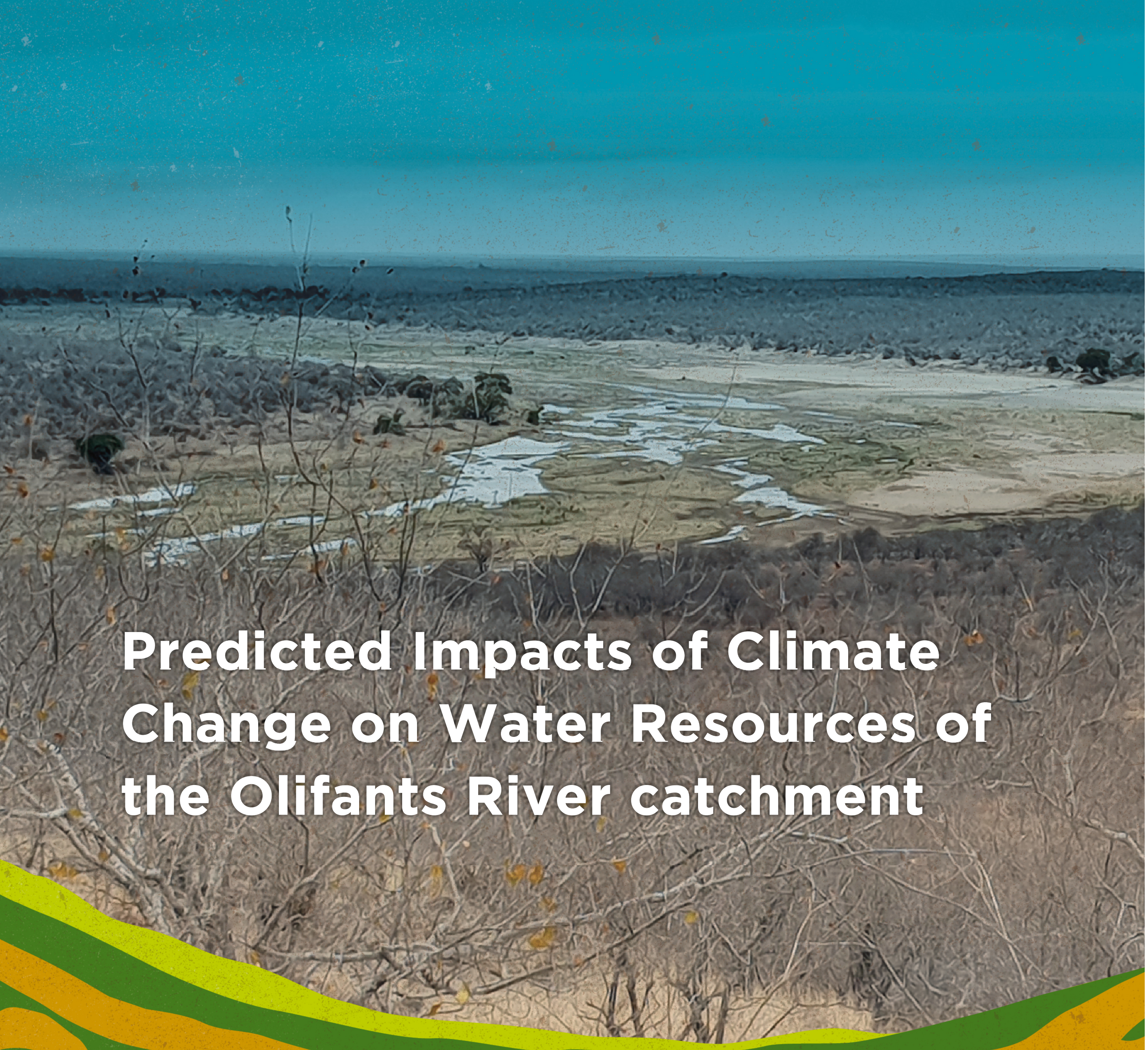

Predicted Impacts of Climate Change on Water Resources of the Olifants River catchment

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Acknowledgements

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Compiled from reports by Sawunyama and Mallory (2014); Kong et al. (2018); Pollard and Retief (various)

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Climate change impacts on the Olifants River Catchment

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[Booklet]

Systemic, collective action duringthe most severe drought on record

2 Integrated Water Resources Decision Support System [INWARDS] for the Olifants Catchment

Facilitating real-time monitoring, early warning & systemic decision-making for water resources

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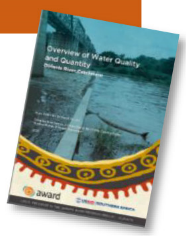

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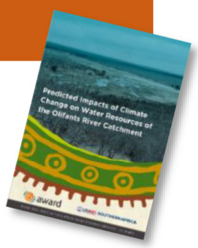

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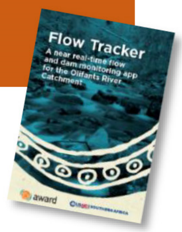

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Summary

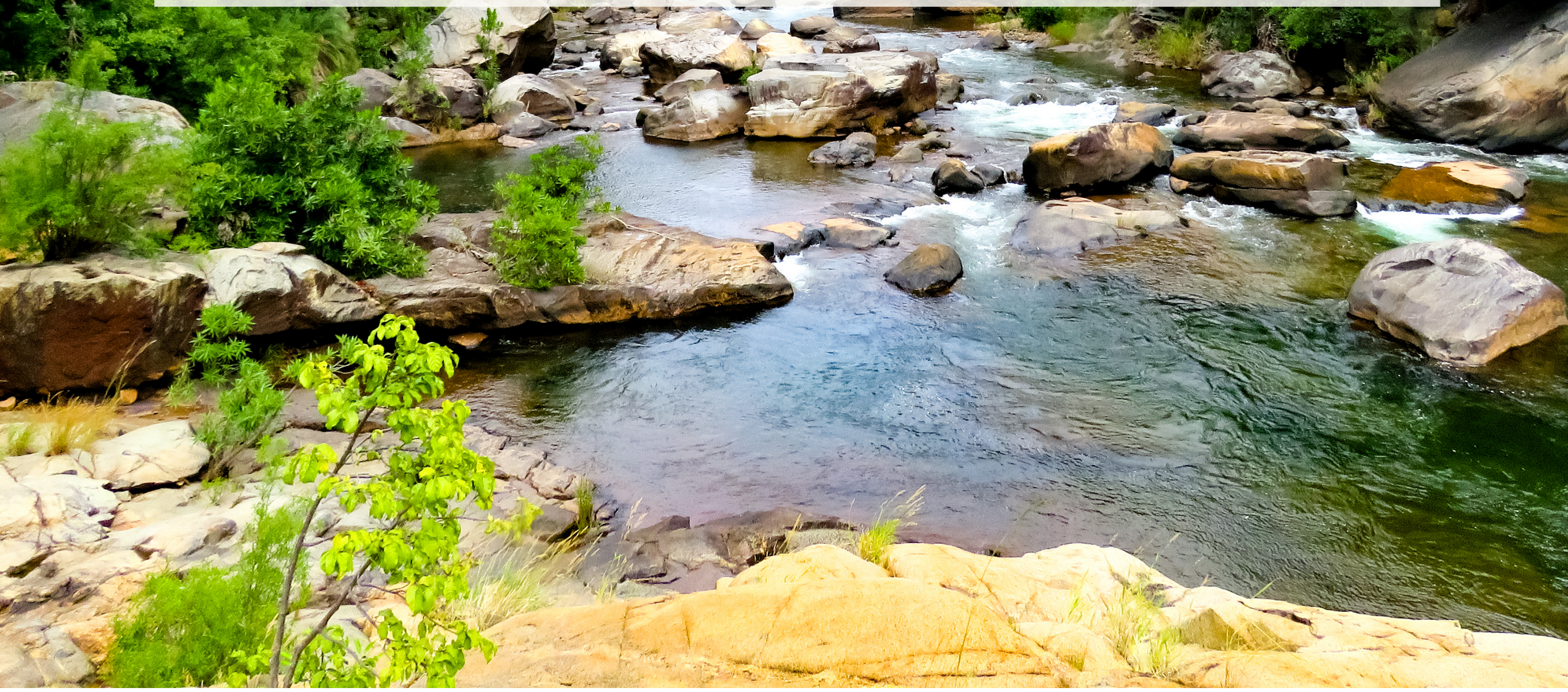
This report summarises an analysis of the effect of climate change on the water resources of the Olifants River Catchment (ORC) developed as part of the RESILIM-Olifants project (Sawunyama & Mallory, 2014). We also share subsequent analyses by ourselves and others. The objective is to provide a user-friendly overview for readers.

All models for the Olifants River Catchment (ORC) show an increase in temperature (1.7 - 4^{0}C by mid-century, up to 4 to 5^{0}C by the end of the century) which corresponds to an increase in evaporation of 10% to 15%. The results of our projections used to simulate hydrology show a decrease in mean annual precipitation (3% to 20% based on sites used), and a decrease in both summer and winter rainfall with increased temperatures. A seasonal analysis of climate and runoff change, based on the GCMs used, indicates a decrease in both summer and winter rainfall and hence runoff. The results do not show a marked change in rainfall season.

The combined effect of an increase in temperature and evaporation results in a decrease in mean annual runoff (ranges from 10% to 60%) which has severe implications for water resources including surface runoff and groundwater resources. In the South African portion of the Olifants River Catchment, streamflows are predicted to decrease by between 20% and 60%, increasing in an easterly direction with a maximum impact at the Mozambican border within the Kruger National Park. The reduction in yield of the major dams in the Olifants River Basin will be dramatic if either of the two climate change scenarios analysed should materialise with reductions in yield of up to 60%.

The potential systemic impacts are summarised, including environmental, economic and socio-political implications. The Olifants River is the major tributary of the larger Limpopo Basin and is responsible for maintaining flows in the lower Limpopo River and estuary so the implications are significant at a transboundary level.

The need for urgent action is highlighted by these results and mitigation measures are outlined based on extensive experience of working in the catchment.



1 Introduction

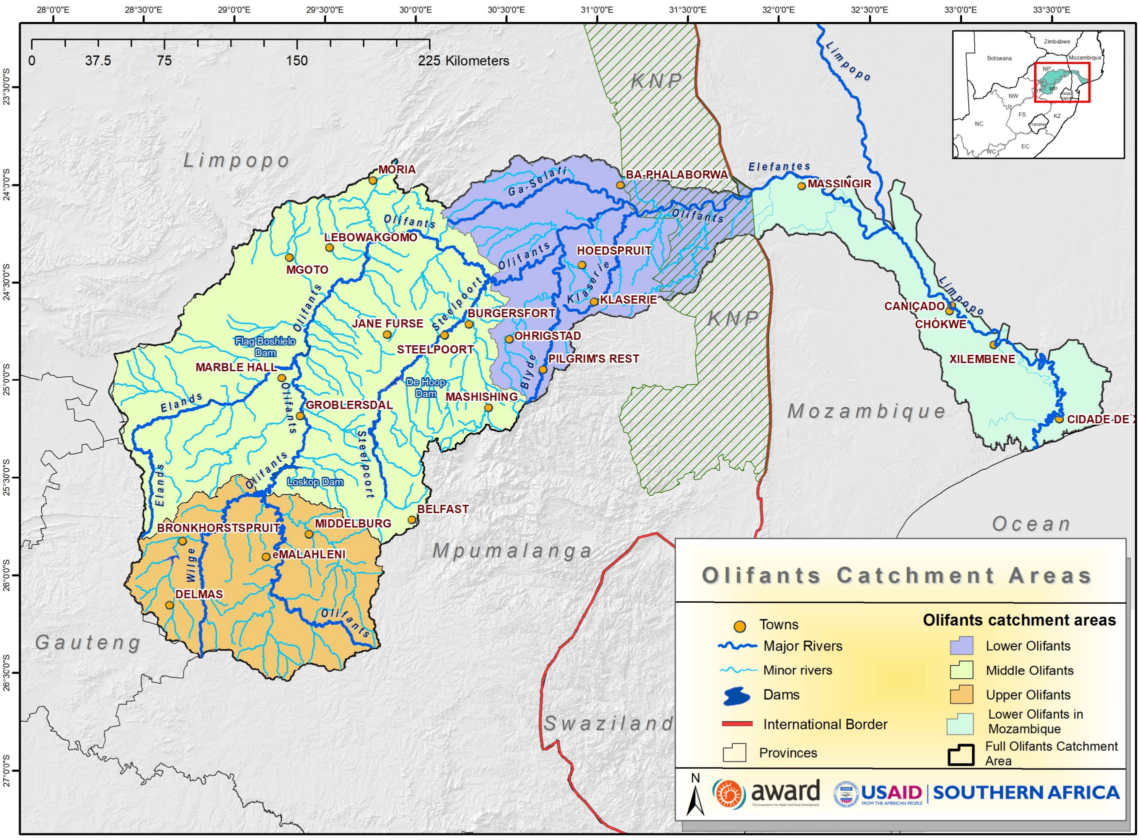


Figure 1: Map of the Olifants River Catchment showing the upper, middle and lower regions of the catchment and the lower Limpopo Basin after the confluence between the Olifants and Limpopo

The Olifants River Catchment falls within the Limpopo River Basin, which is part of an international drainage basin that stretches across South Africa, Mozambique, Zimbabwe and Botswana. The Olifants River contributes nearly 40% of the water that flows in the Limpopo River making it important for the basin as a whole. Currently, the Olifants River is the only tributary that sustains flows of the Limpopo River in the dry season.

RESILIM-Olifants Goal

To reduce vulnerability to environmental (climate) change through building improved transboundary water and biodiversity governance and management of the Olifants Basin through the adoption of science-based strategies that enhance the resilience of its people and ecosystems through systemic and social learning approaches.

The water resources of the Olifants River Catchment are under severe stress with over half the catchment being close to, or in, water deficit *(see Resource 1: Keeping the Olifants River flowing)*. In 2013, the RESILIM-O program of AWARD set out to enhance the resilience of its people and ecosystems under a changing climate. Further details of the RESILIM-O program can be found at www.award.org.za.

Within this, one objective was to secure enhanced long-term water security and protection by supporting collective action, informed adaptation strategies and practices and tenable institutional arrangements for transboundary Integrated Water Resources Management (IWRM).

To this end we undertook an analysis of the predicted impacts of climate change on the Olifants Catchment and on the catchment's water resources (Sawunyama & Mallory, 2014). This document provides a synthesis of those findings to provide an overview of the predicted impacts. We also refer to subsequent research by others which has corroborated our findings.

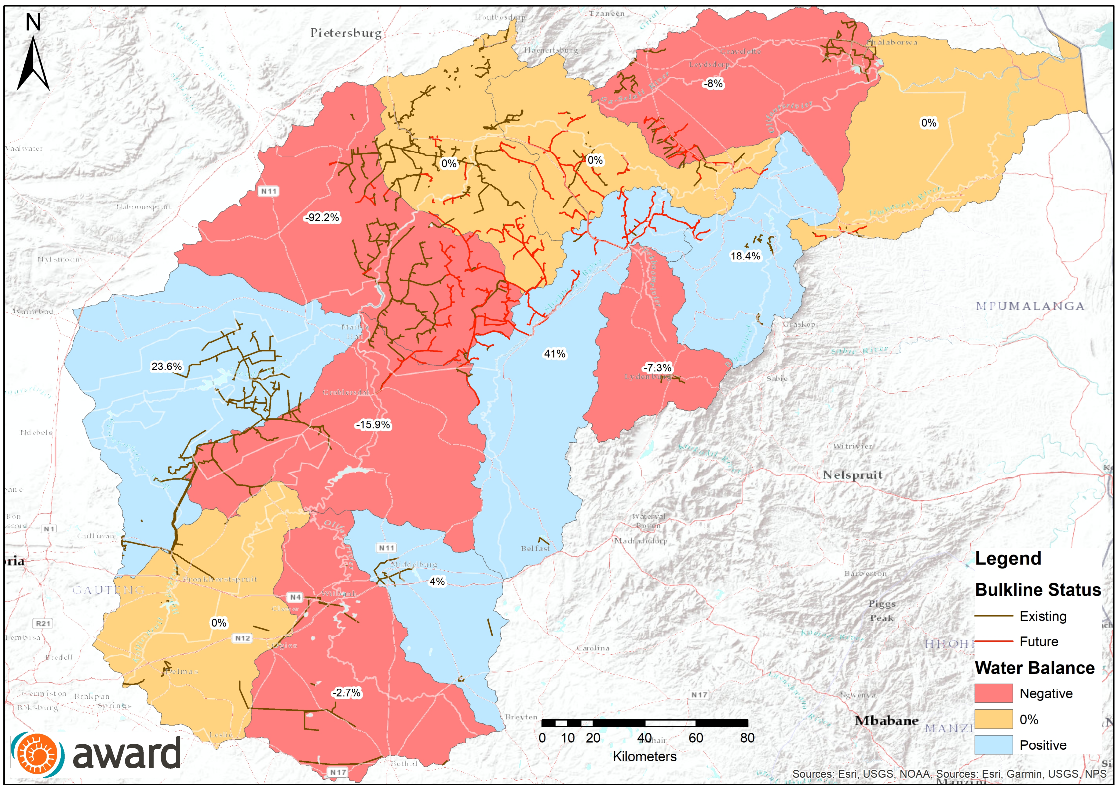


Figure 2: Water balance in the South African portion of the Olifants River Catchment. Note that this is probably an underestimate since it is based on 2010 (DWS 2011) data that needs updating

2 Understanding interacting & complex systems

Climate plays a significant role in defining the flow regime and thus changing the climate has profound implications for water resources which can often redefine a catchment's flow regime. The flow regime is normally described in terms of magnitude, frequency, timing and duration and the rate of change of these. To truly understand the impacts, one needs to acknowledge the complexity and connectedness of both the hydrological cycle (Figure 4) and of a catchment (as a socio-ecological system or SES) and its water resources (Figure 3); *(See Resource 5: Systemic, Social Learning Approaches to Water Governance & Sustainability)* and how each of the "components" of these systems may be affected - directly or indirectly - by changes in the climate. Thus we need to appreciate that changes in each of these interacting systems (a catchment and the hydrological cycle) can ultimately shift the hydrological regime and provoke changes in stream flow volumes, the types of flow (floods, base flows), how long and how often each of these last and even a complete switch in seasonality.

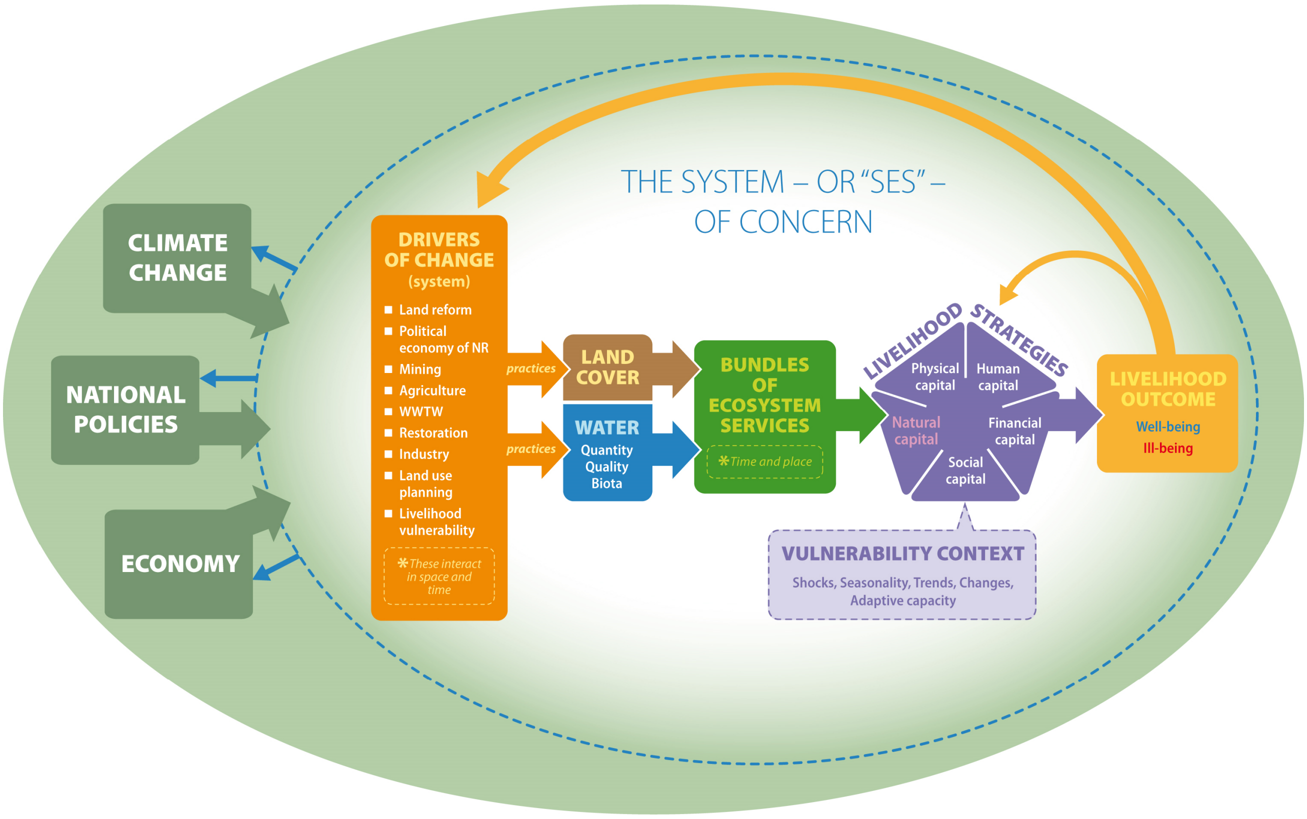


Figure 3: The Olifants Catchment as a socio-ecological system (SES)

A catchment as a complex socio-ecological system (SES): Exploring the impacts of climate change on water & the SES

A catchment can be thought of as a socio-ecological system or SES (Holling, 1987), made up of socio-political and biophysical components or sub-systems (such as the hydrological cycle) Their interaction in space and time is dynamic and changing, producing complex – and often surprising or unexpected outcomes. Systems thinking seeks not only to understand these interactions but also to explore how these might propagate through a system (e.g. the SES) so that we are better prepared for unanticipated consequences.

A closely related concept of resilience broadly refers to the capacity of a system to absorb disturbance and re-organise so as to retain essentially the same function, structure and feedbacks (see Berkes et al. 2003).

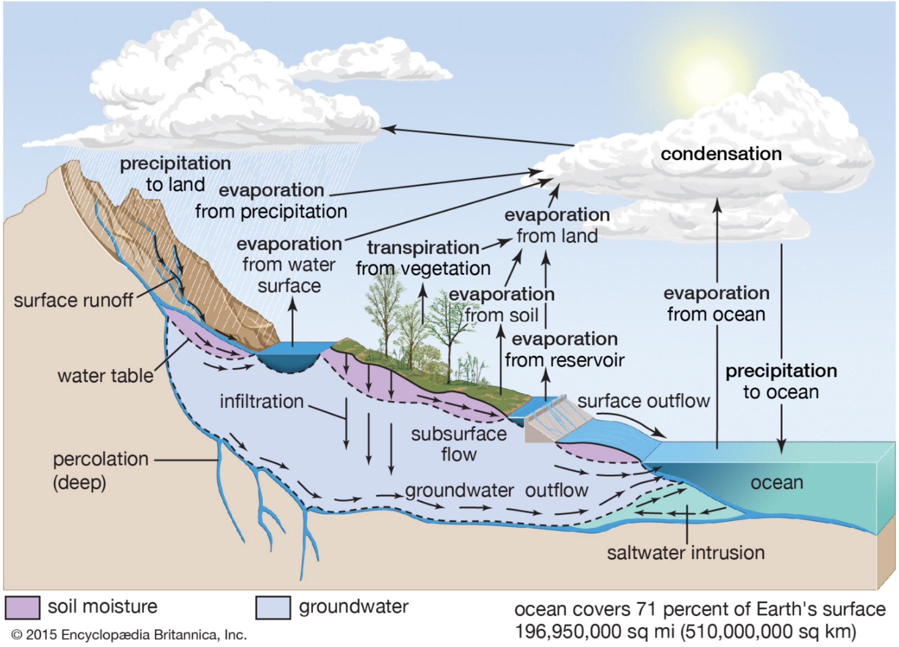


Figure 4: The hydrological cycle which then interacts with a catchment, in itself a complex system
Source: https://www.britannica.com/science/water-cycle

By modelling the hydrology of the Olifants River Catchment under various climate change scenarios, we examine potential impacts below. Some examples of pathways for change include higher ambient temperatures and increased evaporation. Together with either decreased precipitation or changing seasonality, these result in decreased run-off (that part of the water cycle that flows over land as surface water instead of being absorbed into groundwater or evaporating) and consequently stream flow in the catchment.

Decreased stream flows reduces:

- Water storage in reservoirs and dams;
- The recharge of groundwater; and
- Water quality, with a reduction in the dilution capacity.

A change in the intensity of rainfall event, may result in changes in magnitude and timing of streamflow and ultimately, in extreme floods and droughts.

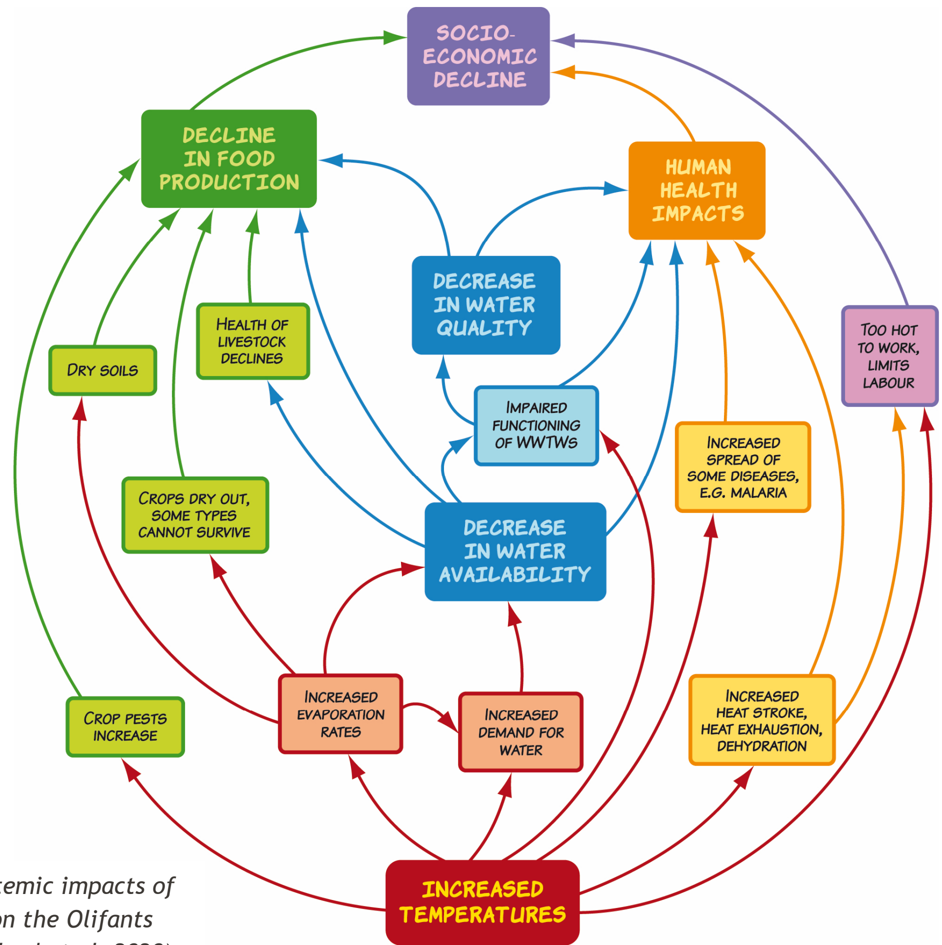


Figure 5: The potential systemic impacts of increased temperatures on the Olifants River Catchment (from Pollard et al. 2020)

Weather, climate & future scenarios

Climate refers to the average weather conditions over a long period of time (+30 years) whilst weather refers to the day-to-day state of the atmosphere (a combination of temperature, humidity, precipitation, cloudiness, visibility, and wind), and its short-term variation in minutes to weeks. To make projections, climate scientists use greenhouse gas (GHG) scenarios or "what if" scenarios of plausible future emissions, to drive global climate model simulations of the Earth's climate. Both the scenarios and models are periodically updated as the science of climate change advances. The most recent climate change projections for 21st century are from the Intergovernmental Panel on Climate Change (IPCC, 2014; 5th Assessment Report). Since it is impossible to predict exactly how much GHG will be emitted, scientists consider the implications of a range of different future conditions. We do not know with any certainty which scenarios are more likely but based on trends and responses, we can make choices about likely scenarios we are heading towards. Since it is important to consider a range of potential outcomes, uncertainty is part of understanding climate change futures (this does not imply that we do not know because there is no data).

Representative Concentration Pathways

Scenarios of the future

Representative Concentration Pathways (RCPs) are four trajectories of GHG concentrations (not emissions) adopted by the IPCC in 2014. They describe four possible climate futures depending on how much GHG is emitted, ranging from an extremely low emissions-scenario involving aggressive emissions reductions, to a high 'business as usual' scenario with substantial continued growth in greenhouse gases. These pathways are used for climate modeling and research.

TABLE 1: GREENHOUSE GAS SCENARIOS AND DESCRIPTIONS

SCENARIOS	SCENARIO CHARACTERISTICS	DESCRIPTION
RCP 2.6	An extremely low scenario that reflects aggressive greenhouse gas reduction and sequestration efforts	"Very Low"
RCP 4.5	A low scenario in which greenhouse gas emissions stabilize by mid-century and fall sharply thereafter	"Low"
RCP 6.0	A medium scenario in which greenhouse gas emissions increase gradually until stabilizing in the final decades of the 21st century	"Medium"
RCP 8.5	A high scenario that assumes continued increases in greenhouse gas emissions until the end of the 21st century	"High"

All scenarios result in similar warming until about mid-century. Prior to mid-century, projected changes in climate are largely driven by the warming that is from historic emissions of greenhouse gases. In contrast, warming after mid-century is strongly dependent on the amount of greenhouse gases emitted in the coming decades (Snoveretalsok, 2013). Globally, GHG emissions are higher and increasing more rapidly since 2000 than during the 1990s (Figure 6). We are believed to be on the RCP 8.5 trajectory (Sanford et al., 2014).

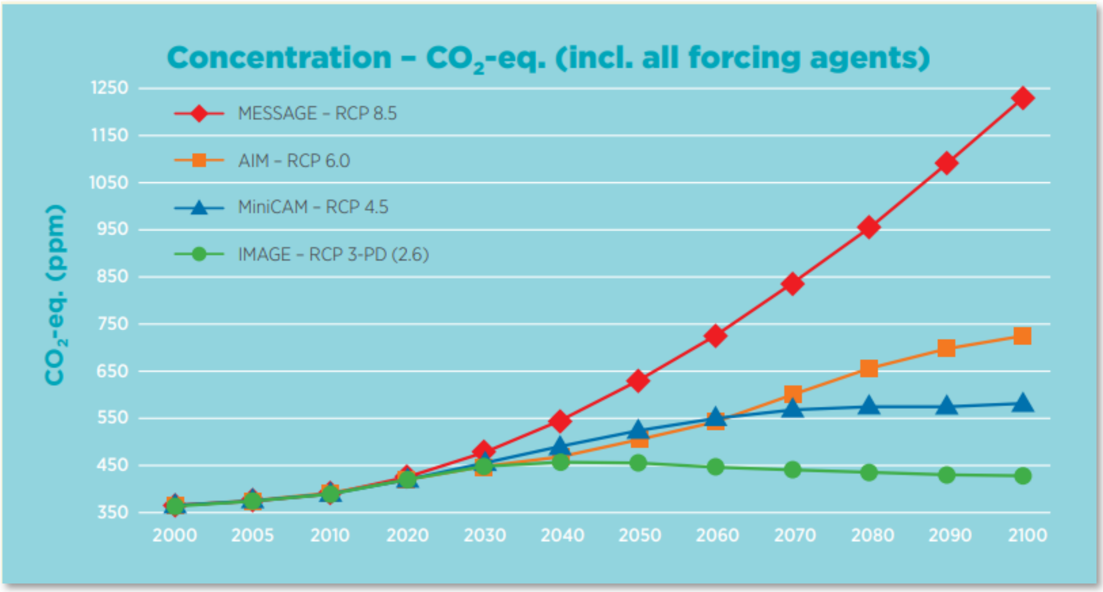


Figure 6: CO_2 concentrations according to the Representative Concentration Pathways (RCPs)
(Source: https://en.wikipedia.org/wiki/Representative_ Concentration_Pathways#/media/ File:All_forcing_agents_ CO2_equivalent_ concentration.png)

3 Impact of climate on water resources

The different parts of the flow regime play different roles in sculpting and maintaining the river ecosystem such as for example through the onset of increased flows, which may affect breeding cycles of biota, or the magnitude of the annual floods, which may inundate a floodplain. Removal of part or all of a particular component of the flow regime will affect the riverine ecosystem differently (and hence the freshwater goods and services to people).

Even without considering the future impacts of climate change, a preliminary analysis by AWARD indicated that by 2015 some areas of the Olifants River Catchment have already undergone major hydrological alterations of greater than 68% (Figure 7).

The flow regime can be defined as the hydrological profile of a water resource and is determined by geology, topography, climate, vegetation and land use/land cover.

The five components of a flow are:

Magnitude
Frequency
Duration
Timing
Rate of change

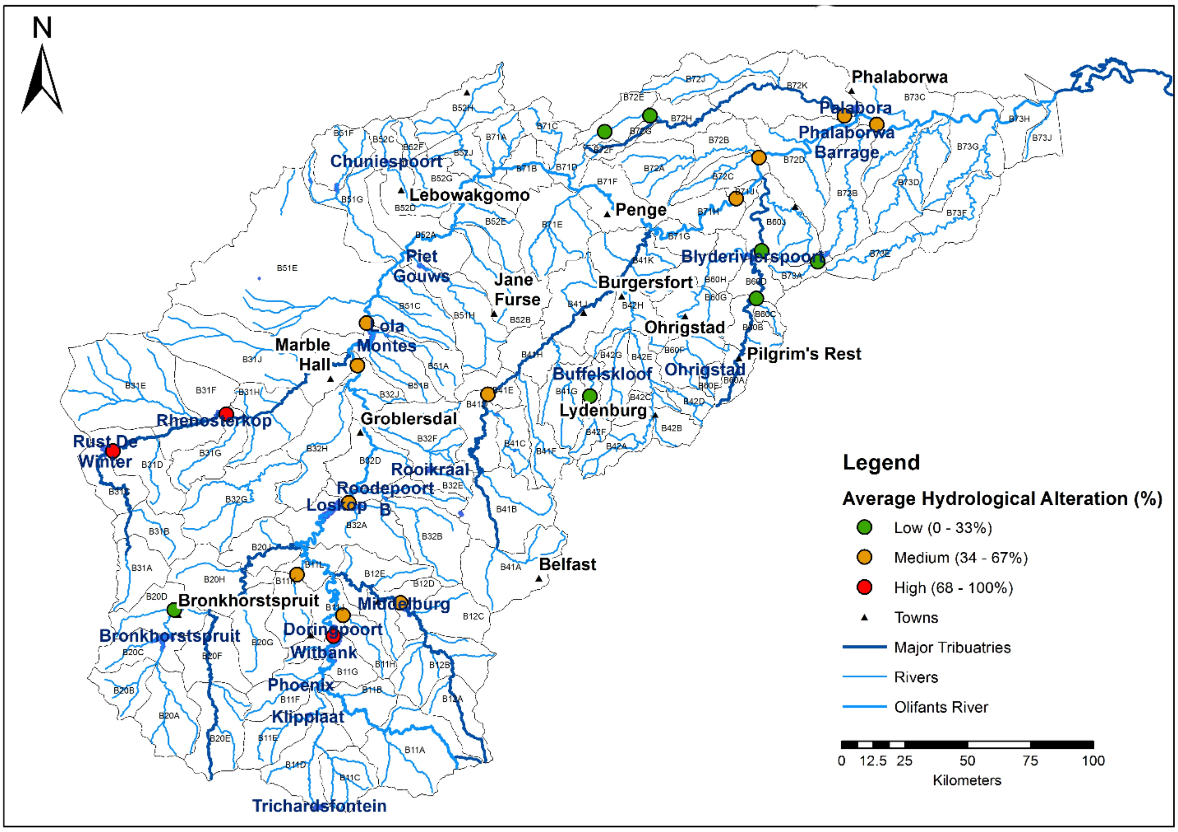


Figure 7: Map of discharge points analysed for hydrological alteration in the Olifants River Catchment pre and post 1990 (after which there were significant increases in irrigated agriculture and mining)

3.1 Modelling approach

It is important to remember that modelling future climate does not produce predictions in the way that daily weather forecasts produce predictions. Rather, climate models produce projections of possible futures that depend not only on the mechanics of the global climate system, but also on factors that influence future emissions of greenhouse gases – such as global population, economics, development and adoption of new technologies, laws and regulations and the politics of global socio-economic relations. Climate modelers use scenarios of plausible socio-economic futures because predicting a century's worth of global economic interactions would be impossible.

Using different models

It is important to note that while our meteorological analysis uses all models to determine the statistical significance in change in precipitation, for the hydrological modelling, the climate models with the best fit for base period (see Figure 8) were used (i.e. that concurred with observed data).

Therefore, while there is no common agreement amongst all models regarding rainfall, the hydrological fits suggested that some models (e.g. BNU-ESM) were better than others.

Future climate projections are a product of modelling of global climate response to increasing greenhouse gas (GHG) concentrations. These models are called General Circulation Models (GCMs), which simulate the physical processes in the atmosphere, ocean, cryosphere and land surface. There are many GCMs developed by different climate research institutes around the world. Each

GCM may simulate a different climate response for the same inputs because of the way certain processes and feedbacks are modelled. Among the scientific community, one way to manage this uncertainty is to use an ensemble of GCMs instead of an individual model (as done by CSAG to provides downscaled data for the Olifants River catchment). Modeling the impacts on water resources used a technique called the GCM 'skill' analysis. Further details are given in Appendix 1.

3.2 Predicted impacts of climate change on temperature & rainfall

Temperature

The analysis indicated a strong signal of change for temperature *(see Resource 9: Technical Report 25-29: Historical Trends & Climate Projections for local Municipalities).* The annual mean of daily maximum and minimum temperatures has already significantly increased over the past decades, and is projected to continue to increase. Furthermore, the number of very hot days, although not having changed significantly over the last decades, is projected to increase under both scenarios. There is generally concurrence with other data (Appendix 2).

TABLE 2: YEARLY MEAN OF DAILY MAXIMUM TEMPERATURE AS PREDICTED BY STUDIES IN THE OLIFANTS RIVER CATCHMENT

The first three studies represent hydrological modelling based on selected models (see text)

	BASE PERIOD	MID-CENTURY (CELSIUS)	END-CENTURY (CELSIUS)	NUMBER OF GCMS USED	NOTES
SAWUNYAMA & MALLORY, 2014	**1960-1980**	**2-4**	**10**		
CSAG	**1979 - 2013**	**2-3**	**Up to 4-5**	**15**	**Statistical downscaling**
TALUKDER, 2019	**1985-2005**	**1.7**	**4.6**	**9**	

Rainfall

For rainfall, the results are less clear. When running all models, most models projected no change in rainfall patterns into the future (see Kong et al., 2018). However, there were discrepancies amongst the models and future rainfall patterns are uncertain[1]. Only the Coastal region had a statistically significant increase in the total annual rainfall, in terms of the number of days with rainfall exceeding 20 mm and duration of dry spells per year.

However as noted above, for the purposes of hydrological modeling, only best-fit models are used (i.e. they best model observed rainfall data; see Appendix 1). In our study, all projections show a decrease in mean annual precipitation (3% to 20%) for the Olifants Catchment (based on sites used), and a decrease in both summer and winter rainfall with increased temperatures (Sawunyama & Mallory, 2014). There is generally concurrence with other data.

[1] Results aligned with findings from the CSIR Long-term Thematic Programme, South Africa, and International Development Research Centre, which also found strong signals for increased temperature, but less clarity in projected changes in rainfall for the region.

TABLE 3: PERCENTAGE CHANGE IN ANNUAL MEAN PRECIPITATION AS PREDICTED BY STUDIES IN THE OLIFANTS RIVER CATCHMENT

The first three studies represent hydrological modelling based on selected models (see text)

REFERENCE	BASE PERIOD	MID-CENTURY (%)	END-CENTURY	NUMBER OF GCMS USED	NOTES
SAWUNYAMA & MALLORY, 2014	1960-1980	-9.1 to +8	N/A	10	
SCHULZE & DAVIS, 2019	1976-2005	-12 to + 4		5	
TALUKDER, 2019	1985-2005	-11	-23	9	Mean annual max % change
CSAG	1979 - 2013	*	*	15	Statistical downscaling

* mostly no significant change other than coastal area increase, however there was statistical significance showing increase in rainfall events above 20mm and an increase in duration of dry spells

TABLE 4: CHANGES IN RUNOFF AND POTENTIAL EVAPORATION TRANSPIRATION FOR THE OLIFANTS RIVER CATCHMENT

STUDY	BASE PERIOD	MID-CENTURY (%)		END-CENTURY (%)		NUMBER OF GCMS USED
		Runoff	EVT	Runoff	EVT	
SAWUNYAMA & MALLORY, 2014	1960-1980	-20 to 60	11			15
SCHULZE & DAVIS, 2019	1976-2005	-20 to -60	4 to 12*			5
TALUKDER, 2019	1985-2005	-30	4	-40	11	9

*Crop irrigation requirement

3.3 Stream flow reduction

Based on the GCMs results (baseline and future), a significant decrease in runoff of over 60%[2] is expected (Figure), mainly due to the impacts of increased temperatures (by about 0.5 to 3^0 C) and to a lesser extent a possible reduction in rainfall of 10- 20%) Higher temperatures result in an increase in evaporation of between 10 to 15% (see Table 4). Flows are projected to decline between 20 to 60% in the Olifants River Catchment (Table 2 and Figure 8). Again, this is supported by Schulze and Davis (2018).

[2] *It is assumed in this study that two scenarios representing a wet and dry scenario of streamflow will cover the envelope of all GCMs and can be used as a basis for future planning.*

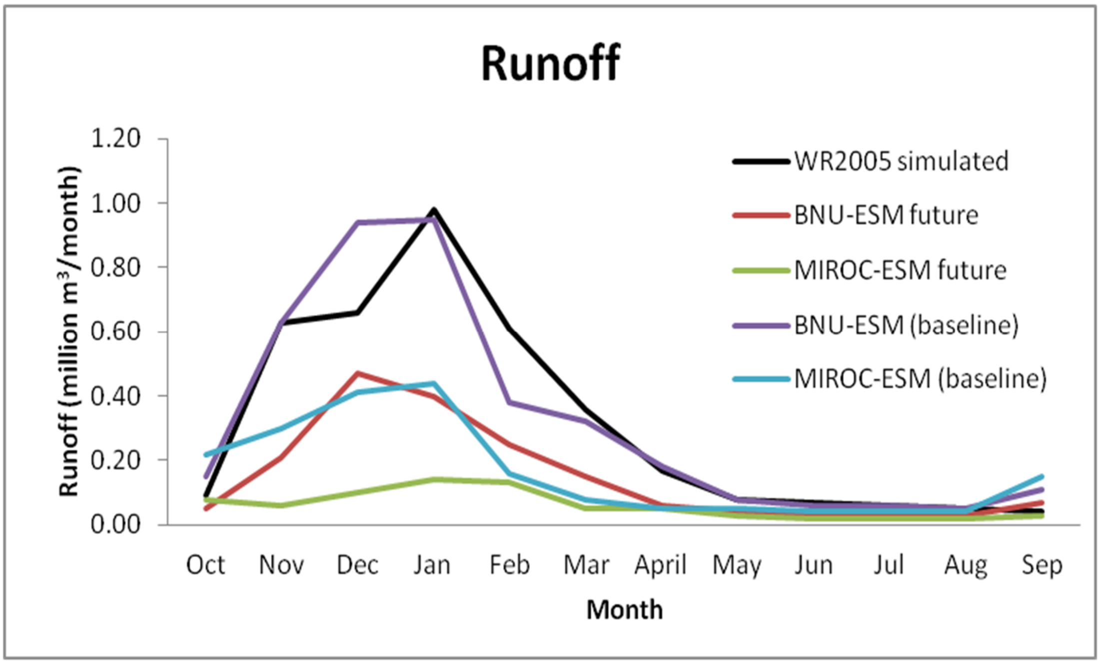


Figure 8: Illustration of seasonal impacts of climate change to runoff (wet and dry scenarios) for B31E quaternary catchment (near Groblersdal) (from Sawunyama & Mallory 2014). For an explanation of each scenario refer to Appendix 1.

These results are corroborated by findings from more recent studies which emphasise the significant role that evaporation plays in the reduction of stream flow (Table 4). Schulze and Davis (2019) indicated a decline in streamflow of between 20 to 60% increasing in an easterly direction to the Mozambican border along the western boundary of the Kruger National Park (Figure 9). This is some of the highest in the country.

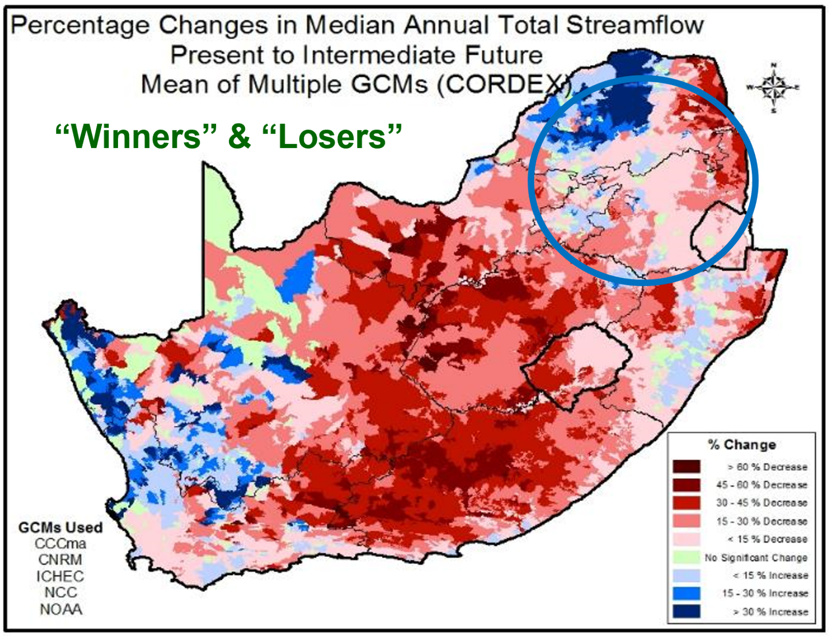


Figure 9: Map of percentage predicted changes in streamflow. The darker the red colour the greater the percentage change (>60%). The circle roughly indicates the Olifants River and neighbouring catchments. (from Schule & Davis 2018)

3.4 Water availability

This section summarises the results from a water availability assessment as part of the climate change modelling for the Olifants River catchment. The future yield for 10 major dams in the catchment was modelled using the Water Resources Modelling Platform (WReMP) using projected climatic variables such as precipitation and evapo-transpiration. The latter variable was estimated based on projected temperature changes.

The Sawunyama and Mallory (2014) study showed climate projections based on the Coupled Model intercomparison Project Phase 5 (CMIP5) models3 from the IPCC 5th Assessment Report for the scenario of RCP 8.5. Ten global climate models (GCMs) were empirically downscaled by the Climate Systems Analysis Group (CSAG) at the University of Cape Town, using the Self-Organizing Map Downscaling (SOMD) technique.

Based on this analysis, there will be a dramatic reduction in yield of the dams in the Olifants River catchment (see Table 5). Moreover, it should be pointed out that the climate change analysis did not include the Letaba Catchment and hence the reduction in yield of the Massingir Dam is probably underestimated. The reduction in yield will be dramatic if either of the two climate change scenarios analysed should materialise, with reductions in yield of up to 60%. Again this will have a potentially devastating effect on the economy of the region and livelihoods if mitigation measures are not taken.

TABLE 5: RESULTS FROM THE CLIMATE CHANGE YIELD ANALYSIS

DAM	CHANGE IN MEAN ANNUAL RUNOFF (%)		CHANGE IN YIELD (%)	
	Wet Scenario	**Dry Scenario**	**Wet Scenario**	**Dry Scenario**
BRONKHORSTSPRUIT	-3.43	-9.14	0.00	-19.70
WITBANK	-8.13	-8.69	-52.48	-60.14
MIDDELBURG	-8.07	-8.07	-59.63	-59.17
LOSKOP	-6.86	-8.44	-23.06	-54.68
MKHOMBO	-8.03	-8.86	-53.33	-55.83
FLAG BOSHIELO	-7.22	-8.58	-65.09	-65.09
DE HOOP	-7.61	-7.61	-40.32	-40.32
BLYDERIVIERSPOORT	-9.53	-9.44	-57.80	-55.57
PHALABROWA	-8.68	-9.22	-48.66	-43.16
MASSINGIR	-8.75	-9.25	-9.01	-9.43

3.5 Systemic impacts

Such a large reduction in stream flow is like to significantly alter the flow regime by impacting on all components of the hydrological regime (Figure 4) and may ultimately negatively impact the riverine ecosystem and the production of ecosystem goods and services (Figure 5). For example, when looking at what increased temperatures might mean for the agricultural sector, Schulze and Davis (2019) found that the crop irrigation requirements in the Olifants River catchment were likely to increase significantly by between 4 to 12 % across the catchment (Figure 7). This increase in demand, due to increased evapo-transpiration, would change the water balance drastically and may push some sub-catchments into water deficit. *(See Resource 3: Overview of Water Quality & Quantity Olifants River Catchment).* Irrigation is the largest water use in the Olifants Catchment– accounting for approximately 68% of total water requirements. Farmers may attempt to keep the same areas of crops under irrigation but with a higher irrigation demand resulting in an increase in unlawful use if not regulated.

Currently, due to the high abstraction from the rivers of the ORB, implementing the Reserve and water for Mozambique relies heavily on the operations of dams rather than simply run-of-river. The possible reductions in yield are likely to spark tensions between ensuring short-term economic development and longer-term sustainability of river systems so that they can continue to support livelihoods and development. Additionally, availability may decrease due to a decline in water quality as reduction in streamflow results in reduced dilution potential (for pollutants). Furthermore, as flows reduce, we may see more silt deposition in the rivers and dams further reducing the storage capacity. Availability of water with acceptable quality is necessary for potable water supplies and economic activities such as irrigated agriculture and nature-based tourism. Together with livelihood insecurity, dimensions of human well-being such as economic and social well-being and public health are all threatened by climate change through the impacts on water resources.

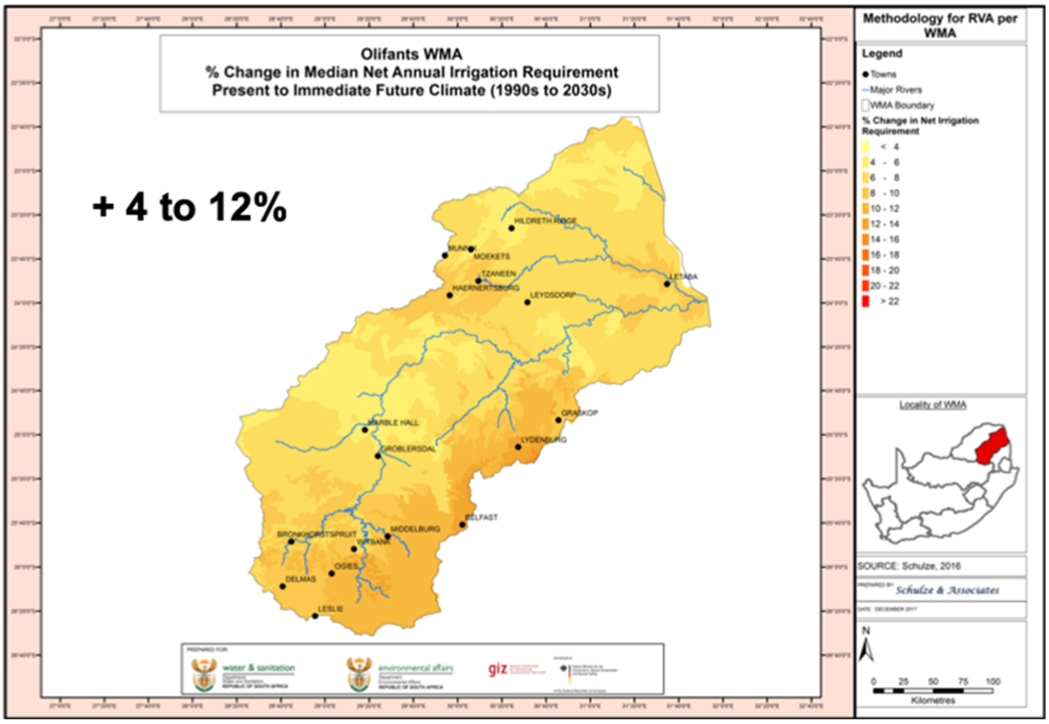


Figure 5: Net annual irrigation requirements under conditions of climate change
Source: Schultze and Davis (2019)

4 Conclusion

Excessive demand (mainly from expanding mining and agriculture) combined with unlawful use, weak governance and outdated planning documents have rendered water security of the Olifants River Catchment highly vulnerable. Water quality is a major problem and declining water availability and stream flow in many sub-catchments is already severely compromised. The predictions of climate change impacts on water resources of three recent studies all concur: with increased temperatures and evaporation and evapo-transpiration, and a potential decline in rainfall, we are likely to see major declines in water availability and stream flows.
The impacts will propagate through the system in multiple ways, impacting not only on aquatic health but also directly on human livelihoods, human health and the economy. The potential for social and political strife is high.

***Mitigation measures** need to be urgent & a key focus needs to be water resources management in the Olifants Catchment*.

As we persistently report, this requires:

1. A systemic approach to IWRM and water governance of the catchment
2. The re-instatement of catchment-based management
3. An updated reconciliation study that takes into account climate change as well as international needs, the needs of the Reserve, proper regulation of water use, integrated water allocation and operation practices
4. If need be, compulsory licencing

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The Association for Water and Rural Development

AWARD is a non-profit organisation specialising in participatory, research-based project implementation. Their work addresses issues of sustainability, inequity and poverty by building natural-resource management competence and supporting sustainable livelihoods. One of their current projects, supported by USAID, focuses on the Olifants River and the way in which people living in South Africa and Mozambique depend on the Olifants and its contributing waterways. It aims to improve water security and resource management in support of the healthy ecosystems to sustain livelihoods and resilient economic development in the catchment.

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About USAID: RESILIM-O

USAID: RESILIM-O focuses on the Olifants River Basin and the way in which people living in South Africa and Mozambique depend on the Olifants and its contributing waterways. It aims to improve water security and resource management in support of the healthy ecosystems that support livelihoods and resilient economic development in the catchment. The 5-year programme, involving the South African and Mozambican portions of the Olifants catchment, is being implemented by the Association for Water and Rural Development (AWARD) and is funded by USAID Southern Africa.

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