Southern Africa Projections and Impacts Guidance Paper

Cross Cutting - Climate Resilience

Final

July 2019

www.cridf.com

Contents

List of Figures

List of Tables

List of acronyms and key terms

Acronym	Long-Form
CRIDF	Climate Resilient Infrastructure Development Facility
AR	Assessment Report
CCRA	Climate Change Risk Assessment
CCRM	Climate Change Risk Management ltd.
CMIP3	Coupled Model Intercomparison Project Phase 3
DFID	Department for International Development
ENSO	El Nino Southern Oscillation
GHG	Greenhouse Gas
GM	Genetically Modified
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
MAAT	Mean Annual Air Temperature
PMU	Project Management Unit
RCP	Representative Concentration Pathway
“the region”	Southern Africa
SADC	Southern African Development Community
SOM	Self-Organising Map
SST	Sea Surface Temperature
VMT	Vulnerability Mapping Tool

1.1 Introduction

The Climate Resilient Infrastructure Development Facility (CRIDF) is a DFID supported programme working to provide long-term solutions to water issues that affect the lives of the poor in Southern Africa. CRIDF has three core mandate areas that guide its efforts: **pro poor** – ensuring that water infrastructure benefits the poorest; **climate resilience** – delivering infrastructure that is appropriate to both current extreme events and future climate change, and **transboundary** – promoting cooperation over the use of international water resources. CRIDF is therefore committed to ensuring climate resilience is practically integrated into all stages of the project preparation cycle; in order to do so, there is a need to apply a systematic assessment of the vulnerability and risks associated with CRIDF's portfolio of infrastructure projects (Figure 1).

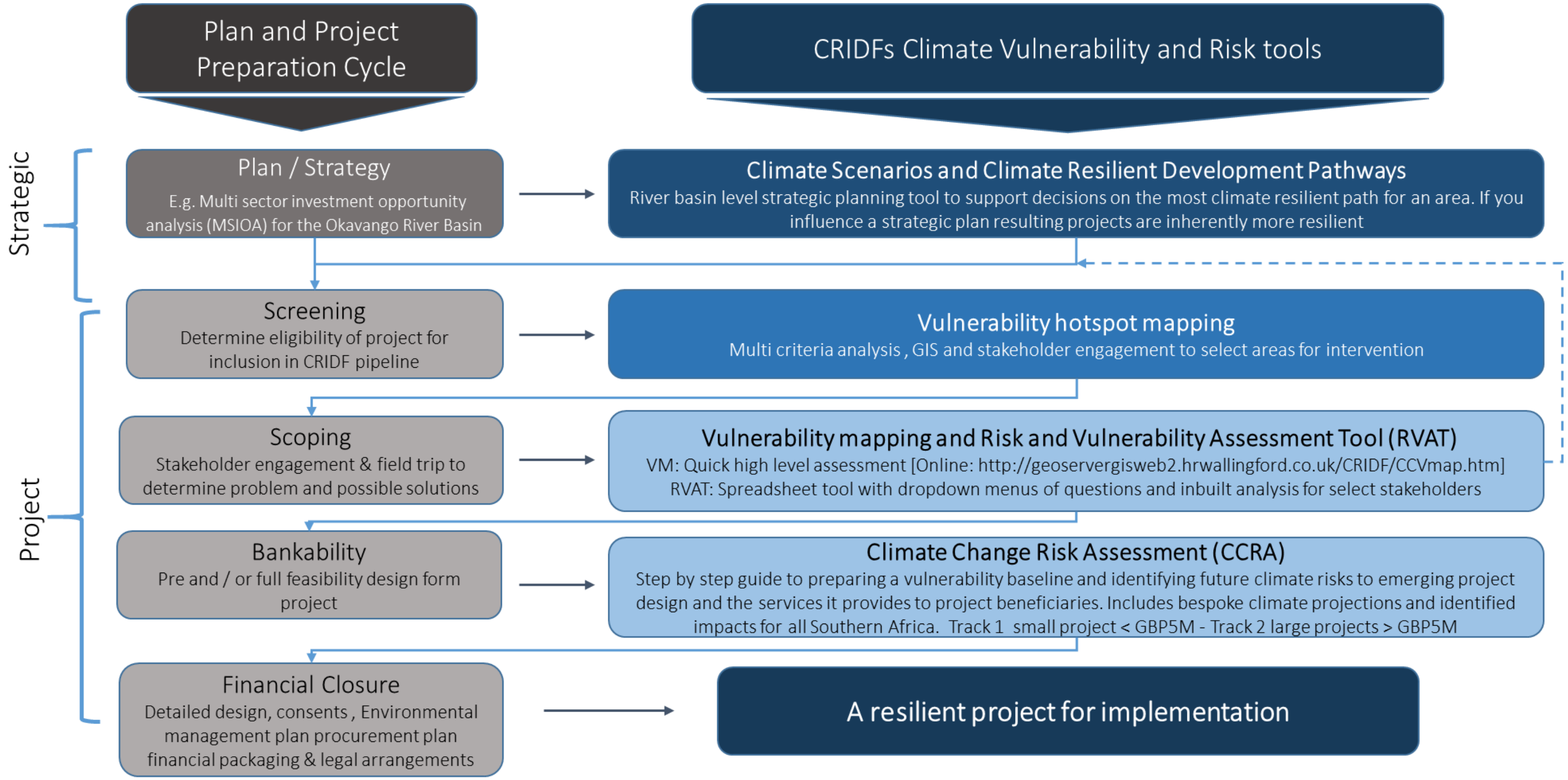

Figure 1: Mainstreaming climate resilience into water infrastructure preparation

Progress to date

After successfully developing and rolling out a Vulnerability Mapping Tool (VMT) for application during the Scoping/Pre-Feasibility Stages of all projects, CRIDF proceeded with designing a systematic protocol[1] for assessing the climate risks associated with each infrastructure project as it reaches detailed design. It was envisaged that the Climate Change Risk Assessment (CCRA) protocol would consider the following aspects:

- Past climate risks and capacity of beneficiary communities to adapt;
- Current vulnerability (using the Vulnerability Mapping Tool[2] as a preliminary basis)
- An analysis of future climate variables (including *projections, impacts* and *uncertainty*)
- Details of the project's technical components, as well as topography, environment, demographics, institutions and socio-economic considerations.

Purpose of the paper

The purpose of this paper is to complement the CCRA Track 1 Protocol developed for smaller projects[3], by providing a consistent set of Southern African climate projections in the most cost appropriate and effective manner. These are accompanied with the identification of the most likely on-the-ground impacts associated with these projections, which have been derived from a literature review conducted by climate scientists (located in both South Africa and the United Kingdom). For the purposes of reporting theses impacts in as meaningful way as possible (noting the large scale of the region), Southern Africa has been divided into 5 agri-climatic zones where particular projections and impacts are approximately correlated (see Figure 2).

Moreover, these projections and impacts are accompanied by a discussion on the risks and uncertainty associated with these information sets, using evidence from a statistical technique called Self Organising Maps (SOMs) which help to provide a basis for managing the uncertainly inherently associated with using a suite of climate models[4].

It has always been envisaged that the projections, impacts table, tools and CCRA methodology developed by CRIDF should ultimately be disseminated to a broad range of players, for wider application across the region. This paper therefore also serves as a summary document for external audiences, and references more detailed literature, CORDEX mapping outputs and SOMs produced by CRIDF Experts that support the information and findings contained in this document. These documents, along with the Protocol, can be found at www.cridf.com.

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[1] See '*Resiliency Screening and Climate Change Risk Assessment Guidelines (Protocol)*', www.cridf.com
[2] http://geoservergisweb2.hrwallingford.co.uk/CRIDF/CCVmap.htm
[3] Definition of 'smaller' versus 'lager' projects is explained in Figure 1, according to the monetary value of a project's CapEx; footnote 8 on page 11 further elaborates this.
[4] Described in more detail in Section 0

1.2 Methodological approach to developing SADC projections and impacts tables

In recent years, over 40 global atmospheric and oceanic climate models have been developed, summarised and reported against in the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (AR). The IPCC's AR5 states that future climate changes will have a wide range of impacts across Southern Africa – including changes in ecosystems, water stresses and agricultural systems. In addition, there is a high confidence that managing risk and developing adaptive capacities for ensuring food security, managing health vulnerabilities and governance systems will be insufficient to deal with the predicted impacts of climate change in the short (2025) and medium (2055) term.

Predicted future patterns of atmospheric circulcation in Southern Africa are not well known, but it is widely recognised and accepted that the zonal circulation within the Hadley cell[5], the Inter Tropical Convergence Zone (ITCZ) location and dynamics, the passage of cyclones from the Atlantic and Indian oceans, and the impacts of changing El Nino strength, are important as climate drivers in the region. This has been examined in numerous studies, where the climate impacts on key aspects of sustainability in Southern Africa (primarily food and water security) have been explored. However, what is still missing is an integrated approach to consider feedback loops and interconnections between physical and human environmental systems, and the ways in which they converge on aspects of sustainability of the human environment, health and wellbeing.

The following sub-sections outline key elements of the methodological approach that have shaped the development of the sets of projections and corresponding impacts, in a form that is consistent with available science.

Sub-Regional climatic zones

IPCC findings indicate that the extent, type and intensity of hydroclimatological hazards will differ significantly across the region; the region should therefore not be viewed as a single climatic zone, but rather as five sub-regional zones (see Figure 2 below). The boundaries between adjacent zones are particularly sensitive to change; there is thus highest climate variability and predictive uncertainty in these areas. However, more information is still needed on the rate of environmental change as a result of climate change at these boundary areas between climatic zones, and any analyses of the projections and impacts of climate change at project sites located near these boundaries must acknowledge these uncertainties.

[5] The Hadley Cell is a tropical atmospheric circulation: air rises up at or near the equator, flows toward the poles above the surface of the Earth, returns to the Earth's surface in the subtropics, and flows back towards the equator.

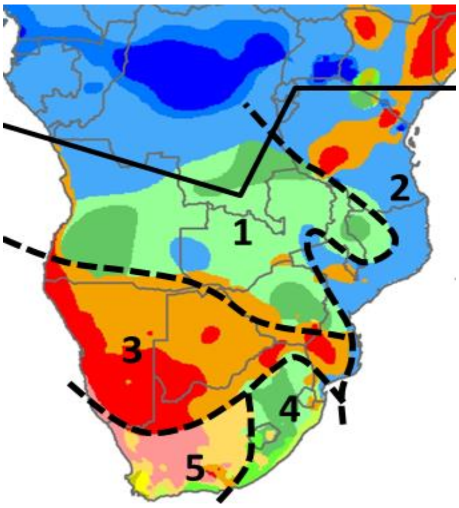

Figure 2: Climatic zones in SADC

- **Region 1**, Summer ITCZ region. Angola, Zambia, and Malawi, central and NE Zimbabwe - This is a temperate/tropical region with dry winters (subtropical high-pressure cells) and rainy summers (tropical lows driven by seasonal migration of the ITCZ).
- **Region 2**, Summer Indian Ocean cyclone/monsoon zone. Mozambique, Tanzania - Tropical/seasonal monsoon climate characterized by incoming cyclones from the Indian Ocean.
- **Region 3**, Arid descending arm of Hadley cell. Namibia, Botswana, SW Zimbabwe, S Mozambique - This region has a negative hydrological balance, low and variable precipitation and seasonally high temperatures.
- **Region 4**, Temperate cyclonic zone. E South Africa, Swaziland, and Lesotho - This region has a wet summer regime with thunderstorms and subtropical cyclones.
- **Region 5**, Semi-arid/winter rainfall zone. W South Africa - This region is characterized by a steppe climate inland with winter rainfall and fog at the coast.

Representative Concentration Pathways

Representative Concentration Pathways (RCPs) are greenhouse gas concentration trajectories that describe varying climate future scenarios, where the higher the number at the end of each 'RCP', the higher the emissions and atmospheric GHG concentrations. The five RCPs used in the 5th Assessment Report by the IPCCC (AR5) are in order of concentration, from least to more concentrated.

- RCP 2.6
- RCP 4.5
- RCP 6
- RCP 8.5

The work undertaken by CRIDF toward developing the projections and impacts data for the five SADC climate zones focussed on two of the four RCP scenarios considered by the IPCC AR5 – that is, RCP4.5[6] and

[6] RCP4.5 is a stabilisation scenario that assumes climate policies on GHG emission prices will be invoked in time for emissions to peak around 2040, and then begin to decline

RCP8.5[7]. Climate Scientists currently expect that the most likely scenario will fall somewhere between these two RCPs – although it is worth flagging that some recent studies have suggested that climate change could exceed the projections under RCP8.5.

It should be noted that while temperature changes increase progressively across higher RCPs, the same cannot be said for rainfall. Models indicate that rainfall does not consistently intensify in the same direction as the concentration of GHGs due to the extensive number of variables affecting precipitation, and the complex relationships between annual totals and seasonality of precipitation and evaporation. The impacts table therefore presents median estimates of change in precipitation with corresponding guidance in the text on appropriate values to be used for infrastructure planning purposes.

Timescales

The climate change projections and impacts have been considered under two time scales; i) short term (2025: representative of the period 2016 – 2035) and ii) medium term (2055: representative of the period 2046 – 2065)[8]. High-level predictions at these time scales include:

- **Short time scale**: Over the next ten years, climate variability is expected to increase across the region, consistent with present day climate patterns and synoptic circulation. Over this are superimposed short time scale variations imposed by strong ENSO (El Nino Southern Oscillation) events, although the effects on the strength of the Indian Ocean dipole are uncertain. It is more likely that strong cyclone events from high SST (sea surface temperature) in the Indian Ocean will continue at this time, resulting in flooding to eastern coasts of southern Africa.
- **Medium time scale**: Changes in temperature and precipitation patterns will show higher variability across the region, with feedbacks associated with decreased humidity and land surface aridification under hotter climates as a result of decreased rainfall, especially seasonally. Land surface feedbacks become more significant controls on hazard responses and climate impacts. That is, geomorphology (land surface processes) and land use play an increasingly important role in driving hazards and in understanding the impacts of climate change. Continentality effects become more pronounced as inland areas become dryer, with smaller changes observed along the coast.

[7] RCP8.5 is characterised by increasing GHG emissions throughout the 21st Century. It assumes anthropogenic GHG emissions continue beyond 2100 and is the most extreme trajectory currently considered by climate scientists

[8] These are considered sufficient for smaller scale infrastructure planning (below £5,000,000). Larger scale projects should also use the third IPCC time scale of 2080.

1.3 CORDEX Projection Mapping

CORDEX is a set of projections from Regional Climate Models (RCMs). RCMs work over a limited domain at higher resolutions than the global models, both spatially and temporally.

CRIDF's climate modellers undertook to look at the range of IPCC CMIP3 (Coupled Model Intercomparison Project Phase 3) (AR4), CMIP5 (Coupled Model Intercomparison Project Phase 5) (AR5) models and CORDEX downscaled outputs, to understand the variability in projections for temperature, rainfall and seasonality for the southern African region.

These sets of projections provide one with an ensemble of what probable future temperatures and annual rainfall totals may be at a given timescale and at a specific geographic location in southern Africa (see Figure 3 and Figure 4 below).

It should be noted that CORDEX projections do not provide one with information on variability and timing/duration of rainfall, heatwaves, frosts etc. It is therefore recommended that the information drawn from the CORDEX maps be coupled with discussions and interviews[9] with the project team and key stakeholders to ascertain whether/what noticeable changes in the variability and intensity of rainfall may have occurred in recent years. This will allow one to develop a more useful interpretation of the information contained in the CORDEX maps. An example of this is that the maps may suggest a high increase in annual rainfall at a certain location, which would support the notion of rain fed agriculture. However, local stakeholders may inform the project team that they receive majority of this rain over a very short space of time and do not have the infrastructure in place to collect and store the water – rendering it useless for sustained agricultural practices year-round.

[9] Detailed guidance on conducting these interviews provided in '*Resiliency Screening and Climate Change Risk Assessment Guidelines (Protocol)*', www.cridf.com

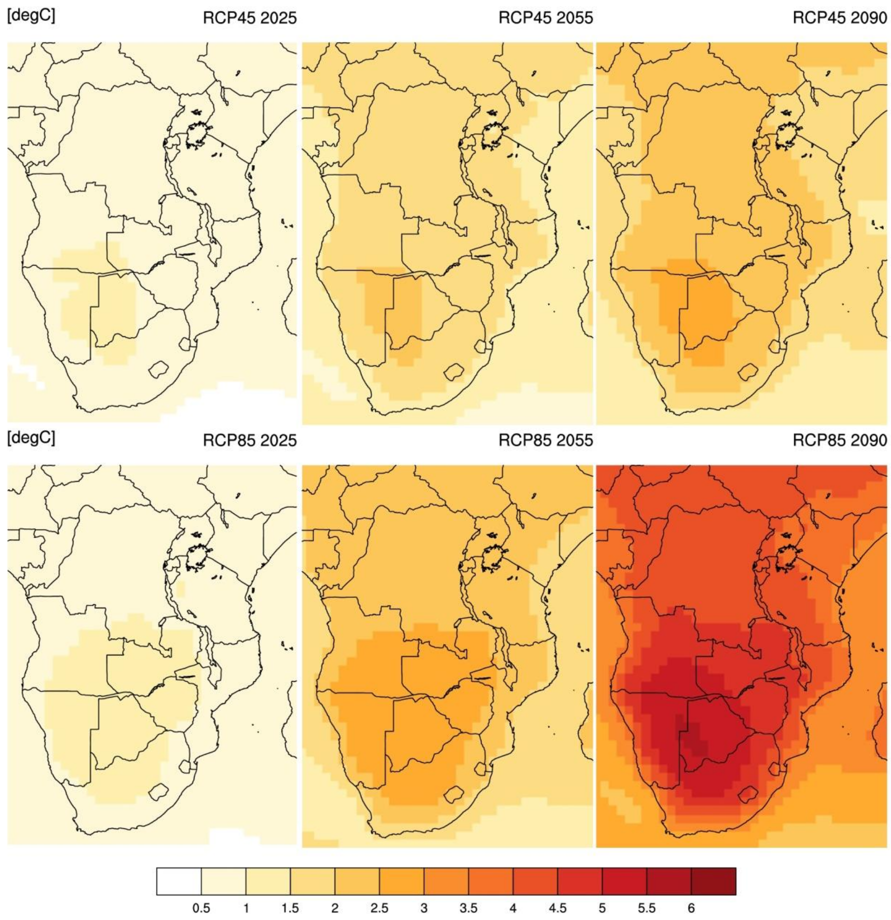

Figure 3: Ensemble mean average annual temperature rises from the AR5 ensemble; the scale is the change in °C for timescales 2020, 2055 & 2090

In general, the greatest rises in temperature are in central parts of the SADC region, in particular over western Zimbabwe and eastern Namibia, with predicted annual average temperature rises approaching an unprecedented 6°C by the end of the 21st Century under RCP8.5. Increases for the coastal areas are a little lower than this, although in the upper region they still exceed 5°C by the end of the Century under RCP8.5.

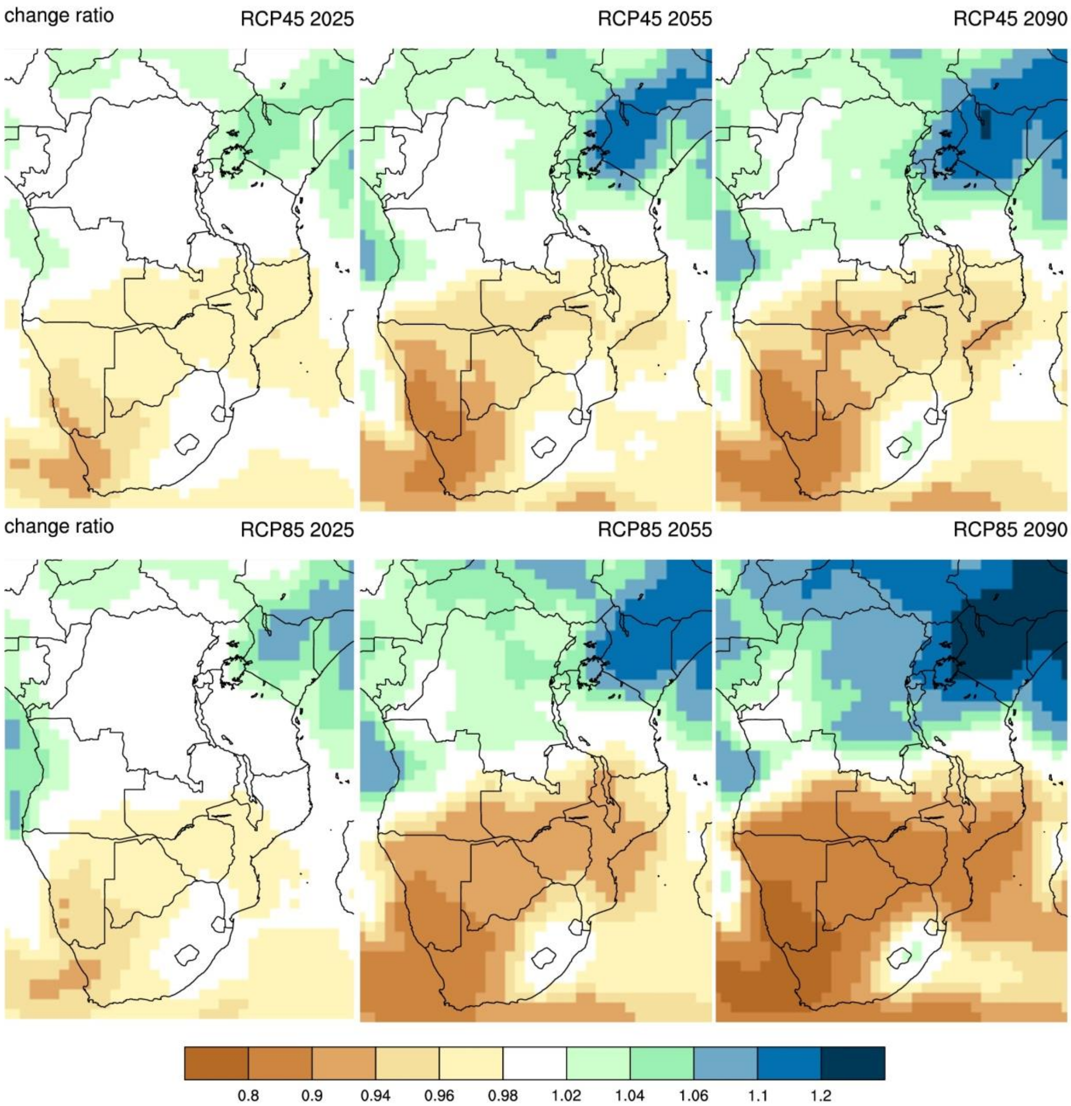

Figure 4: Changes in annual rainfall totals according to the ensemble means for RCPs 4.5 and 8.5 calculated as ratios (on scale) for timescales 2020, 2055 & 2090

According to these ensembles, mean average annual rainfall totals will decline into the future, to below 70% of current values by the end of the Century in an area to the north of Cape Town under RCP8.5. Almost the only parts of the SADC region in which future increases will occur according to these results are north-western Angola, northern Tanzania, small areas of South Africa around Kwazulu-Natal, and Lesotho.

1.4 Climate Scenarios for southern Africa

Future climate scenarios for different parts of southern Africa have been developed for various CRIDF projects using a statistical technique called Self Organising Maps (SOMs). As discussed above, there are a wide range of climate models generating a range of results in terms of temperature and rainfall projections. The figure below is a scatter graph showing the temperature and rainfall plots of over 30 models for the Angolan highlands. The plot shows that this is not normally distributed and using a simple mean will not capture the range in the future climate variables. SOMs is a statistical technique that groups similar data together in clusters. Essentially, it simplifies and displays similarities among data. The red and blue triangles are the two data points that were identified using SOMs on the GCMs that covered the Angolan Highlands.

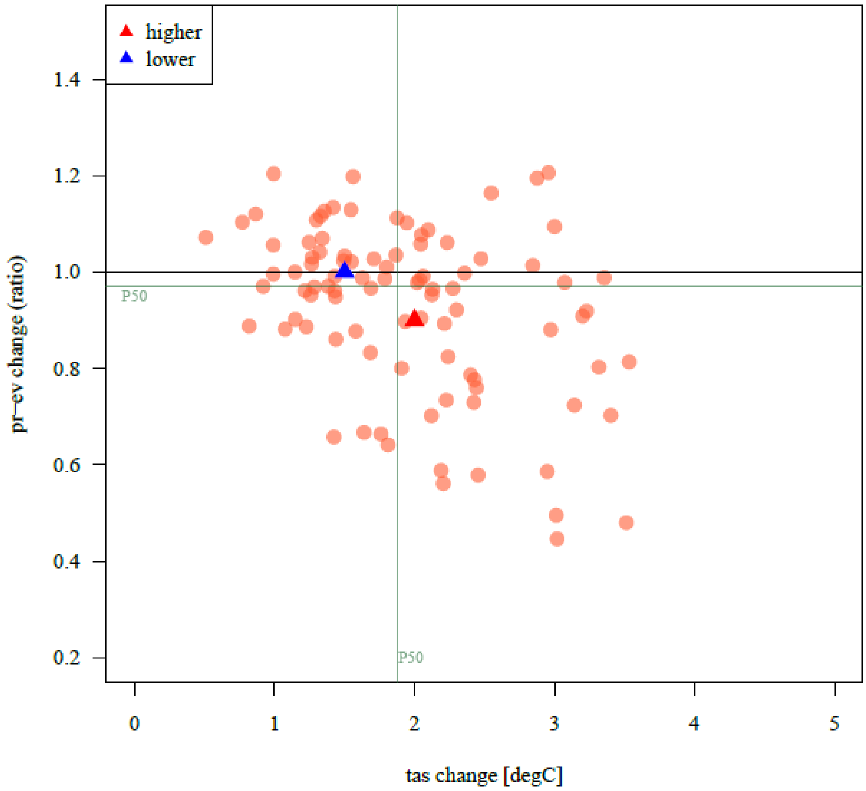

Figure 5: Scatter graph of temperature and rainfall plots for the Angolan highlands

SOMs are a good basis for creating future climate scenarios. CRIDF has now undertaken a number of these analyses within southern Africa. A SOMs analysis was undertaken for the whole of southern Africa but it was regarded as being too high level and not able to account for the sub regional variations contained in the climate zone map (Figure 2). The map and list below show the coverage of the more detailed SOM projections; whilst there are some gaps, they do provide coverage for a large portion of the region.

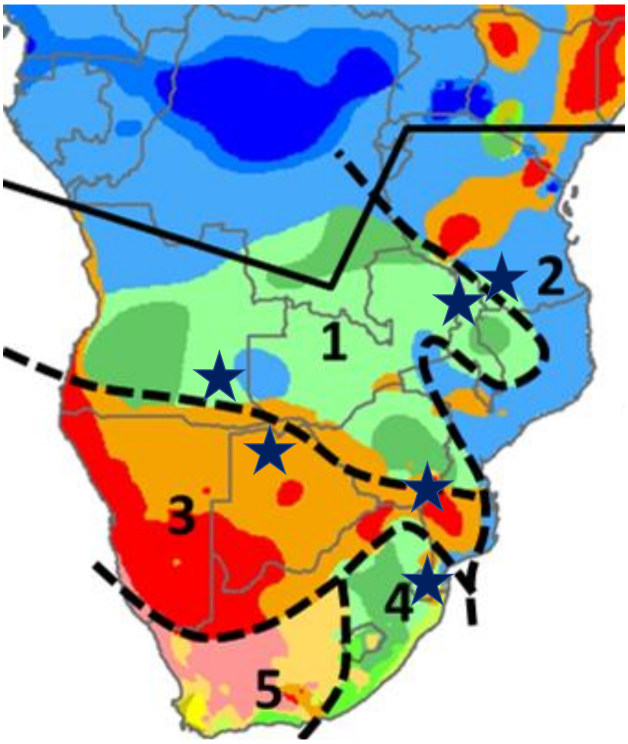

Figure 6: Coverage of more detailed SOM projections – indicated with 'star' symbols

- Zone 1 - Angolan Highlands
- Zone 1 - Northern Malawi
- Zone 2 - Southern Tanzania
- Zone 3 - Southern Zimbabwe / Mozambique
- Zone 3 - Botswana Okavango Delta
- Zone 4 - Swaziland

Climate scenarios developed for specific CRIDF projects are reproduced below. The closest of these scenarios can be used to inform a vulnerability and or climate change risk assessment for any new CRIDF investment in the relevant area. The scenarios do not cover the whole region perfectly and many of them are on the edges of agri-climatic zones; these issues must be taken into consideration during an analysis. Consequently, it is probably better to regard these scenarios as an indication of the direction and possible extent of change in the area the project is located, rather than unimpeachable predictions.

The scenarios are designed to demonstrate the range of possible climate changes that project preparation teams need to be aware of during the planning and design stages. When trying to decide how to incorporate these scenarios into project planning and design, it is useful to remember the old risk saying, *"hope for the best but plan for the worst".*

The scenarios include a notional indication of the relative likelihood of them occurring. It is important to understand that the first two scenarios are regarded as 'core' scenarios and not extremes. Some of the locations also have extreme scenarios to help understand the full range of possible futures**. Consequently, it is recommended that you do not regard the difference in likelihood between the core scenarios as significant**.

An additional consideration for incorporating the range of possible future scenarios into a project's design is the need to study the nature of the project. If the project is large scale with a long design life and is likely to influence further economic development in the region in years to come, it is worth designing a project to withstand more risk. If the project is smaller scale and has a shorter viable life span, then one may be willing to accept the greater risk associated with a less resilient design.

Angola: Zone 1 (South West)

Likelihood	2020s		2050s		2090s	
	Temp	*Rain - Evap*	*Temp*	*Rain - Evap*	*Temp*	*Rain - Evap*
60%	0,75^{0}C	1.00	1,5^{0}C	1.05	2.0^{0}C	1.05
35%	1.25^{0}C	0.75	2.0^{0}C	0.75	2.5^{0}C	0.75
5%	2.0^{0}C		5.0^{0}C		7.0^{0}C	0.45

Scenario 1 – (current climate no climate change): The Angolan highlands in the southern part of the country are the headwater areas for the Okavango and the Zambezi river basins as well as the Cuvelai and Cunene rivers. It is characterised by higher elevation areas, orographic rainfall, a high river drainage density, and falls within the ITCZ which is a summer rainfall zone with dry winters. The hottest months in the Okavango are December to February where average daytime temperatures can be as high as 40°C and humidity is high. The Okavango delta experiences heavy afternoon thunderstorms during this period accounting for most of the annual rainfall. March to June temperature cools down and average temperatures reach around 30°C. The winter months of June to September are dry and cold with night-time temperate dropping to close to freezing10.

Scenario 2 – (higher likelihood): By 2025 the average annual temperature in the upper basin will be 0.75ºC higher than the average annual temperature between 1986 and 2005. This rises to 1.5 ºC by 2055. The rainfall (less evaporation) remains the same or may slightly increase during these two time periods. In most emissions pathways there are more variations in the early season rainfall than in the late season. In addition, the late season better reflects the full season. There are likely to be substantial increases in warm spells suggesting extended droughts. Unsurprisingly, there are decreases in cold spells which mean there are fewer days with reduced evaporation. Similarly, three of the indicators of flood seem to indicate that there could be either increased or reduced flood risk. On the other indicators for flooding there is a slight bias to reduced flood risk from rainfall less evaporation. Furthermore, there could be a 36% increase to the dry season length.

Scenario 3 – (lower likelihood): By 2025 the average annual temperature is 1.25 ºC higher than the average annual temperature between 1986 and 2005. This rises to 2.0ºC by 2055. The rainfall less evaporation in the upper basin reduces by 25% by 2025 from the 1986 – 2005 average, and maintains this reduction though to 2055 and beyond. In most emissions pathways there are more variations in the early season rainfall than in the late season. In addition, the late season better reflects the full season. There are likely to be substantial increases in warm spells suggesting extended droughts. There are decreases in cold spells which mean there are fewer days with reduced evaporation. Three of the indicators of flood seem to indicate that there could be an increase in flood risk due to rainfall intensity and maximums of between 3 and 30%. On the other indicators of flood there is a slight bias for reduced risk. Furthermore, there could be a 36% increase in the dry season length.

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[10] Read more: http://www.wordtravels.com/#ixzz4cu0TL0vx

In short there is over 25% difference in the rainfall between the lower and higher options. Temperature differences only vary by 0.5ºC. There seems to be more potential variation in scenario 1 than scenario 2, where scenario 2 suggests a clearer reduction in rainfall (less evaporation).

Scenario 4 – (extremes): By 2025 average annual temperatures could be approaching 2.0ºC above the 1986-2005 average, 5.0ºC by 2055 and over 7.0 ºC by 2090. Rainfall could see up to a 55% reduction *or* a 50% increase by 2055 through to 2090.

While the extreme projections fall outside of the higher and even lower probability scenarios, they are *still possible*. It is also clear that temperature increases and precipitation variability within this range would fundamentally alter the conditions for ecosystem and livelihood sustainability and the operation of infrastructure designed according to historic and present day framework conditions in the Okavango basin.

Botswana: Zone 3 (North Central)

Likelihood	2020s		2050s		2090s	
	Temp	*Rain - Evap*	*Temp*	*Rain - Evap*	*Temp*	*Rain - Evap*
60%	1.0^{0}C	0.8	2.0^{0}C	0.8	2.25^{0}C	0.8
35%	1.0^{0}C	1.05	1.5^{0}C	1.10	2.0^{0}C	1.10
5%	2.0^{0}C		5.0^{0}C		7.0^{0}C	0.45

Scenario 1 – (current climate - no climate change): Botswana lies within the arid climate zone of the descending arm of Hadley cell, with low and variable precipitation, high temperatures, and a negative water balance. This covers the part of the basin in Namibia and Botswana. The hottest months in the Okavango are December to February where average daytime temperatures can be as high as 40°C and humidity is high. The Okavango delta experiences heavy afternoon thunderstorms during this period, accounting for most of the annual rainfall. March to June temperature cools down and average temperatures reach around 30°C. The winter months of June to September are dry and cold with night-time temperatures dropping to close to freezing.

Scenario 2 – (higher likelihood): By 2025 the delta experiences slightly warmer conditions (1.0 ºC) during the same period. This rises to 2.0ºC in the delta by 2055. The rainfall (less evaporation) reduces by 20% during these two time periods. In most emissions pathways there are more variations in the early season rainfall than in the late season. In addition, the late season better reflects the full season. There are likely to be substantial increases in warm spells suggesting extended droughts. Unsurprisingly, there are decreases in cold spells which mean there are fewer days with reduced evaporation. Similarly, three of the indicators of flood seem to indicate that there could be both increased and reduced flood risk. On the other indicators of flood there is a slight bias to reduced flood risk from rainfall less evaporation. Furthermore, there could be a 36% increase to the dry season length.

Scenario 3 - (lower likelihood): By 2025 the average annual temperature is 1.0 ºC higher than the average annual temperature between 1986 and 2005. This rises to 1.50 ºC by 2055. The rainfall less evaporation increases by 5% by 2025 from the 1986 – 2005 average and 10% by 2055 and beyond. In most emissions pathways there are more variations in the early season rainfall than in the late season. In addition, the late season better reflects the full season. There are likely to be substantial increases in warm spells suggesting extended droughts. There are decreases in cold spells which mean there are fewer days with reduced evaporation. Three of the indicators of flood seem to indicate that there could be an increase in flood risk due to rainfall intensity and maximums of between 3 and 30%. On the other indicators of flood there is a slight bias to reduced risk. Furthermore, there could be a 36% increase to the dry season length.

In short there is over 25 - 30% difference in the rainfall between the lower and higher options. Temperature differences vary by 0.5ºC. There seems to be more potential variation in scenario 1 than 2, where scenario 2 suggests a clearer reduction in rainfall (less evaporation).

Scenario 4 - (extremes): By 2025 average annual temperatures could be approaching 2.0ºC above the 1986-2005 average, 5.0ºC by 2055 and over 7.0ºC by 2090. Rainfall could see up to a 55% reduction or a 50% increase by 2055 through to 2090.

While the extreme projections fall outside of the higher and even lower probability scenarios, they are not impossible. It is also clear that both an increase in temperature and precipitation variability within this range would fundamentally alter the conditions for ecosystem and livelihood sustainability as well as the operation of infrastructure designed according to historic and present day framework conditions in the Okavango basin.

Malawi: Zone 1 (North East)

Likelihood	2020s		2050s		2090s	
	Temp	*Rain - Evap*	*Temp*	*Rain - Evap*	*Temp*	*Rain - Evap*
70%	1.25^{0}C	0.975	1.75^{0}C	0.95	2.0^{0}C	0.925
30%	1.0^{0}C	1.0	1.5^{0}C	1.025	2.0^{0}C	1.05
5%	1.25^{0}C	1.0	2.50^{0}C	0.8	3.5^{0}C	0.7

Scenario 1 – (more likely): Steady rise in temperature throughout the century from 1.5^{0}C in 2030 to 2.0^{0}C by 2080. Precipitation less evaporation in the early season reduces throughout the century, from 5% in 2030 to 15% by 2080. However, the later season sees a slight increase in rainfall of 5% by 2060 and 10% by 2080. In terms of the extremes indices, they suggest a decrease in wet spells and an increase dry spell by 5-10% in both cases. In short, extended periods of heat, longer dry spells, briefer wet spells, and sometimes heavier rainfall events, when these occur, can be expected. The earlier season will be affected more than the later by extended warm and dry spells, and also reduced wet spells. Most likely any changes in rainfall intensity would be distributed throughout the rainfall season. This scenario suggests the greater change in the climate than the average from literature.

Scenario 2 – (less likely): There is a rise in temperature in the second half of the century but slightly less than in scenario 1 (1.25^{0}C in 2060 to 1.5^{0}C by 2080). Precipitation less evaporation in the early season increases in the second half of the century by 5% by the 2060s and 10% by the 2080s. However, the later season sees no change in rainfall less evaporation throughout the century. In terms of the extremes indices, they suggest a decrease in wet spells and an increase in dry spell by 5-10% in both cases. However, as the temperature is less than in scenario 1, this is expected to exhibit less change that of scenario 1. In short, extended periods of heat, longer dry spells, briefer wet spells, and sometimes heavier rainfall events, when these occur, can be expected.

Scenario 3 – (extreme): a slight increase in temperature is expected by the 2030s, however by the 2060s this increases to 2.5^{0}C and 3.5^{0}C by the 2050s. Precipitation will remain the same by 2030 but then decrease significantly by 2060 (20%) and 30% by 2080. The extremes indices are likely to exhibit a more extreme version of the same trends mentioned in scenarios 1 and 2 above.

Swaziland: Zone 4

Likelihood	2020s		2050s		2090s	
	Temp	*Rain - Evap*	*Temp*	*Rain - Evap*	*Temp*	*Rain - Evap*
50%	0.5^{0}C	1.05	1.25^{0}C	1.075	1.75^{0}C	1.1
50%	0.75^{0}C	0.95	1.5^{0}C	0.925	2.0^{0}C	0.9

Scenario 1: This scenario is characterised by an increase in rainfall of about 5-10% throughout the time period. It also shows a moderate increase in temperature from 0.5^{0}C to 1.75^{0}C by the end of the centuary.in terms of extremes there may be a reduction in the frequency of the heaviest rainfall events but there will be an increasing trend to heavier events in terms of daily distribution. There will be an increase in the number of hot days by 40% as well as the overall length of warm spells. The length of the cold season will reduce considerably.

Scenario 2: This scenario shows a slightly higher increase in temperature so that by the end of the century the average temperatures will be around 2.0^{0}C greater than present day. Rainfall reduces in this scenario by a similar amount of the projected increase in scenario 1. The reductions predicted to grow from a 5% reduction by 2025 to a 10% reduction by the end of the century. There is also a predicted increase in the number of hot days perhaps up to 50% and in the length of warm spells. The length of cold spells reduces considerably. In terms of rainfall extremes there will be a reduction in the length of wet spells, an increase in the length of dry spells and an increase in precipitation amounts on the heaviest days.

Tanzania: Zone 2 (South)

Likelihood	2020s		2050s		2090s	
	Temp	*Rain - Evap*	*Temp*	*Rain - Evap*	*Temp*	*Rain - Evap*
Higher	1.0^{0}C	1.0	1.5^{0}C	1.0	1.75^{0}C	1.05
Lower	0.75^{0}C	0.9	1.25^{0}C	0.9	1.75^{0}C	0.9
5%	2.0^{0}C		3.0^{0}C		5.0^{0}C	0.5

Scenario 1 – (higher likelihood): By 2025 the average annual temperature is 1^{0}C higher than the average annual temperature between 1986 and 2005. This raises to 1.5^{0}C by 2055. The rainfall remains the same or may slightly increase during these two time periods. In most emissions pathways there are reductions in early season rainfall and increases in the late season. There are likely to be substantial increases in warm spells suggesting extended droughts. Unsurprisingly, there are decreases in cold spells which means there are less days with reduced evaporation. Most indicators of flood suggest an increase of around 10% in rainfall intensity and length of rainfall. In days above 20mm there is an increase of over 40%, and rainfall intensity could increase by 50% over the most intense days compared with 1961 and 1990. There is likely to be an increase in the dry season length.

Scenario 2 – (lower Likelihood): By 2025 the average annual temperature is 0.75^{0}C higher than the average annual temperature between 1986 and 2005. This raises to 1.25^{0}C by 2055. The rainfall reduces by 10% from the 1986 – 2005 average by 2025 and maintains this drop though to 2055 and beyond. In most emission pathways there are reductions in the early season and no change or a slight increase in the later season. There are likely to be substantial increases in warm spells suggesting extended droughts. Unsurprisingly, there are decreases in cold spells which means there are less days with reduced evaporation. Most indicators of flood for this scenario show both increases and decreases in flood potential and an increase of around 10% in rainfall intensity and length. There may be both decreases and increases in the dry season in this scenario.

In short there is a 10% difference in the rainfall between the two scenarios. Scenario 2 seems to show more variability and or possible exposure to extreme events. Both scenarios show increase in drought likelihood by scenario 2 may be both less or more liable to flooding. This may be a tension between more variability but less rain in scenario 2.

Scenario 3 – (extremes): By 2025 average annual temperatures could be approaching 2.0^{0}C above the 1986 2005 average by 2055 over 3.0^{0}C and by 2090 over 5.0^{0}C. Rainfall could be up to a 50% reduction or a 60% increase in rainfall by 2025 through to 2090.

Zimbabwe: Zone 3 (South)

Likelihood	2020s		2050s		2090s	
	Temp	*Rain - Evap*	*Temp*	*Rain - Evap*	*Temp*	*Rain - Evap*
More likely	1.0^{0}C	0.95	1.5^{0}C	0	2.5^{0}C	0.95
Less likely	1.0^{0}C	0.8	2.0^{0}C	0.8	3.0^{0}C	0.8
5%	1.0^{0}C	0.8	2.50^{0}C	0.85	4.5^{0}C	0.7

Scenario 1 - (more likely): The more like scenario shows a steady increasing temperature throughout the century rising to 2.5^{0}C by the end of the century. The precipitation shows a slight reduction in the near future with perhaps a slight recovery by mid-century and then a slight reduction again thereafter. In terms of extremes, warm spells are set to double in length. Intense rainfall is also likely to increase somewhat, although there may be a slight decrease over Mozambique. Nevertheless, the general trend is for heavier rainfall periods over the century. There is likely to be an extension of the dry summer season and a reduction in wet spells.

Scenario 2 - (less likely): The less likely scenario shows a large reduction in precipitation (20%) as well as a large increase in temperature (3.0^{0}C by the end of the century). This precipitation reduction and large temperatures are likely to lead to significant reduction in water availability. Intense rainfall is likely to increase somewhat, although there may be a slight decrease over Mozambique. Nevertheless, the general trend is for heavier rainfall periods over the century. There is also likely to be an extension of the dry summer season and a reduction in wet spells.

1.5 Climate Impacts

Climate Change Themes

Using the aforementioned RCPs, time scales and CORDEX projections, climate impacts have been identified under the following themes:

- **Precipitation variability**, including rainfall events (annual total, seasonality, intensity, precipitation source), humidity/cloudiness, river systems, aquatic ecosystems/aquaculture, groundwater, water security, water supply and variability;
- **Temperature variability**, including heatwaves, seasonal temperature ranges, frost, wildfires, aridity;
- **Extreme events**, including floods/droughts;
- **Agriculture**, including food production, food security, land degradation/soil erosion, ecosystems/biodiversity;
- **Health**, including disease epidemiology, air/water pollution, biohazards, nutrition, sanitation

The Impacts Table (

Table 1) provides an up-to-date and consistent approach to interpreting the climate change projections in the five southern Africa sub-regions (Figure 2) based on current scientific literature (largely from IPCC AR5), as well as additional interpretation from leading climate scientists.

The purpose of the table is to help the project team interpret the likely impacts that each of the themes may have on the project site at future time scales. The information contained in the below table should be coupled with information gathered from site missions, reports and interviews with the project team and key stakeholders, to ascertain whether i) any of these impacts have started occurring already, and the effect this is having on the local population; and ii) an impact/occurrence is noted by a stakeholder or team member, but does not fit within the Impacts Table template, in which instance further internet/desktop research and analysis should be conducted.

This process should allow the project team to both identify risks and justify a risk score in the CCRA track 1 Risk Matrix (see

Table 2), with the aim of highlighting which key risks need to be carefully considered prior to finalising the project designs and thereafter providing recommendations as to how these risks can be managed and/or mitigated through design choices.

Table 1: Climate Impacts Table

REGION	CLIMATE CHANGE TREND	IMPACTS	
		BY 2025	BY 2055
1	Precipitation variability	Continuing trend of seasonal and interannual variability in precipitation. A transition zone between areas where the annual rainfall is more likely to increase (to the north) and more likely to decrease (to the south). Any changes are most likely (but not definitively) in the range −10% to +10%. The possibility of increased rainfall rises with higher emissions.	Continuing trend of seasonal and interannual variability in precipitation, decreased winter rainfall and increased aridity, in combination with wind gustiness, drying out of seasonal wetlands/pans and ephemeral rivers. Variability in particular at the boundary with the southernmost extent of the intertropical convergence zone (ITCZ). A transition zone between areas where the annual rainfall is more likely to increase (to the north) and more likely to decrease (to the south). Any changes are most likely (but not definitively) in the range −10% to +10%. The possibility of decreased rainfall is higher than for 2025. Water supply is challenged by increased temperatures (and associated evaporation), and more erratic rainfall patterns, leading to vulnerability of perennial river systems and decreased level of the groundwater table.
	Temperature variability	Continuing trend of increased mean annual air temperature (MAAT). Likely increase of MAAT by 0.5ºC to 1.5°C, but lower/higher values cannot be excluded; some increase in length of warm spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, aridity trend will reinforce decreased humidity especially under more erratic seasonal precipitation regimes; increased heatwaves; increased thunderstorm activity, etc. Likely increase of MAAT by 0.5ºC to 3.0°C, but lower/higher values not excluded; almost certain increase in length of warm spells and reduced frequency of cold periods.
	Extreme events	More erratic precipitation and temperature regimes, resulting in some likely increase in extreme flood/drought events.	More erratic precipitation and temperature regimes, resulting in an increased likelihood of extreme flood/drought events, both in severity and duration. This will have a multiplier effect in increasing vulnerabilities to other risk events and thus result in wider likely impacts.
	Agriculture	Food insecurity arising from political instability across the region and challenges to both food production and supply, and climatic instability.	Increased overall drying trend and decreased winter rains result in decreased food production in total and land surface degradation and soil erosion due to increased aridity and soil moisture loss. Deforestation and loss of biodiversity will be an increasing issue. Aridification and spread of sand dunes in Sahelian areas. Rain-fed agriculture will be likely less reliable in many areas and irrigated agriculture will become more significant, but this poses problems for famers’ access to technology, investment and training (including provision of GM seeds).
	Health	Pockets of different disease types as a result of site-specific water/air/pollution, amplified by incorrect water, agricultural and land management practices, and mining waste. Low nutrition/health in some areas due to food insecurity.	Widespread health effects due to food/water insecurity, availability of potable water, water contamination by runoff, and low water quality due to biological diseases, pollution/sewage runoff into rivers, wastewater and groundwater contamination due to poor sanitation in informal settlements and due to industries, such as mining.
2	Precipitation variability	Continuing trend of seasonal and interannual variability in precipitation related to strength of ITCZ and frequency/magnitude of incoming cyclones from Indian Ocean. For planning purposes, it might be best to work on decreased annual rainfall, with any decrease most likely not exceeding 10%; however, increases of up	Continuing trend of seasonal summer and interannual variability in precipitation. Variability in particular at boundary with southernmost extent of ITCZ. Variations in strength of cyclones also associated with storm surges, coastal flooding, and wind damage. For planning purposes, it might be best to work on decreased annual rainfall, with any decrease most likely not exceeding 10%, although decreases of

REGION	CLIMATE CHANGE TREND	IMPACTS	
		BY 2025	BY 2055
		to, perhaps, 10% are also possible. Limited dependency on emissions.	perhaps 20% are possible in parts; however, increases of up to, perhaps, 10% are also possible. The likelihood of decreased rainfall rises with greater emissions. Possibility of higher rainfall, and stronger winds and storm surges with Indian Ocean tropical cyclones. Likely greater seasonal water availability but issues of water quality.
	Temperature variability	Continuing trend of increased MAAT. Likely increase of MAAT by 0.5ºC to 1.5°C, but lower/higher values cannot be excluded; some increase in length of warm spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, increased thunderstorm activity, higher sea surface temperatures (SST) driving strong cyclone events, drying out of coastal wetlands. Likely increase of MAAT by 0.5ºC to 3.0°C, but lower/higher values cannot be excluded; almost certain increase in length of warm spells and reduced frequency of cold periods.
	Extreme events	More erratic precipitation regimes and increased subtropical cyclones, resulting in some likely increase in extreme flood events.	More erratic precipitation regimes, resulting in an increased likelihood of extreme flood events, both in severity and duration. This will have a multiplier effect in increasing vulnerabilities to other risk events and thus result in wider likely impacts, in particular in agriculture and health.
	Agriculture	Food insecurity arising from soil erosion linked to climatic instability and changes.	Food insecurity arising from climatic instability, deforestation, increased intensity of rain events driving higher soil erosion and soil fertility loss, higher sediment and nutrient runoff posing problems for eutrophication, water quality, precipitation hazards impacting on food production especially in rainfed agricultural areas.
	Health	Health effects mainly as a result of short term problems with food production due to climatic variability.	Health and nutrition impacts, mainly as a result of longer term decreases in food production due to land surface erosion, effects on water quality due to soil erosion and floodwater contamination by sediments and organics, and waterborne and biological diseases, including pests and diseases on agricultural crops. Flood events result in low water quality with implications for sanitation and waterborne diseases.
3	Precipitation variability	Continuing aridity of desert and semiarid environments. For planning purposes, it is best to work on decreased annual rainfall, especially to the west, with any decrease perhaps reaching 20% in parts; increases are unlikely in the west but may reach 10% in the east.	Continuing aridity of desert and semiarid environments; increased wind erosion; migration of sand dunes; decreased air quality and pollution; and health effects due to land surface aridity. Episodic thunderstorms may result in soil erosion and flooding, especially in coastal areas. Increased borehole extraction will result in decreased groundwater table; some ephemeral rivers will become permanently dry, perennial rivers may become ephemeral. Groundwater recharge will be reduced under all scenarios. For planning purposes, it is best to work on decreased annual rainfall, especially to the west, with any decrease perhaps reaching 20%, or even 30%, in parts; increases are unlikely in the west but may reach 10% in the east. Water supply will decrease under all future scenarios.
	Temperature variability	Continuing trend of increased MAAT. Likely increase of MAAT by 0.5ºC to 2.0°C, but lower/higher values cannot be excluded; some increase in length of warm/drought spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, heatwaves inland, increased thunderstorm activity. Likely increase of MAAT by 0.5ºC to 4.0°C, but lower/higher values cannot be excluded; almost certain increase in length and severity of warm/drought spells and reduced frequency of cold periods.

REGION	CLIMATE CHANGE TREND	IMPACTS	
		BY 2025	BY 2055
	Extreme events	Increased frequency of drought and heatwave events.	Increased frequency and magnitude of drought events and soil moisture anomalies, which will have significant impacts on agricultural systems and sustainability.
	Agriculture	Food insecurity arising from climatic instability.	Increased aridity may result in increased food insecurity, spread of invasive plant and insect species (locusts), loss of rainfed agriculture and subsistence agricultural systems become less viable, decreased food production in some areas.
	Health	Health effects mainly as a result of short term problems with food production due to climatic variability.	Health and nutrition effects, mainly as a result of longer term decreases in food production due to increased aridity, deflation of dry soils from the land surface, episodic soil erosion. Food and water insecurity will increase, may be health impacts due to increased pests and diseases, and / or to decreased water and air quality. Decreased surface water availability results in increased health and sanitation risk.
4	Precipitation variability	Continuing trend of seasonal and interannual variability in precipitation related to frequency/magnitude of incoming cyclones from Indian Ocean. For planning purposes, it is best to work on decreased annual rainfall, especially to the west, with any decrease perhaps reaching 10%, any increases are more likely east of the escarpment.	Continuing trend of seasonal summer and interannual variability in precipitation, variations in strength of cyclones also associated with storm surges, coastal flooding, wind damage, heavy rainfall inland resulting in river flood events. For planning purposes, it is best to work on decreased annual rainfall, especially to the west, with any decrease perhaps reaching 10%; any increases are more likely east of the escarpment. Possibility of higher rainfall, and stronger winds and storm surges with Indian Ocean tropical cyclones. Water supply is maintained despite increased variability, but there could be issues of decreased water quality during flood events.
	Temperature variability	Continuing trend of increased MAAT. Likely increase of MAAT by 0.5ºC to 1.5°C, but lower/higher values cannot be excluded; some increase in length of warm spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, increased thunderstorm activity, higher SST driving strong cyclone events, and drying out of coastal wetlands that are important biodiversity hotspots. Likely increase of MAAT by 0.5ºC to 3.0°C, but lower/higher values cannot be excluded; almost certain increase in length of warm spells and reduced frequency of cold periods.
	Extreme events	Increased frequency of flood/wind events as a result of likely increased frequency of subtropical cyclones.	Increased frequency and/or magnitude of flood and wind events from the Indian Ocean.
	Agriculture	Food insecurity arising from climatic instability, deforestation and land degradation.	Food insecurity arising from climatic instability, increased intensity rain events driving higher soil erosion and soil fertility loss, higher sediment and nutrient runoff posing problems for eutrophication, water quality issues, precipitation hazards impacting on food production especially in rainfed agricultural areas, increased coastal flooding due to sea level rise.
	Health	Health effects mainly as a result of short term problems with food production due to climatic variability.	Health and nutrition effects, mainly as a result of longer term decreases in food production due to land surface erosion, effects on water quality due to soil erosion and floodwater contamination by sediments and organics; waterborne and biological diseases, including pests and diseases on agricultural crops, salinization of low lying areas, impacts on sanitation through wastewater and sewage contamination of surface water, especially during floods.

REGION	CLIMATE CHANGE TREND	IMPACTS	
		BY 2025	BY 2055
5	Precipitation variability	Likely increases in rainfall variability and some evidence for increased annual rainfall totals. For planning purposes it is best to work on decreased annual rainfall, especially to the west, with decreases up to 10% but perhaps reaching 20% in parts; any increases are most likely only in the far east of the region; some evidence for larger decreases with highest emissions.	Increasing variability in rainfall patterns, with variation in strength of winter cyclones from the Atlantic, resulting in coastal flooding and over mountains; aridity in northern and inland locations, decreased groundwater table in areas of increased aridity, variations in river discharge with associated changes in water quality during low flow stages and with increase water temperatures; increased land surface instability, soil erosion and deflation. Water supply and variability is driven by winter cyclone strength. Similar to the situation around 2025 but with greater chances of decreases to 20%, perhaps even towards 30%, along the west coast. There is some possibility that storm tracks affecting the south-west Cape region may move further south, consistent with reduced overall rainfall.
	Temperature variability	Continuing trend of increased MAAT. Likely increase of MAAT of 0.5ºC to 1.5°C, but lower/higher values cannot be excluded; perhaps 0.5°C less warming over coastal regions; some increase in length of warm spells and reduced frequency of cold periods.	Continuing trend of increased MAAT, heatwaves inland with increased aridity, increased thunderstorm activity. Likely increase of MAAT of 0.5ºC to 3.0°C, but lower/higher values cannot be excluded; perhaps 0.5°C less warming over coastal regions; almost certain increase in length of warm spells and reduced frequency of cold periods.
	Extreme events	Increased variability of winter storm events from the Atlantic.	Increased frequency and/or magnitude of winter storms especially along the coast, flood events and thunderstorms inland especially over the Great Escarpment.
	Agriculture	Food insecurity and land surface degradation arising from climatic instability.	Increased aridity may result in increased food insecurity in inland locations, spread of invasive plant and insect species especially affecting the fynbos biome, loss of rainfed agriculture and subsistence agricultural systems become less viable, decreased food production in some areas with less surface water availability and increased cost of extracting water by groundwater pumping.
	Health	Health effects mainly as a result of short term problems with food production due to climatic variability.	Health and nutrition effects, mainly as a result of longer term decreases in food production due to increased rainfall variability, deflation of dry soils in northern parts of the area, episodic soil erosion and impacts on water quality; may be health impacts due to increased pests and diseases. Implications for sanitation where flood events result in water contamination.

Table 2: CCRA Track 1 Risk Matrix Example

	Hazard					
Project component	**Flood**	**Drought**	**Fire**	**High Winds / Cyclones**	**Sea level rise**	**…**
Irrigation pipe work	High	Low	Medium	No risk - N/A	No risk - N/A	Medium
River off-take infrastructure	High	Low	Low	No risk - N/A	No risk - N/A	Low
Boreholes	Medium	Low	Low	No risk - N/A	No risk - N/A	Low
Weir or dam	Medium	Low	Low	No risk - N/A	No risk - N/A	Low
Power generators	High	Low	Medium	No risk - N/A	No risk - N/A	Medium
Roads	High	Low	Low	No risk - N/A	No risk - N/A	Low
VIP Latrines	High	Low	Low	No risk - N/A	No risk - N/A	Low
Training & capacity building	Low	Low	Low	No risk - N/A	No risk - N/A	Low
… etc.	Low	Low	Low	No risk - N/A	No risk - N/A	Low