraordinary mineral resources and is exceptionally rich from a biodiversity point of view. It is also largely semi-arid, but with important exceptions. It is contains portions of South Africa's most important major urban and industrial centers – which includes the conurbations within the Gauteng Province. The LRB is also critically short of water and this scarcity resultantly restricts socio-economic growth and development. Current uses and the impacts of all the activities in the basin have an impact on biodiversity, as well as affecting ecosystem services. Extremes of climate are frequent. Intensive flooding approximately every ten years results in the displacement of hundreds of thousands of people in the lower reaches of the basin and frequent drought can affect millions of people.

The trajectory of the basin over time conveys a picture of increasing difficulty in the obtaining of enough water, increasing environmental degradation and climate change – whilst millions of people are trying to escape poverty.

In this document we broadly examine the confluences of the major driving forces, with the intention of developing a picture that creates the foundations for adaptation projects at scale. This means possible changes across large parts of the basin, based on concerted or focused actions. We take a whole system view, meaning that we look for the linkages between different actors within the system and emphasize the interrelationships operating in the LRB in such a way as to show how changes in one part of the system affect those elsewhere. Previous studies have generally presented compartmentalized views on aspects of the LRB; one of the major shortcomings of this silo approach is that consequences and system-wide effects have not been addressed.

Purpose and Context

The purpose of this document, then, is to put in place some markers of what adaptations at scale in the LRB could be and where they could begin. Previous studies have identified and described eight "hotspots", which are zones of increased vulnerability of the populations living there to climate and economic hazards, some of which may originate from the environment. The hotspots are not self-contained units of vulnerability. Firstly they represent particular types of vulnerability that are repeated elsewhere in the LRB. For example, the Sekhukune (Lebowa) hotspot represents a broad stretch of vulnerability that stretches from Sekhukhune (Hotspot 7) in the south northwards to Vehmbe (Venda), as well as the Capricorn Municipality to the north-west (also originally part of Lebowa) (See Figure 1).

Secondly, the drivers of vulnerability within a hotspot are not only internal - they are, in part, external. Climate effects are the obvious example, but so is the water resource, where the characteristics of duration, timing and quality of flows change from one place to another along the drainage network. Deficiencies caused in one place are projected onto another. Therefore, reducing the vulnerabilities in each hotspot involves, for many cases, minimizing the drivers of those vulnerabilities that are outside that particular hotspot. Investments that reduce the vulnerabilities within a hotspot may only address the symptoms of vulnerability and will be wasted if they do not address the ultimate source.

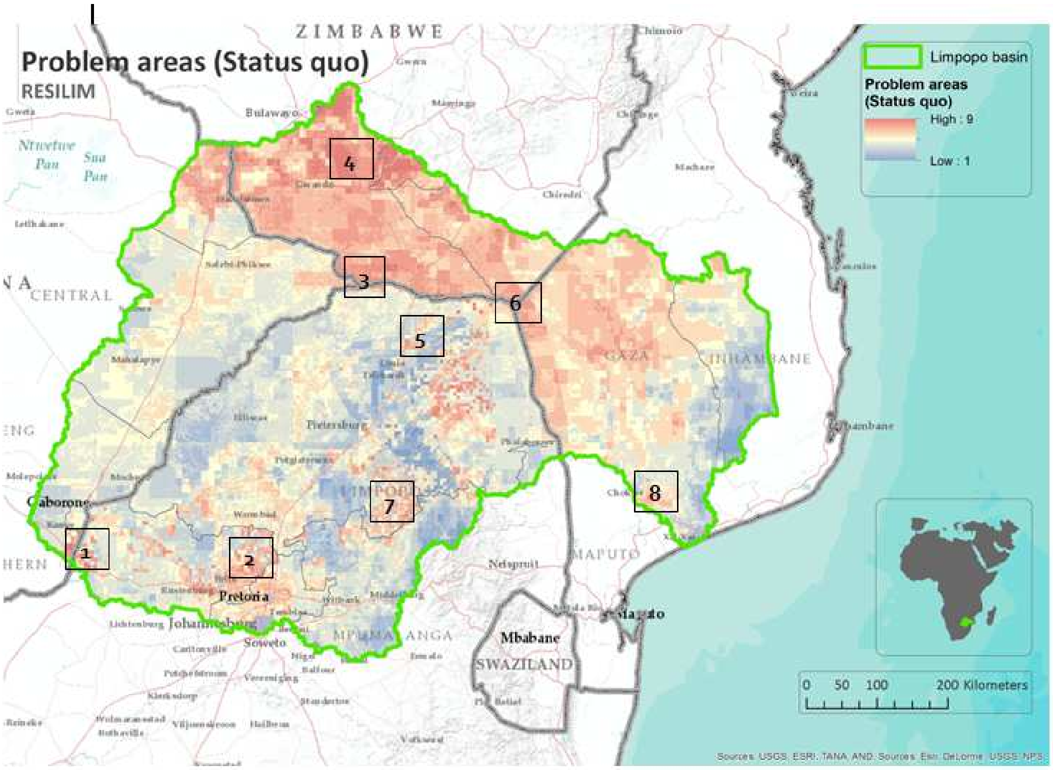

Figure 1. Hotspots in the Limpopo River Basin; 1-Upper Limpopo, 2-Pretoria North, 3-Shashe-Limpopo confluence, 4-Mzingwane, 5-Soutpansberg, 6-Pafuri, 7-Sekhukhune (Lebowa), 8-Chokwe-Lower Limpopo.

At this point it is necessary to discuss some ideas of systems thinking. The LRB, its ecosystems, human habitation and livelihoods and the economies within it are all interconnected in a large complex system. It is appropriate to apply systems thinking to the dynamics of the LRB. Systems thinking has as one of its tenets proximate and ultimate (distal) causation, which are chains of cause and effect. A proximate cause is the immediate or direct cause of an effect or result. The ultimate or distal cause is a cause much further up the chain of cause and effect. More than one distal cause can converge to create the proximate cause. We can use this concept as an interpretive lens on how to increase resilience of the LRB as a whole.

The central argument in this paper is that increasing the resilience of a hotspot by addressing the symptoms of proximate causes does not solve the problem. An example could be the flooding experienced in the Pretoria North hotspot (Midgley et al., 2013). The flood originates somewhere else in the subcatchment, it may be partly driven by altered land-use conditions elsewhere in the tributary sub-basin. Poor land-use practices in the Mzingwane catchment area are partly driven by macro-economic conditions elsewhere in Zimbabwe. The key vulnerability of people at Chokwe-Lower Limpopo is partly driven by large floods that are generated higher up in the LRB. The other aspect of vulnerability at Chokwe is the intense pressure on the land and the inhabitation within or on the banks of the flood plain, directly exposing people to the major hazard. The system drivers and pressures that lead to the need for such hazardous exposure to floods probably lies outside the immediate vicinity of each hotspot.

In summary, increasing the resilience of each hotspot and similar areas requires solutions and interventions into the LRB at a wider system level than the proximate causes at each hotspot. This paper provides one entry point for doing that.

Nexus Thinking

We used a nexus approach in sketching out the system. A formal definition of '*nexus*' is a means of connection between members of a group or 'things in series', or even the core or center of a situation. In the context of this study of the LRB, a nexus exists where the dimensions of water, ecosystems and livelihoods are tightly linked and interrelated, a change in one has significant impacts on the others, and vice versa. There are few or no buffers or excesses in this system of linkages in the LRB, so that small changes in an input pathway usually lead to clearly observable impacts on output pathways or products.

The quantum of each dimension as illustrated in Figure 1 drives the other dimensions and also limits them. Typically, demand from a dimension or system exceeds supply and the interlinked system is in deficit, or is already constrained by the limits placed on it by one of more of the other dimensions. In this thought piece, we interrogate the interactions between climate change and ecosystems, between water and ecosystems and between water and climate change. We then evaluate the influence of the external drivers (of this conceptual system) to the nexus dimensions. These external influences are those of population dynamics and growth (including the economic effects), livelihood needs and the effects of governance.

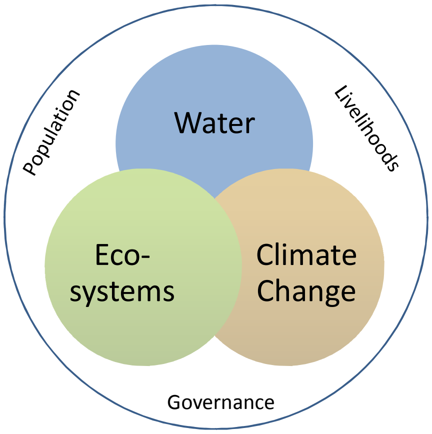

Figure 2. The nexus dimensions of ecosystems, water and climate change represented in the Limpopo River basin

Nexus Dimensions and Interactions

Water-Ecosystems Interactions

The LRB has been over-allocated for two decades (Basson *et al.*, 1997) i.e. water abstracted to supply irrigation demands, urban and industrial use, including mining, as well as that allocated to the ecological reserve, exceeds the budget. What this means practically is that the deficit is extracted from the ecological reserve, with negative consequences for ecological functioning and aquatic biodiversity. So much water has been abstracted for human use that the basin is now categorized as 'closed', meaning that there is no water left for allocation to further consumption.

All tributaries to the west and north of the Limpopo River main stem contribute relatively little water to the larger system (Figure 3). Most water in the system comes from the south, on the Highveld. These rivers either flow north-west, north or north-east and tend to have more stable flows than the other rivers. Those flowing out of Botswana and Zimbabwe tend to be ephemeral, while those flowing northwards have been highly altered by human abstraction. By 2000, the demand for water had already exceeded supply in the Limpopo River Basin.

Four inter-basin transfers (IBTs) bring water into the LRB: the Vaal-Olifants IBT; the Vaal-Crocodile IBT; the Komati-Olifants IBT and the Usuthu-Olifants IBT (Basson *et al.*, 1997). Water from as far as Lesotho is brought into the LRB via the Vaal-Crocodile transfer. In the south, the Olifants River receives very significant amounts of water from inter-basin transfers. 171 million m^3.a^{-1} of water is transferred into the Olifants system from the Vaal and 85 million m^3.a^{-1} from the Incomati water management area.

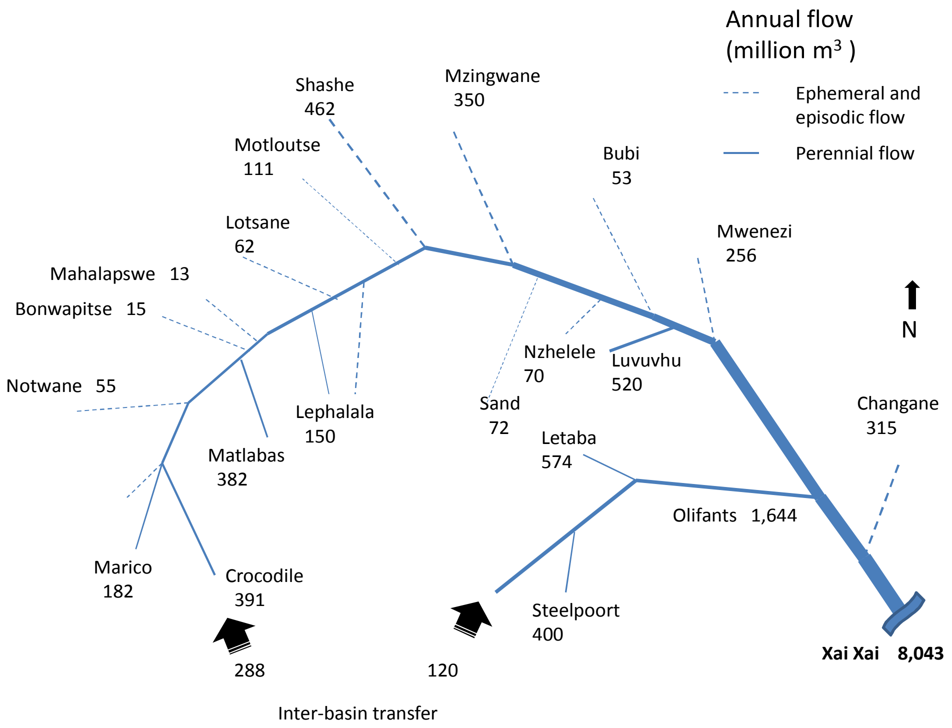

Figure 3. The Limpopo River system with contributions from tributaries and inter-basin transfers (Sources: All values from Boroto and Görgens, 1999 except the interbasin transfer values, which are from Aurecon, 2013)

Falkenmark (1989) calculates that people need on average 1000 m^3/a for drinking, hygiene and food production. On this basis, he developed a Water Crowding Index (WCI), which is the number of people existing on 1 million m^3 per year. An index WCI of 1000, meaning 1,000 people per 1 million m^3 per year, is the theoretical upper limit, beyond which (i.e. more than 1,000 people), it becomes more difficult to supply sufficient water for all of society's needs. All four river basins are already beyond the 1,000 WCI mark, particularly Limpopo, which is at 4,219 as of 2000 and will be at 4,974 by 2025, even given the low population growth scenario and significant water projects planned for the river basin to deliver 18% more water. This water poverty will constrain future development in the region (Ashton *et al.*, 2008). The water projects will, however, increase the tension with neighboring downstream states that also require secure flows (Nkhata, *et al.*, 2007)

The general trend is a decline in per capita quantity of water available to be supplied to meet the needs of society. Most suitable sites for storage dams have been used already and the construction of new ones will be increasingly expensive (Bohensky and Lynam, 2005). Per unit costs of water supplied in future will therefore rise.

Groundwater is an extremely important resource in the Limpopo River basin for all of the riparian countries. The quantity and dependence on groundwater is unknown, however (Aurecon, 2013). There are four major types of aquifer in the LRB – fractured, inter-granular, karst and low permeability. The first three of these have relatively low storage volumes. Sixty three percent of all aquifer areas across the LRB are of the low-permeability, low-yielding type. Moderate to high-yielding aquifers of fractured (19%), inter-granular (14%) and karst (4%) make up the rest. Karst aquifers can be very high-yielding and are very important to the hydrology of the whole basin because they serve as the source in the Upper Limpopo River basin region (Groot Marico River sub-basin). Important Transboundary aquifers include the Ramotswa dolomite basin (an extension of the Transvaal Supergroup dolomites into Botswana) and the Tuli Karoo Basin between Zimbabwe and Botswana. The groundwaters in the Ramotswa dolomite basin have been severely polluted by inappropriate strategies for dealing with the sanitation needs of the Ramotswa community (Tredoux and Talma, 2006). Nitrate pollution of these groundwaters required the shutdown of the well field. Nevertheless, the Transvaal Supergroup dolomites are an extremely important source of groundwater in the upper LRB.

In the lower parts of the LRB, in Mozambique, very substantial groundwater resources exist in places and are high yielding, but will require careful management.

Water Quality

Poor water quality in the LRB is one of a number of causes of the reduced availability of water for people and aquatic ecosystems. Effluents from industrial and urban uses in the Olifants headwaters around Gauteng and decant of acid mine drainage from defunct coal mines on the Mpumalanga Highveld results in severe contamination of waters further downstream. Return flows and runoff from agricultural areas contributes pesticides, herbicides and nutrients to the waters. These activities contribute to excessive loading of sulphates, ammonia, chlorides, pH extremes and unacceptable trophic conditions (related to nutrient loading), making the river waters of main tributaries such as the Crocodile, and especially the Olifants River, toxic to the healthy functioning of aquatic ecosystems.

Toxicological and pollution studies (Wepener, 1997, Dabrowski and de Klerk, 2013) record the presence of toxic metals within biota and sediments. Copper (Cu), chromium (Cr), iron (Fe), nickel (Ni), cadmium (Cd), lead (Pb), arsenic (As), aluminum (Al), vanadium (V) and zinc (Zn) have all been recorded in different phases of water and sediment in the Olifants River and its tributaries and have an impact on the biota of the Kruger National Park (Wepener, 1997, Dabrowski and de Klerk, 2013). The origin of some of these contaminants is the mining along the eastern rim of the Bushveld Igneous Complex as well as the Phalaborwa mine. Fish and crocodile kills are the result of pulses of excessively contaminated waters and storage dams in the upper and mid catchment of the Olifants River, such as at the Loskop and Flag Boshielo dams, down to that section of the river transiting the Kruger National Park (Ashton, 2010).

The critical issue to consider from a management point of view is that ambient metal concentrations rise during low water conditions (towards the end of winter and as a result of droughts), and spike during floods when there is increased exposure of suspended sediments to metals adsorption. Adverse effects have been experienced 300km away from the pollutant source, with the consequence that people and ecosystems are exposed to and challenged by poor water quality water over very large distances. In general, the abstraction of water for irrigation, industrial and urban use compromises water quality in the system by reducing flows and increasing the ambient concentrations of harmful substances. The addition of extra water through the IBTs at the headwaters of the Crocodile and Olifants rivers works to benefit the system, because without these inflows, the quality of waters in the rivers could be much worse.

In general, impacts on aquatic biodiversity occur throughout the LRB through water abstraction, flow, bed and channel modifications, inundation of riparian zones through barrier construction, the existence and invasion of exotic aquatic fauna and macrophytes, addition of pollutants, bank erosion and the removal of riparian indigenous buffer vegetation. Especially damaging to general water quality is the poor standard of waste water treatment plants.

Ecosystems for Water – The Importance of High Altitude Catchments

Biodiversity patterns have been generally relatively poorly studied in the LRB. However, the region is mostly covered by a savanna biome, which is a tree-grass interaction, controlled in part by the seasonal climate in which a long dry season and a shorter wet season affects vegetation-fire dynamics. Land degradation in the LRB is strongly associated with high population densities and bare ground (although not always) and these are primarily defined by the communal farming areas. These are closely associated with the Lebowa and Venda areas. About 58% of Limpopo Province (not LRB) was mapped by Gibson (2006) as being degraded. The primary land use is extensive grazing of domestic animals, particularly of the savanna and grassland vegetation types, but of this, 13% is commercial and dryland agriculture.

The key ecosystem aspects are, however, the upland catchment areas which also correlate to centers of endemism, high biodiversity and of conservation importance. The Soutspansberg-Blouberg complex is a center of plant endemism and is extremely diverse (van Wyk and Smith, 2001; Mostert *et al*., 2008). Other centers of endemism include the Wolkberg and Sekhukhuneland (Van Wyk and Smith, 2001), the Waterberg, Strydpoortberg, the Lebombo mountains in the Kruger National Park, the Tswapong Hills in the Botswana portion of the basin and bounding on the Matopos in Zimbabwe. All of these are situated along escarpments and mountain chains, which, as major geographical features, constitute the important high runoff-generating areas (see Figures 4 and 5), with higher rainfalls, steep terrains and high rainfall-runoff coefficients. These give rise to high runoff yield. While their value for water generation has been intrinsically recognized through human settlement, this same activity and exploitation is also causing degradation. A National Protected Areas Expansion Strategy seeks to protect these areas of high endemism (DEA, 2010). However, although it is not the richness of the biodiversity *per se* that creates the important effect of ecosystem provisioning and regulating that is necessary for preserving water flows in the LRB, it provides a powerful spatial indicator of these important services.

Mist-belt forests (Afromontane forests), such as those found in the Soutpansberg, the Wolkberg (Cloud Mountain) and along the northern Drakensberg, are important hydrological modifiers. The Wolkberg mist-belt forests (which include patches of grassland) are about 65,000 ha in area. The mist-belt appellation refers to the frequent incident of orographic mist, which, condensing on the vegetation at high altitude, can increase total precipitation dramatically. Entabeni Forest (a commercial plantation) in the Soutpansberg, receives about 1,800 mm.yr^{-1} rainfall. Fog interception boosts total precipitation to about 3,230 mm.yr^{-1}, adding another 1,400 mm for the year (Olivier and Rautenbach, 2002; Mostert *et al*., 2008). It is worth remembering that mean annual rainfall at lower altitudes in the LRB, such as Musina, is around 300 mm. Fog interception by the vegetation alone can add nearly five times the precipitation to the land surface. Mean annual rainfall for the whole LRB is around 530 mm and these high altitude catchments have a large impact on the general rainfall statistics.

Bruinzeel (2004) describes how tropical forests moderate streamflow by firstly maintaining a high infiltration rate because of the thick vegetation cover and a relatively high water storage which is released later during the dry season. Baseflow is maintained and this ecosystem service of modifying hydrological behavior by the tropical forests is highly valued all over the tropics and sub-tropics (Bruinzeel, 2004). See Figures 4 and 5. The mean annual runoff per unit area from the upland catchments is 100 times that of the low-lying areas of the LRB. From this point of view, the mist-belt forests and upland grasslands of the LRB are of exceptional value to the hydrological resilience of the LRB because firstly, the high rainfall is supplemented by a high fog catch, and secondly the forests maintain a significant baseflow during the dry season.

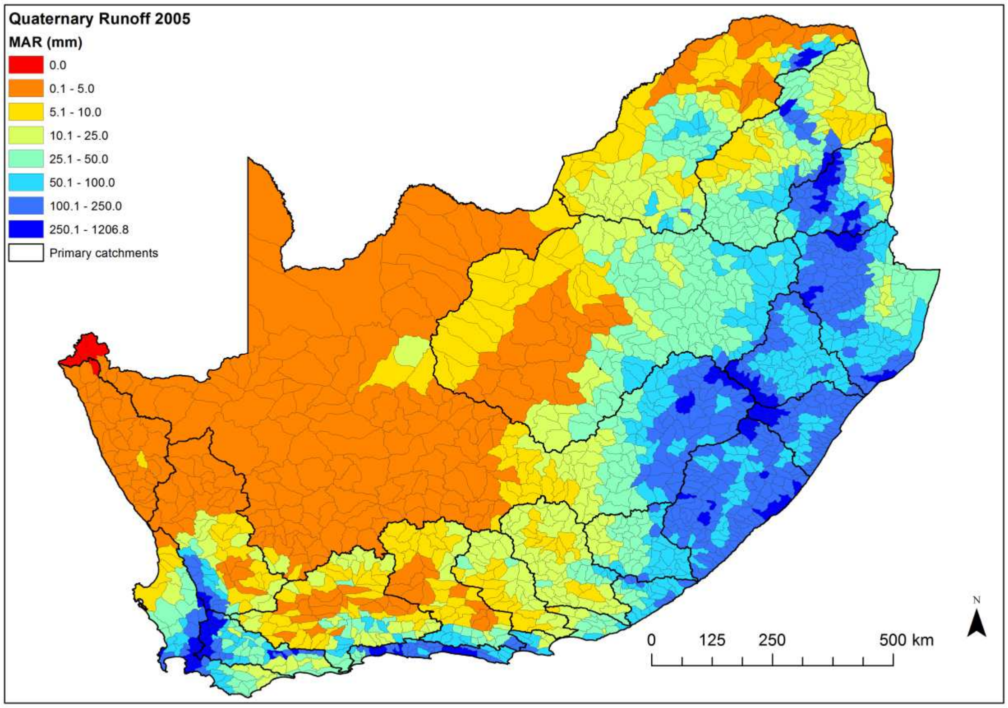

Figure 4. Runoff mapped for quaternary catchments at national scale for South Africa, illustrating the importance of the escarpment as a topographical feature for generating runoff. The blue subdivisions represent those catchments with the highest runoff (Source: D le Maitre, CSIR, 2013).

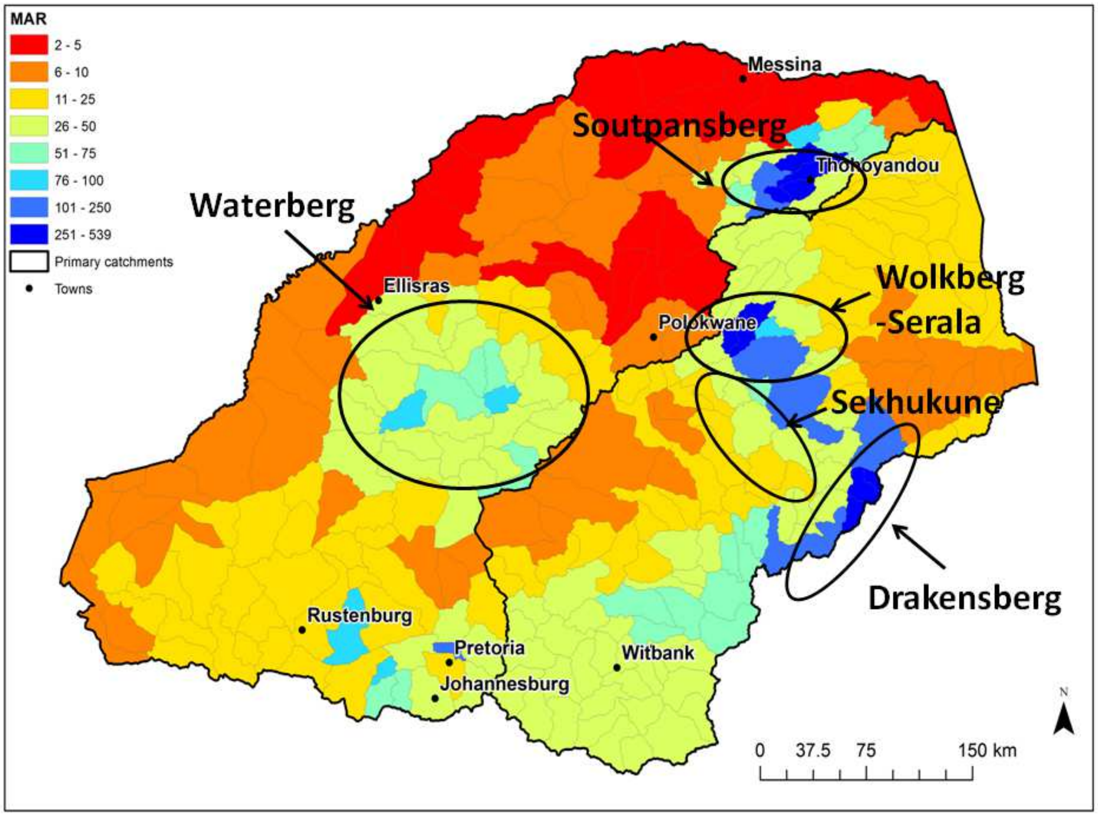

Figure 5. Runoff (in mm) mapped for the South African part of the Limpopo River Basin, illustrating the location of the high runoff-generating catchments along the escarpment of the Drakensberg, Wolkberg, Soutpansberg and Waterberg (Source: D le Maitre, CSIR, 2013).

Upland grasslands exist alongside the forests because a grassland climax vegetation is maintained by fire. Forests exist where fire frequency is very low or the area is protected from fire penetration in some way. With the moist and warm conditions, these grasslands are, however, exceptionally vulnerable to invasion by alien woody vegetation. Chapman (2006) documents the existence of invasive species on the upper Lekgalameetse Nature Reserve and estimates that they will be utilizing more than 3 million $m^3.yr^{-1}$ of water that might otherwise flow down the Ga-Selati River to its confluence with the Olifants River at Phalaborwa (See Figure 6). Le Maitre *et al*. (2013) estimate that the mean annual runoff is reduced by up to 15% for some areas of the Soutpansberg by invading alien plants. Along the escarpment elsewhere, the value is between 1 and 10% of mean annual runoff (Figure 6). The invasion process is continuing, therefore the problem is worsening without interventions. Left unattended, the costs of control will increase dramatically into the foreseeable future.

Figure 6. Eucalypts and acacias invading into the grasslands of the upper Ga-Selati River catchment of the Lekgalameetse Nature Reserve (Photo: A Chapman).

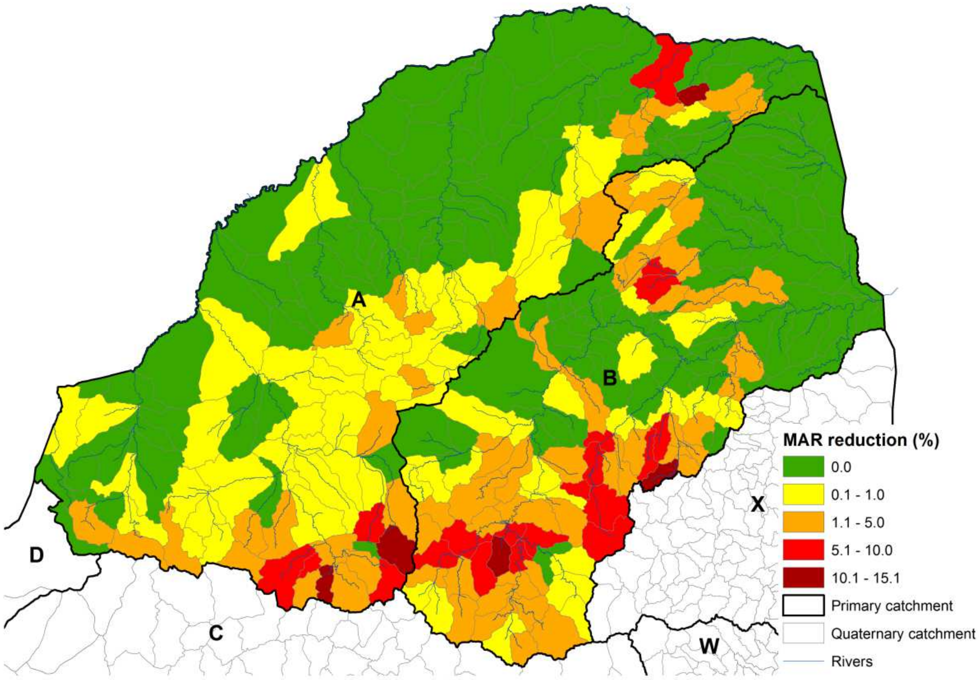

Figure 7. The percentage reduction of mean annual runoff of the South African portion of the Limpopo River Basin (le Maitre *et al.*, 2013).

The Climate-Ecosystems Interactions

The general aridity of the LRB, (with small areas along the uplands and mountain slopes receiving much more rain) has been well documented elsewhere. The major circulation pattern responsible for the continent-wide band of aridity is that the LRB lies on or close to the descending limb of the Hadley cell circulation, meaning dry and warm anticyclonic air. Climate has an effect on all parts of system functioning. Located mostly within the tropics, the region has a long dry season during the austral summer. This gives rise to the savanna biome which covers most of the basin.

There is another aspect to the climate-ecosystems interaction in which the land surface is coupled to the climate and land surface conditions have an effect on the regional and local climate (Feddema *et al*., 2005). The degradation of land through over-use and erosion removes litter and the topsoil layers that usually have high soil-water storage capacities. Surface sealing (a feature of land degradation) reduces infiltration and increases runoff, forcing a rapid transfer of water out of the local area during rainfall. These processes result in drier soils, less evapotranspiration, lower boundary layer air temperatures and reduced relative humidity. Fluxes of water vapor from the land surface to the upper atmosphere (momentum transfer) decline. Dew point temperature falls and the altitude of the cloud base increases. Cloud formation and rainfall frequency possibly decrease, reinforcing further soil desiccation.

Soil moisture is a key factor of ecosystem functioning and provisioning for human wellbeing. The soil moisture balance is controlled by moisture and energy supply, the evapotranspiration rate, and the quantum of partitioning to runoff and groundwater. Changes to any of these controls will cause the soil water balance to move to a new equilibrium, with concomitant effects on ecosystem functioning. Fluxes to the atmosphere will also change, potentially changing moisture cycling from atmosphere to ground and back to the atmosphere. Land-use changes therefore can affect climate and conversely climate is an important control on land use. Dirmeyer *et al*. (2013) note that land-atmosphere coupling is likely to intensify in the future and that means a greater control on surface fluxes (of moisture) and the lower troposphere (where clouds form) by soil moisture. These authors believe that the land surface will amplify hydrologic extremes, i.e. droughts and floods, in the future. Ruiz-Barradas and Nigam (2013) find the opposite effects over the Southern Great Plains. Taylor *et al*. (2012) in another study, found that across all six continents, later afternoon rain (derived from convection) is likely over drying soils, and that the signal is most pronounced over semi-arid regions, where surface fluxes are sensitive to soil moisture and convective events are frequent – characteristics which the LRB meet. These authors find no evidence for a greater likelihood of rainfall over wetter soils, which is one of the arguments for the reasons for persistence of rainfall after an initial random event. The science is not settled. One of the biggest problems facing the science is the lack of data on which to verify modeled processes. It does seem clear that modification of the land surface ultimately has a level of control over climate and particularly extremes.

Nevertheless, the LRB landscape has been heavily modified through agriculture and settlements. This is clearly visible on satellite-based images (Figure 8). These show up in the image as light-colored or speckled areas, representing bare or poorly vegetated ground. Often, the impact of landscape conversion can be ascertained by the curvilinear edges of lighter colors. The dark green areas represent the well-vegetated mountain slopes and wetter catchments.

Figure 8. A satellite image of the Limpopo River Basin in which light-colored areas represent bare ground, often the location of settlements or heavily altered land. Dark green represents vegetated mountain slopes (Source: Google Earth)

Regional-scale forcing is partly diurnal. Daytime heating of the land surface, and nocturnal cooling, is partly controlled by the heterogeneity of the land surface and other factors, such as vegetation cover and soil moisture content. These smaller-scale variations will have some influence on local convection systems, which is what brings most of the rainfall to the LRB.

The following adaptations are based on the low regrets options model: Focus on maintaining a decent vegetation cover and soil characteristics. Vegetation usually has darker colors and therefore lower albedo or reflectivity, meaning that it absorbs more radiation and so should become warmer than a more highly reflecting surface. However, maintaining an improved vegetation cover usually has the result that soil moisture is better preserved and the higher partition of incoming solar radiation into latent heat (through evapotranspiration) has the end result of reducing temperatures. High temperatures can be mitigated somewhat by a better vegetated surface.

A side effect of these interactions is bush encroachment. Human disturbance of the natural grassland-tree balance has affected the equilibrium of the vegetation system, with the consequence that bush or thicket encroachment is a growing problem right across southern Africa in the warm and semi-arid areas. The reasons for bush encroachment are many, including changes to grazing regimes, animal pressure (cattle taking over from elephants), changed fire regimes and interactions with soil characteristics (Ward, 2005). Even carbon fertilization has a likely strong influence (Higgins and Scheiter, 2012). Much can be written on the subject and it seems from a cursory examination of the literature that the problem is quite widespread in Limpopo. The problem species include *Acacia* *mellifera, Acacia tortilis* and Dichrostachys *cineria* and it is pertinent to note that they are all nitrogen-fixing legumes and thus are primed to increase their growth rates by taking advantage of higher atmospheric CO_2 concentrations (Bond and Midgley, 2012). The dynamics of the problem and impacts are the same as those created by invading alien plants. Additionally, bush encroachment will also alter the land surface energy-climate dynamics. Solutions will require changes to rangeland management to prevent further encroachment. The literature does suggest that these changes are irreversible and that from this point of view, an ecological tipping point has been reached and the ecosystem has entered a new state which has not yet achieved its equilibrium.

Climate-Water Interactions

Climate in the region generally responds to drivers at inter-annual and decadal time-scale variations of sea surface temperatures in the Indian and Atlantic oceans, as well as teleconnections (climate anomalies related to each other over global distances) to the El Niño / Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). The inter-annual variations in rainfall that lead to droughts are driven largely by El Niño Southern Oscillation (ENSO) in the Pacific Ocean and its influence on the Intertropical Convergence Zone (ITCZ). Williams and Hanan (2011) note that "ENSO is a leading mode of tropical climate variability at inter-annual timescales and is characterized by sea surface temperature (SST) and surface pressure anomalies across the Pacific Ocean". A positive ENSO (El Niño phase) tends to drive the ITCZ eastwards, leading to regional drought. The teleconnections to ENSO appear particularly strong in southern Mozambique, with a pattern of negative correlation between net photosynthesis (plant growth) and ENSO especially strong in the lower Limpopo River Basin (Williams and Hanan, 2011), but also having an effect across South Africa, Zimbabwe and Botswana.

The relationship between ENSO and drought in southern Africa only really began to be understood in the 1980s, but despite this understanding, there have been failures to predict the onset of drought because the linkages in the atmospheric circulation system are not yet fully understood. Part of the problem is that a similar system in the Indian Ocean exists, where sea-surface temperature anomalies vary with time, and is called the Indian Ocean Dipole (IOD) (Williams and Hanan, 2011). In contrast to the ENSO phase, positive IOD events lead to the advection of moist air over southern Mozambique and the eastern parts of South Africa, leading to the higher incidence of convective rainfall, and with effects on water resource infrastructure. ENSO and IOD do not necessarily operate in-phase, so that the use of ENSO only as a predictor of drought over southern Mozambique is neither efficient nor very useful (Williams and Hanan, 2011).

Both droughts and floods have been observed as becoming more frequent and intense (Tadross, 2009). The most severe flooding occurs when tropical cyclones enter the Mozambican channel and dump enormous amounts of water into the Limpopo River Basin, resulting in extensive areas of the basin and associated wetlands being flooded. Cyclone Eline of 2000 was emblematic in terms of the damage it caused but it should be remembered that four tropical cyclones had an impact on southern Mozambique in that year. The total number of cyclones has not necessarily increased, but the number of Category 4&5 cyclones (a measure of their power on the Saffir-Simpson scale) has increased in the South Indian Ocean over the last 30 years (Webster *et al.*, 2005). In essence, the storms are becoming more powerful and destructive. Ash and Matyas (2010) note that the combined influences of ENSO and IOD also affect tropical cyclone trajectories in the south west Indian Ocean.

Floods therefore are a permanent feature and risk in parts of the LRB and are an almost annual feature. The drivers of floods (e.g. cyclones) cannot be influenced by human actions, even in the long-term. Therefore the only adaptations are to undertake risk mitigation, improve storm warnings, communications systems and disaster response systems across the LRB, possibly with transboundary agreements for assistance, especially for countries like Mozambique, which can be hit hard by such inclement weather.

External Drivers

Economic Drivers of Change

There are three major aspects to the economy of the LRB – mining, agriculture and tourism. The LRB contains vast mineral resources. Specifically, these are associated with the Bushveld Igneous Complex, which contains 80% of the known mineral resources of the rare platinum group metals (platinum, rhodium, palladium and gold) and contains huge reserves of chrome, nickel, copper, magnetite, tin and other minerals, as well as important coal resources. Coal is associated with Karoo rocks in the southern part of the basin on the Mpumalanga Highveld and the developing resources in the Waterberg, all the way up to the Limpopo River. Smaller scale and artisanal mining takes place in Zimbabwe on the Gowanda and Filabuzi greenstone belts. Sulphide deposits (e.g. nickel) are mined in the Botswana component of the LRB. Enormous mineral resources remain and mining development continuing well into the future is inevitable. Mining will therefore continue to have an impact on ecosystems and water resources across the LRB.

Despite its general semi-arid and highly variable nature, the LRB is an important agricultural zone. The tropical aspects of climate allow a variety of tropical fruits (from the mostly commercial farms) to be grown as well as grain, cotton, sunflowers, tea, coffee and forestry. Successful, profitable and productive agriculture invariably requires irrigation unless it is in the limited high altitude areas. Extensive cattle ranching takes place in the drier parts of the basin and game ranching in the even drier portions. The LRB has a very high concentration of game ranches in comparison to the rest of southern Africa. Because of its spectacular scenery, tourism is also a key driver of the economy and an important employer.

Of these activities, agriculture and mining have the largest and most negative impact on water and biodiversity. Tourism tends to be neutral and can even be positive, bringing income that helps promote biodiversity and ecosystem services.

The Livelihoods Dimension

Despites its apparent riches the region is very poor, per capita. Much of this has to do with the export-led nature of the economy of commodities, rather than a multi-layered combination that includes a sizeable proportion of manufacturing and services. The high levels of poverty translate into subsistence farming activities on communal lands, which tend to quickly become degraded and lose productivity. The lower LRB has high agricultural potential in the flood plain of the Limpopo

River, but the population pressure is so high that it constrains the incomes of families living there. The general aridity of the basin also has a large role to play in the high levels of poverty. A lack of water is one of the key constraints on economic growth and progress.

Governance for Change

Improved governance means looking at the basin holistically and agreeing on governance and management procedures applicable to all the riparian states. The Limpopo Watercourse Commission (LIMCOM) is an ongoing project in this direction. The default position is that it will represent all of the riparian countries, but there is a natural dichotomy in that Mozambique is downstream and the other countries are upstream. It will be hard for Mozambique to effect changes across the basin for its benefit. Much of the focus on the types of governance must fall on South Africa, which is by far the largest user of water in the LRB and the largest influence on the region's economy with respect to mining, agriculture and the major urban centers in the upper reaches of the LRB.

Policy changes in South Africa that affect the water resources of the LRB are not necessarily discussed between the riparian states. Dam building and intensifying water resource manipulation is occurring with the acquiescence of the member states. As South Africa proceeds down the path of increasing its utilization of resources, there are fewer options for adopting alternative strategies that might support downstream economic activities. For example, recent proposals to change the water laws in South Africa so that the government can direct more water away from agriculture towards mining, which has a higher value and return to the South African economy, illustrates the conundrum which the conveners of transboundary institutions will face.

Towards Adaptation at Scale

The overriding principle is to take the 'low regrets' option of adaptation and therefore to avoid committing the basin to only one possible path of future water resources management. Options must be kept open. Based on the above analysis, the following paths suggest themselves:

- A critical focus on conserving and maintaining the high altitude – high rainfall grassland and forest catchments needs to be put in place. These catchments generate up to 100 times more runoff, per unit area, than do lower-lying, lower rainfall areas. Maintaining the runoff potential of these areas must be an obvious strategy for the continued supply of good quality water to the surrounding lowland farming areas and towns. This recommendation also supports the National Protected Areas Expansion Strategy of the Department of Environment Affairs of South Africa (DEA, 2008), which has published a strategy of conservation of protected areas for promoting ecological sustainability and climate change adaptation. Conservation of ecosystem functioning and biodiversity has the payoff of conserving ecosystem services (water production in the dry season), thereby increasing the resilience of downstream settlements and economic activities to dry periods. The DEA (2008) strategy lists additional reasons such as promoting rural livelihoods and supporting socio-economic development. .That report lists the Blouberg Langian focus area #5 (Soutpansberg) and the Northeast Escarpment focus area #29, which includes the Lekgalameetse and Wolkberg reserves. These are also areas of concern in this report which, however goes further and identifies the Waterberg region as an area of concern.

Protection of all of these areas is an attainable goal, the Northeast escarpment and mountain uplands are already owned mostly by the state and increasing protection through improved governance is achievable. Much of the Waterberg is managed as game farms and is already under a level of protection.

- The problem of poor water quality particularly in the Olifants and Crocodile (West) river systems requires a sustained effort towards improvement. An improved quality of water in the river systems means a greater quantity of water is available for maintaining aquatic ecosystems and for abstraction and use in domestic and farming systems. The acidic decant from defunct coal mines on the Mpumalanga Highveld must be neutralized. New mining ventures in this region require close attention to their environmental management and wastes streams. The problem is best tackled on a sub-basin by sub-basin approach in which the greatest contributors to poor water quality are resolved first.
- A strategy of re-establishing the vegetative cover or biomass over large areas of degradation needs to be considered. An increased vegetative cover combats and is adaptive higher air temperatures brought on by global warming. This strategy is also adaptive to local climate changes that include a greater intensity of convective system rainfalls, which are what drives erosion and sediment transport. Such adaptations would be focused on the Sekhukune, Capricorn and Vhembe district municipalities where the problem of environmental degradation is most severe. Changes in cultural approaches to land management, as well as farming systems and land tenure would be required. These will not be easy to achieve.
- An improvement in the understanding of regional climate circulation and behavior with respect to ENSO and the Indian Ocean dynamics is required. This should be aimed at a more accurate medium-term prediction of droughts, which will enable decision-makers within the region to implement change management strategies, for example of water resources, according to these projections. This intervention will require a focus on the climate science of region and should specifically look at the relationships between the ENSO, the Indian Ocean dipole and the position of the ITCZ. Climate-land surface interactions will have to be accommodated into this research. At present, much of the climate-based science appears to be going into GCM projections of 5-7 decades into the future. It would be more useful to focus on a shorter-term objective of understanding how atmospheric circulatory changes and Pacific and Indian ocean dynamics can be used to derive improved shorter-to medium term projections of the likelihood of drought.
- Severe storm warnings are already a focus of the South African Weather Service (SAWS), which serves the region, but there is a large amount of work that is needed to reduce the human impact and severe displacement of people when major floods occur in the Lower Limpopo region. Much of this has to do with farming systems within the Lower Limpopo River floodplain, which is intensively cultivated. Floods will be unavoidable and people will continue to farm the floodplain, therefore the most effective responses will be to target how and where settlements are located, how early warnings are distributed and what the appropriate responses are in the face of an oncoming flood.
- The largest portion of the basin and most runoff generation (79%) is in South Africa. Most management changes and adaptations for resilience therefore must take place in that country.

- A greater focus on groundwater is required throughout the LRB. Groundwater will be one of the key resources that will maintain the economy in the LRB. Overuse and pollution are the key threats and these have already occurred to some extent in parts of South Africa and Botswana. Forward thinking, careful monitoring and the management of the land surface (e.g. not locating pit latrines on a shallow dolomitic aquifer system as a Ramotswa) are required. Future developments and exploitation of groundwater resources in the Mozambican part of the LRB will be possible. The careful management and preservation of groundwater resources across the LRB will become a critical component of future sustainability.
- More rigorous control on water abstraction right across the LRB will be required. . Basin-scale adaptations mean engaging legislative and governance approaches across all four riparian countries in order to encourage greater rigor in protecting the resources for the mutual benefit of all.

References

Ash, K. & Matyas, C. (2010), The influences of ENSO and the subtropical Indian Ocean Dipole on tropical cyclone trajectories in the south-western Indian Ocean Dipole on tropical cyclone trajectories in the south-western Indian Ocean, *Int. J. Climatol.* Online at: [DOI: 10.1002/joc.2249]., Pp 16.

Ashton, P. (2010), The demise of the Nile crocodile (Crocodylus niloticus) as a keystone species for aquatic ecosystem conservation in South Africa: The case of the Olifants River, *Marine and Freshwater Ecosystems* 20, 489–493.

Aurecon (2011), Development of a Reconciliation Strategy for the Olifants River Water Supply System: WP10197, Technical report, *Water Quality Report, Report no.: P WMA 04/B50/00/8310/7*, Report submitted to the Department of Water Affairs by Aurecon.

Aurecon (2013), Limpopo River Basin Monograph LRBMS-81137945: Draft Final Monograph, Technical report, Aurecon AMEI (Pty) Ltd Report Number 8337. Prepared for LIMCOM with the support of GIZ.

Basson, M. Van Niekerk, P. & Van Rooyen, J. (1997), Overview of Water Resources Availability and Utilisation in South Africa, Technical report, Department of Water Affairs and Forestry, Pretoria. P 72.

Bohensky, E.L. and Lynam, T. (2005). Evaluating responses in complex adaptive systems: Insights on water management from the Southern African Millennium Ecosystem Assessment (SAfMA). *Ecology and Society*, 10(1): 11. Available [online] at: http://www.ecologyandsociety.org/vol10/iss1/art11.

Bond, W. & Midgley, G. (2012), Carbon dioxide and the uneasy interactions of trees and savannah grasses, Phil. Trans. R. Soc. 367, 601-612.

Boroto, R. & Görgens, A. (1999), Hydrological Modelling of the Limpopo River Main Stem, Technical report, Report by Department of Civil Engineering, University of Stellenbosch and Ninham Shand Consulting Engineers, to Department of Water Affairs & Forestry. *DWAF Report No. PA000/00/0399.* 105 pp.

Bruijnzeel, L. (2004), Hydrological functions of tropical forests: not seeing the soil for the trees?, Agriculture Ecosystems and Environment 104, 185-228.

Chapman, A. (2006), Hydrology and land use in the Ga-Selati catchment., CSIR, Pretoria, South Africa and International Institute for Environment and Development, London, UK.

Dabrowski, J. & de Klerk, L. (2013), An assessment of the impact of different land use activities on water quality in the upper Olifants River catchment, *Water SA* 39(2), 231 - 244.

Dirmeyer, P. Jin, Y. Singh, B. & Yan, X. (2013), Trends in Land–Atmosphere Interactions from CMIP5 Simulations, *J. Hydrometeor,* doi: http://dx.doi.org/10.1175/JHM-D-12-0107.1 14, 829–849.

DEA (2010), National Protected Area Expansion Strategy for South Africa 2008: Priorities for expanding the protected area network for ecological sustainability and climate change adaptation, Technical report, Department of Environmental Affairs, Government of South Africa.

Falkenmark, M. (1989), The massive water scarcity threatening Africa-why isn't it being addressed, Ambio 18 (2), 112-118.

Feddema, J. Oleson, K. Bonan, G. Mearns, L. Buja, L. Meehl, G. & Washington, W. (2005), The importance of land-cover change in simulating future climates, *Science* 310, 1674 – 1678.

Gibson, D. (2006), Land degradation in the Limpopo Province, South Africa, Technical report, M.Sc. Thesis, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa.

Higgins, S. & Scheiter, S. (2012), Atmospheric CO2 forces abrupt vegetation shifts locally, but not globally, Nature 488, 209-212.

Le Maitre, D. Forsyth, G. Dzikiti, S. & Gush, M. (2013), Estimates of the impacts of invasive alien plants on water flows in South Africa, Technical report, Council for Scientific and Industrial Research, Draft Report prepared for Andrew Wannenburg, Working for Water Programme, Cape Town.

Midgley, SJE. Petrie, B. Martin, L. Chapman, RA. Whande, W. & Parker, R. (2013), The Limpopo River Basin System: Climate Impacts and the Political Economy, Technical report, For the Resilient Limpopo Programme (Resilim), USAid. OneWorld Sustainable Investments, Cape Town, Pp 139.

Mostert, T. Bredenkamp, G. Klopper, H. Verwey, C. Mostert, R. & Hahn, N. (2008), Major vegetation types of the Soutpansberg Conservancy and the Blouberg Nature Reserve, South Africa, *Koedoe* 50(1), 34-48.

Nkhata, A.B., Breen, C.M. and Freimund, W.A. (2007). Resilient social relationships and collaboration in the management of social-ecological systems. *Ecology and Society*, 12. Available [online] at: http://www.ecologyandsociety.org/vol12/iss6/art.

Olivier, J. & Rautenbach, C. d. W. (2002), The implementation of fog water collection systems in South Africa, *Atmos. Res.* 64, 227–238.

Ruiz-Barradas, A. & Nigam, S. (2013), Atmosphere–Land Surface Interactions over the Southern Great Plains: Characterization from Pentad Analysis of DOE ARM Field Observations and NARR, *J. Climate* 26, 875–886.

Tadross, M. (2009), Climate change modelling and future analysis, *In (Eds) Asante, K., Brundrit, G., Epstein, P., Fernandes, A., Marques, M., Mavume, A., Metzger, M., Patt, A.,Queface, A., Sanchez del Valle, R., Tadross, M. & Brito, R., INGC Climate Change Report:Study on the Impact of Climate Change on Disaster Risk in Mozambique, INGC,Mozambique, chapter*, Pp. 13-31.

Taylor, C. de Jeu, R. Guichard, F. Harris, P. & Dorigo, D. (2012), Afternoon rain more likely over drier soils, *Nature* 489, 423–426.

Tredoux, G. & Talma, S. (2006), Nitrate pollution of groundwater in Southern Africa. In: S.Xu, Y. & Usher, B., (eds.), Groundwater Pollution in Africa, Taylor and Francis/Balkema, The Netherlands, , pp. 15-36.

Van Wyk, A. E. & Smith, G. F. (2001), *Regions of floristic endemism in southern Africa: A review with emphasis on succulents*, Umdaus Press, Pretoria.

Ward, D. (2005), Do we understand the causes of bush encroachment in African savannas?, African Journal of Range & Forage Science 22(2), 101–105.

Webster, P. Holland, G. Curry, J. & Chang, H.-R. (2005), Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment, *Science* 309, 1844-1846.

Wepener, V. (1997), Metal ecotoxicology of the Olifants River in the Kruger National Park and the effect thereof on fish haematology, PhD thesis, University of Johannesburg, Johannesburg.

Williams, C. & Hanan, N. (2011), ENSO and IOD teleconnections for African ecosystems: evidence of destructive interference between climate oscillations, *Biogeosciences.* Online at: [doi:10.5194/bg-8-27-2011] 8, 27–40.