Water for the future:

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES IN THE ORANGE-SENQU RIVER BASIN

D. Knoesen, R. Schulze, C. Pringle, M. Summerton, C. Dickens & R. Kunz

Water for the future:

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES IN THE ORANGE-SENQU RIVER BASIN

D. Knoesen, R. Schulze, C. Pringle, M. Summerton, C. Dickens & R. Kunz

This production has been made possible through the 'New Approaches to Adaptive Water Management under Uncertainty' (NeWater) project (contract no. 511179GOCE) funded by the European Union.

Catherine Pringle & Chris Dickens
Institute of Natural Resources
P.O. Box 100396, Scottsville, 3209, South Africa
Tel: (+27) 033 3460796   Fax: (+27) 033 3460895
www.inr.org.za

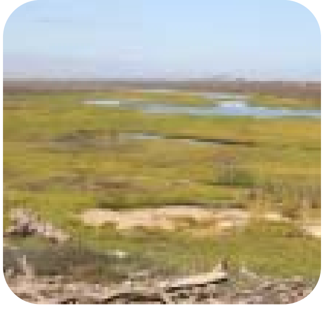
Mark Summerton (Independent)

Darryn Knoesen, Roland Schulze & Richard Kunz
School of Bioresources Engineering and Environmental Hydrology
University of KwaZulu-Natal
Private Bag X01, Scottsville, 3209, South Africa
Tel: (+27) 033 2605489 Fax: (+27) 033 2605818
www.beeh.unp.ac.za

This document should be cited as

Knoesen, D., Schulze, R., Pringle, C., Summerton, M., Dickens, C. and Kunz, R. (2009) Water for the Future: Impacts of climate change on water resources in the Orange-Senqu River basin. Report to NeWater, a project funded under the Sixth Research Framework of the European Union. Institute of Natural Resources, Pietermaritzburg, South Africa.

Contents



Introduction

About the project

This study has been undertaken as part of the European Union funded NeWater Project, which aimed at developing new approaches to water management under uncertain conditions. NeWater recognised that fundamental changes were needed in the way that water is managed (all over the world). The way in which water is *currently* managed is clearly not succeeding everywhere in protecting the water resource and is thus threatening our future access to this resource. This project has promoted Adaptive Management (in reality and not just intention) as a potential way forward. Adaptive Management is essentially "learning by doing", but it needs to be informed if it is to be successful. This project aims to provide information on which current water managers can base certain decisions for doing things better going into the future.

The Orange-Senqu River basin has already been the subject of a scenario generation exercise carried out for the Millennium Ecosystem Assessment (Bohensky et al., 2004). To build on this, the NeWater team conducted hydrological modelling to provide information on the *water resources* in the basin. This work was initiated by the NeWater team in collaboration with the University of KwaZulu-Natal in South Africa, and linked to a project at the University funded by the Water Research Commission of South Africa, and has resulted in a modelled assessment of the projected climate related changes to water resources and hydrological hazards within the Orange-Senqu River basin. It is hoped that not only will this information be of value to decision makers and managers, but that it may also stimulate a response to the rapidly changing conditions in the basin and in this way embrace Adaptive Management of the water resource.

Purpose of this document

This document describes the potential impacts of climate change on the water situation in the Orange-Senqu River basin within South Africa and Lesotho and attempts to identify the consequences of these impacts on people living in the area. It provides the key results of a more detailed study undertaken by Darryn Knoesen. (Knoesen, D.M. 2009. Integrating Hydrological Hazards and Climate Change as a Tool for Adaptive Water Resources Management in the Orange River Catchment. Unpublished PhD thesis, University of KwaZulu-Natal, Pietermaritzburg, South Africa.)

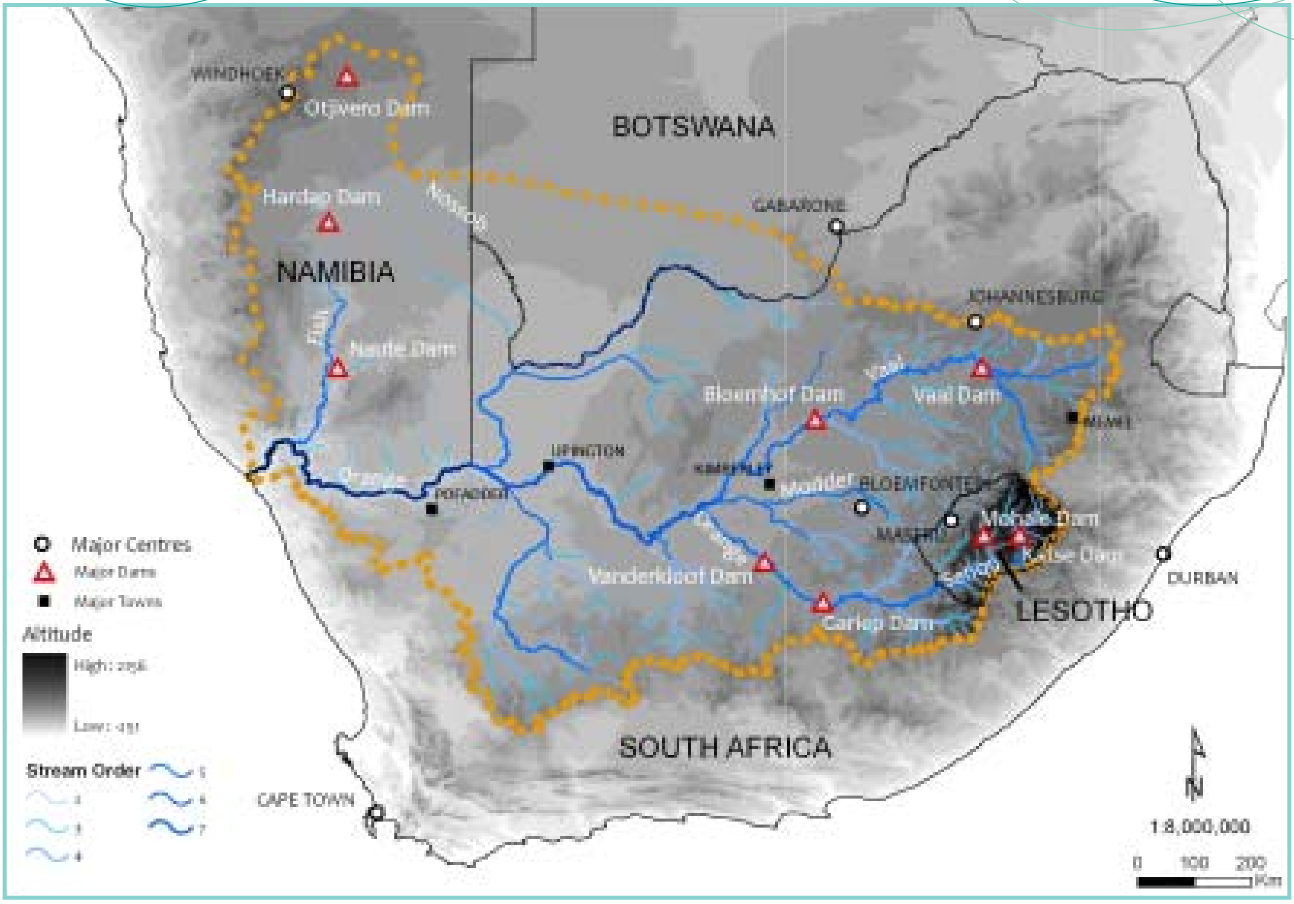


Figure 1: The location of the Orange-Senqu River basin

Study area

The Orange-Senqu River basin is one of the largest river basins in the world. It covers an area of almost 900 000 km^2 and extends across Lesotho, South Africa, Namibia and Botswana (Figure 1) with results from this project focussed on Lesotho and South Africa (62% of the basin). It is also the most developed transboundary river basin in southern Africa and supplies water to many municipalities, industries and farms located inside and outside the basin. Several major tributaries such as the Vaal, Harts, Fish, Caledon, Molopo, Modder and Nossob support the livelihoods of millions of people across the region.

Water resources from the Orange-Senqu River underpin the region's food production and industrial sectors with an estimated 70% of South Africa's cereal crop produced, and 80% of the region's industrial activities contained within the basin. The basin also harbours coal deposits and mineral resources (e.g. gold, coal, manganese) of regional and global importance.

Human well-being in the basin is highly variable. The population is concentrated in the higher rainfall areas in the east and comprises a diverse mix of cultural and ethnic backgrounds, a multitude of languages and wide-ranging socio-economic status. High rates of unemployment, low rural literacy, and high incidence of HIV-AIDS have had a considerable impact on the livelihoods of people living in the region.

The basin is among the most water rich and simultaneously water scarce regions in Africa, with runoff disproportionately distributed. This has resulted in extensive regulation of water resources with the construction of large dams and several water transfer schemes. The water resources are also considered to be close to maximally utilized or developed. In addition, the Orange-Senqu River basin is characterized by hydroclimatic conditions that render the basin a high risk natural environment, with low conversion of rainfall to runoff, high aridity in parts, strong rainfall seasonality and in many areas a short rainy season. As a result, the Orange-Senqu River basin may be more threatened by climate change than many other regions of the world where there is more abundant water.

ORANGE-SENQU RIVER BASIN – KEY FEATURES

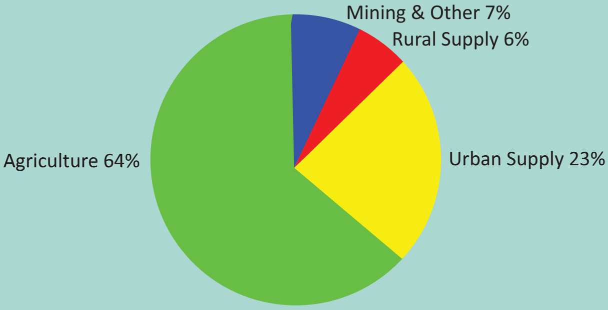
Total Basin Area	896,368 km^2	
Total River Length	2,300 km	
Average Annual Discharge	11,500 Mm^3	
Annual rainfall (mm/annum)	Average: 330 - 400	Range: <50 to >2000
Average Daily Temperature	East: 12°C	West: 22°C
Average Annual Evaporation Rate	East: 1,100 mm/a	West: 3,500 mm/a
Major Dams	Gariep	5,675 Mm^3
	Van der Kloof	3,237 Mm^3
	Sterkfontein	2,617 Mm^3
	Vaal	2,122 Mm^3
	Katse	1,950 Mm^3
	Total Dam Storage	20,412 Mm^3
Major Aquifers	Sedimentary	
Annual Water Demand/Use		
Water Availability (resource potential)	2,000 Mm^3 / a	
Population	19 Million	
Water availability (per capita per annum)	<1000 m^3	
Vulnerability	Increasing aridity and climatic variability to the west	

Table 1: Summary of key features in the Orange-Senqu River basin (Source: Diedrichs et al., 2005)

What is climate change?

Climate change is a significant change in the trends of expected patterns of 'average' climate and its 'average' variability. It reflects abnormal variations to the expected climate of the earth's atmosphere. Evidence suggests that humans are changing the climate through their actions, particularly through the emission of greenhouse gases such as carbon dioxide (CO_2), which result in an enhanced warming of the earth's atmosphere. This rise in temperature will result in a number of consequences for both the natural and human environment.

What are the impacts of climate change?

The effects of climate change are likely to be extensive and diverse. Although temperatures are projected to rise everywhere, some regions are likely to experience higher increases than others. In the Arctic and Antarctic the ice caps and sheets have already begun to melt and glacier retreat has become more rapid than in the recent past. As this additional water enters the world's oceans, and the ocean temperatures increase, so sea levels are likely to rise. Extreme events including violent storms, floods and droughts are also expected to increase in their frequency and intensity. Indeed, evidence suggests that this is already happening.

Climate change will have a significant impact on the world's water resources. This in turn will affect food supply, health, industry and ecosystem integrity and in this way will affect all of society.

Higher levels of CO_2 in the atmosphere will also have a significant impact on plant growth. Some agricultural crops, such as wheat, rice and soya beans may respond more positively to this increase in CO_2 while others such as maize, sugar cane and sorghum may be less responsive. Temperature changes could lengthen the growing season, but the warmer climates may also make conditions more favourable for infestations of pests and diseases. The effects of enhanced atmospheric CO_2 coupled with changes in temperature, rainfall, soil moisture and water availability could affect food supply across the globe – positively in some areas, but negatively in others.

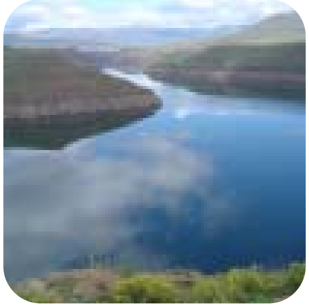
Furthermore, many ecosystems are likely to be damaged by climate change. Air and water temperature rises and changes in the availability of water will force species to migrate in order to survive, something that is already being recorded within the region. In some cases, species extinctions may occur.

These changes may result in enormous economic costs and pose significant challenges for the future.

How do we determine impacts of climate change on water resources?

The impacts of a changing climate on both the natural and social environment need to be carefully considered in planning into the future. This includes incorporating the impacts of climate on the natural hydrological cycle, on the resultant supply and demand of water and on extreme weather and water related events such as floods and droughts. Understanding such impacts is usually achieved through the use of computer models.

Modelling enables us to solve problems by simplifying complex real world situations, testing the models by using historical data and then using the model to ascertain what may happen in the future. Climate models use scenarios of future emissions of greenhouse gases under different population and economic development conditions to project possible future climates. Climate change is expected to increase future temperatures, which will in turn affect the magnitude and variability of rainfall and evaporation. This would lead to changes in the amount of water in a local or regional system, as well as the frequency and intensity of extreme events such as floods and droughts. Water scientists and engineers use this information when designing infrastructure (such as dams or urban stormwater systems) in order to reduce risks to acceptable levels to ensure that the infrastructure is able to withstand the impacts of climate change.



Methodology used in this study

This document is a synthesized version of work undertaken by Darryn Knoesen (Knoesen, D.M. 2009. Integrating Hydrological Hazards and Climate Change as a Tool for Adaptive Water Resources Management in the Orange River Catchment). In this study, modelling of the amount of water that will emanate from the Orange-Senqu River basin was done using the widely tested and applied *ACRU* hydrological model (Schulze, 1995 and updates). The traditional 481 Quaternary catchments (4th level sub-basins) making up the basin in South Africa and Lesotho (but unfortunately not for Namibia and Botswana as there were insufficient data) were subdivided into 1443 hydrologically homogenous and hydrologically linked "Quinary" catchments (5th level sub-basins). The *ACRU* model uses a range of input, including daily rainfall and temperature data, as well as information on the soils and land cover for each of these Quinary catchments, to perform a daily water budget from which the runoff is determined from each sub-basin.

Once this hydrological model has been set up for a basin, key input variables such as rainfall amount and distribution, and evaporation, are then changed to model the impact of *future* climate scenarios on the hydrology and water resources in the basin. The future scenarios rely on information from climate models or *General Circulation Models (GCMs)*. GCMs are sophisticated models which simulate complex processes in the atmosphere, including the impacts of global warming resulting from future increases in greenhouse gas (GHG) emissions. The GCMs provide a high level view (i.e. of the entire globe) and consequently their results need to be *downscaled* to a regional and local level in order to operate at the same scale as the hydrological models. There are over 20 different GCMs, using at least five different GHG emission scenarios and two downscaling options. While they all project increases in temperature, these numerous possible combinations of GCMs and emissions scenarios often lead to differing GCM scenarios of future rainfalls, but when looking into the future, there will always be some uncertaint

For this study a GCM known as ECHAM5/MPI-OM (and hereafter abbreviated to ECHAM5), which was considered to provide 'middle of the road' scenario of future climates over southern Africa, was used. *This GCM is based on the A2 emission scenario, which assumes that GHG emissions continue relatively unabated to the year 2100*. GCM data on daily rainfall and temperature, from which extreme hydrological events could be modelled, are provided at the following time periods:

Present: (1971 – 1990)

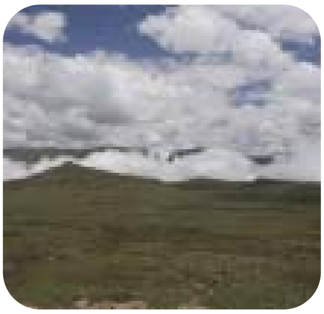
Intermediate future: (2046 – 2065)

More distant future: (2081 – 2100)

Since other GCMs could give different outcomes, these results should not be taken as certain, but rather as an indication of what could happen in future.

WHAT CHANGES CAN BE EXPECTED IN THE ORANGE-SENQU RIVER BASIN?

Temperature



Increasing temperatures will have a profound effect on evaporation, thereby also affecting water storage in the earth's atmosphere. This, in turn, will affect the frequency and intensity of rainfall events, the seasonal and geographic distribution of rainfall and its variability from year to year. Increasing temperatures will also have an impact on other water-related processes through changes in soil moisture, irrigation water demands, heat wave episodes and meteorological and hydrological droughts.

Indications are that mean annual temperatures will increase over the entire Orange-Senqu River basin. These increases are projected to be greater in the more distant future than in the intermediate future, with expected maximum increases in the Orange-Senqu River basin in excess of 5°C, compared with increases in the intermediate future in the range of 2.5°C to 3.5°C.

Figure 2 shows projected mean annual temperature changes in the Orange-Senqu River basin. The blue colours indicate those areas where a slight increase is projected, while the orange to red colours indicate where the future temperatures are projected to be much greater than at present.

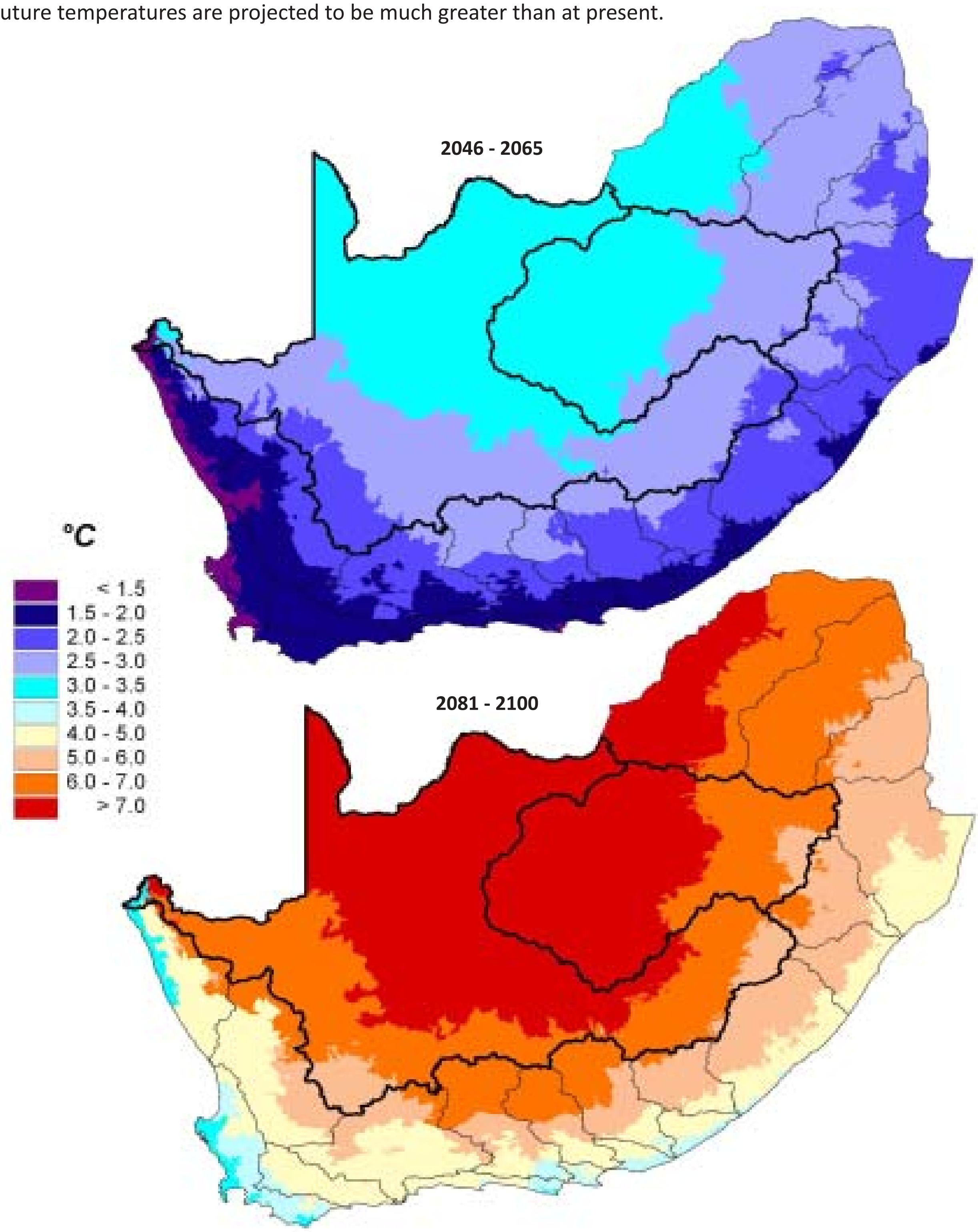
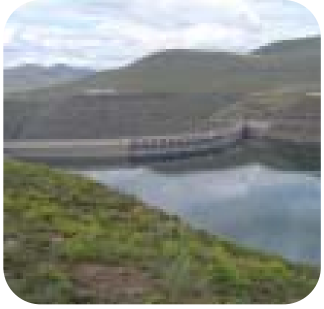
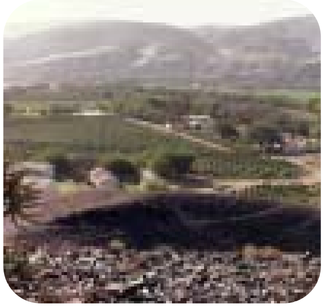


Figure 2: Differences in mean annual temperatures between the intermediate future and present (top), and the more distant future and present climate scenarios (bottom) from the ECHAM5 climate model

Evaporation





Increasing temperature will have a significant impact on evaporation. The amount of water which is evaporated from natural surfaces of the Earth is known as actual evaporation. However, if a system contained an unlimited supply of water, for example an open water body such as a dam, potentially more evaporation would occur. This is known as potential evaporation.

Water can also be evaporated from plants. This is known as transpiration. When plants are small, most water loss is by evaporation from the soil surface; however, when plants are large, then generally more water loss occurs through transpiration. Crop water use through transpiration determines how much water is needed from rain or irrigation for the crop to grow without being stressed.

Various formulae have been developed to calculate evaporation from crops. These formulae take into account variables which affect transpiration including solar radiation, temperature, relative humidity and wind. These formulae are based on measurements of water use by a reference vegetation such as short green grass under different weather conditions, and results are then adjusted for other crops such as maize or wheat.

Crop evaporation rates are projected to increase in both the intermediate and more distant futures. In the intermediate future, crop evaporation is likely to increase in the order of 10 to 15% in approximately one third of the Orange-Senqu River basin. This change is intensified, in magnitude and extent, in the distant future where almost the entire basin is projected to experience increases in reference crop evaporation in the order of 20 to 25%.

Figure 3 indicates ratios of mean annual reference crop evaporation between intermediate future to present climatic conditions (top) and more distant future to present conditions (bottom). The pink areas denote slight increases in evaporation, and thus a potential loss of water from the system, while the red areas show more significant increases.

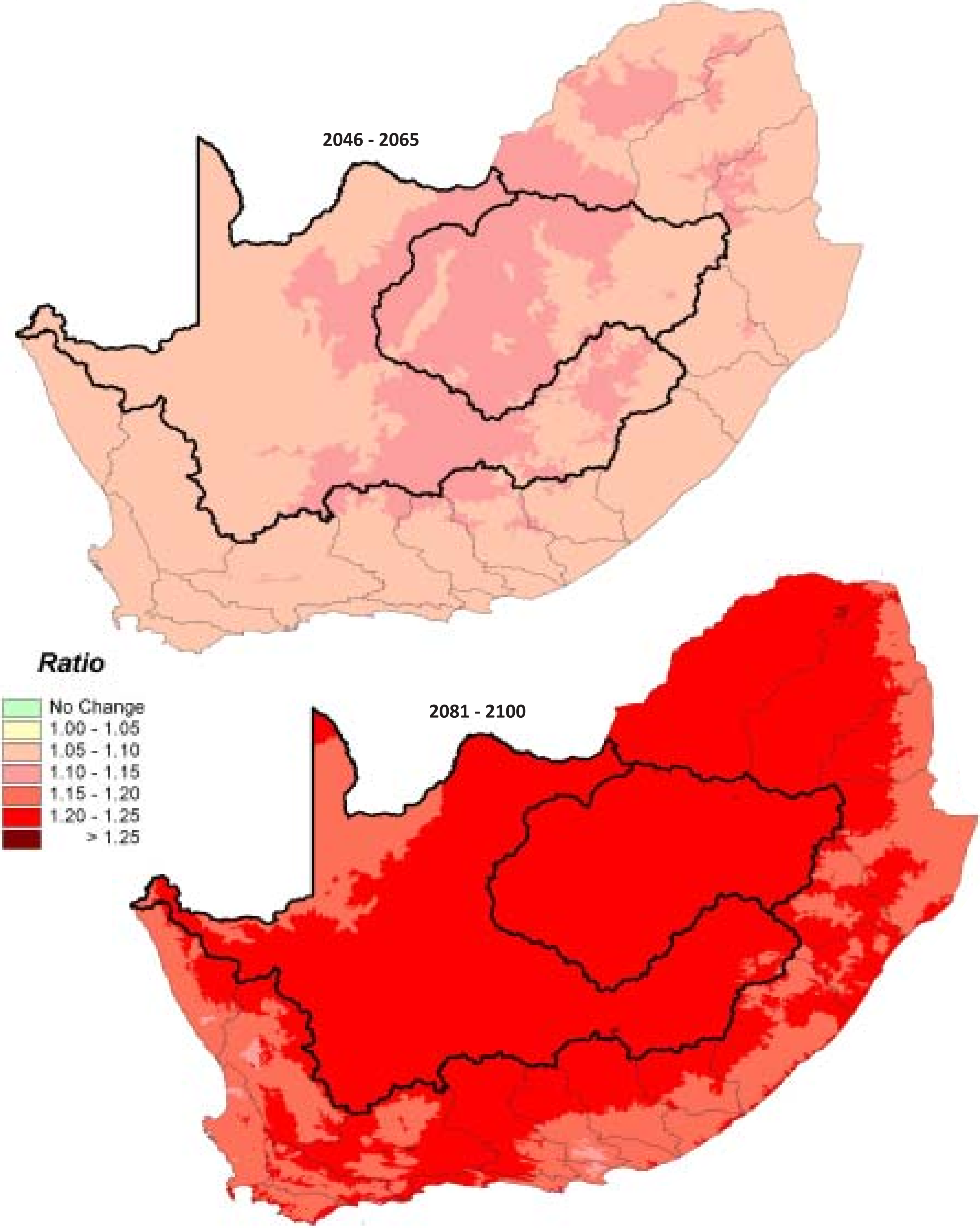
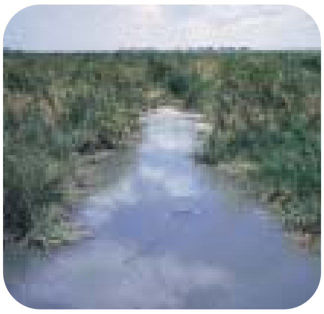


Figure 3: Ratios of intermediate future to present (top), and more distant future to present (bottom) mean annual reference crop evaporation, as derived from evaporation equations with input from the ECHAM5 climate model

Rainfall



What do we need to know when measuring rainfall?

The amount, intensity and frequency of events of rainfall under present climatic conditions can all be measured or calculated. Often the highest, lowest or mean rainfall is measured over a calendar month or year at a particular site. The number of days which experience rain in a calendar month or year are also often counted. Rainfall can be categorized as being of short or long duration. Short duration rainfall occurs over a period of 24 hours or less, and is important in considering hydrological designs from small basins, from urban areas and for local flooding. Long duration rainfall occurs over one to seven days and is important in considering hydrological designs from larger basins, multiple day flooding and regional damage. The frequency of occurrence is denoted by the term 'return period' or 'recurrence interval', which provides an indication of the probability of an event occurring in a given interval of time (e.g. a two year return period or recurrence interval flood will be the size of flood that, given a long record, has a statistical likelihood of occurring on average once every two years).

Mean Annual Rainfall

Mean annual rainfall provides an indication of the long-term quantity of water available to a region for hydrological and agricultural purposes. Mean annual rainfall is projected to generally increase across the Orange-Senqu River basin. In the intermediate future these increases could be up to 20% while in the more distant future increases are likely to be in the order of 20 to 100%. Generally, relative increases in mean annual rainfall are greatest in the eastern runoff-producing regions of the basin and tend to decrease westwards. Results from this study also show that rainfall across the basin is likely to become more variable in both the intermediate and more distant futures. This projected increase in variability will be of particular concern for water managers since it could result in increases in floods and droughts.

Figure 4 indicates the ratios of intermediate to present climatic conditions (top), and more distant future to present conditions (bottom) for mean annual precipitation. The darker blue areas show a projected increase in mean annual precipitation while the pink areas represent a projected decrease.

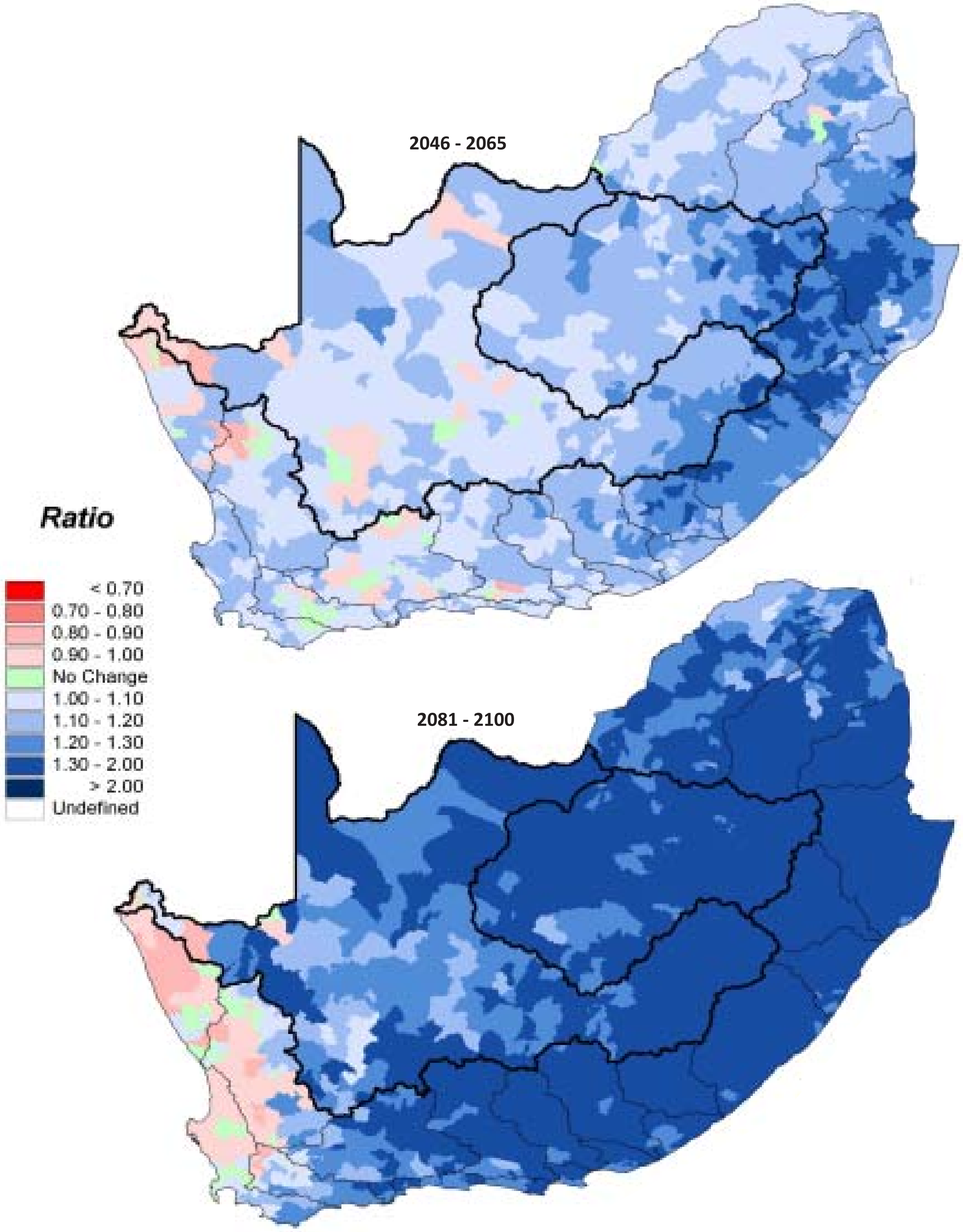


Figure 4. Ratios of the intermediate future to present (top), and more distant future to present (bottom), mean annual precipitation as projected when using output from the ECHAM5 climate model

Rain days

The number of days with rainfall above a certain amount is expressed as a ratio of the number of rain days projected for both the intermediate and more distant futures to those presently experienced. The higher the ratio, the more rain days are likely to occur.

Results from this study using the ECHAM5 climate model suggest that climate change will increase the number of rain days per annum over much of southern Africa, including the Orange-Senqu River basin (note that the darker blue areas are projected to experience the greatest increases in rain days). Limited areas in the extreme west of the basin are, however, likely to experience a reduction in the number of rain days.

The results displayed in Figure 5 reflect ratios for the number of days per annum with rainfall greater than 10 mm. A similar trend was found to be evident in the results for days per annum with rainfall greater than 2 mm and 25 mm.

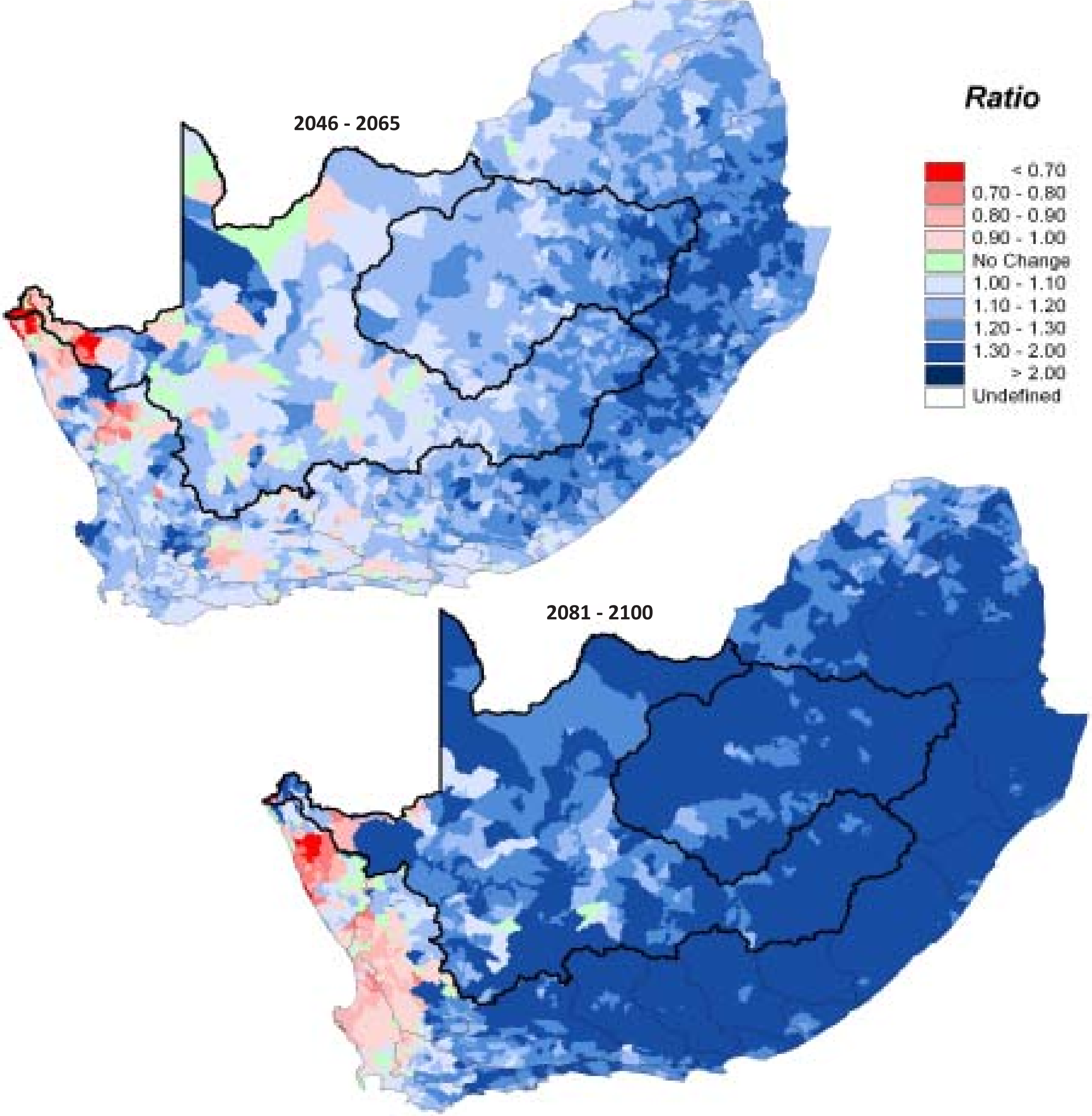


Figure 5. Ratios of the intermediate future to present (top) and more distant future to present (bottom) number of days per annum with rainfall greater than 10 mm, as projected when using output from the ECHAM5 climate model

Short duration rainfall

The results for the analysis of short and long duration rainfall are also expressed as a ratio of values expected in the intermediate and more distant futures with those currently experienced. The blue areas on Figure 6 indicate projected increases in short duration rainfall amounts while the pink areas represent projected decreases, irrespective of the return period of the rainfall.

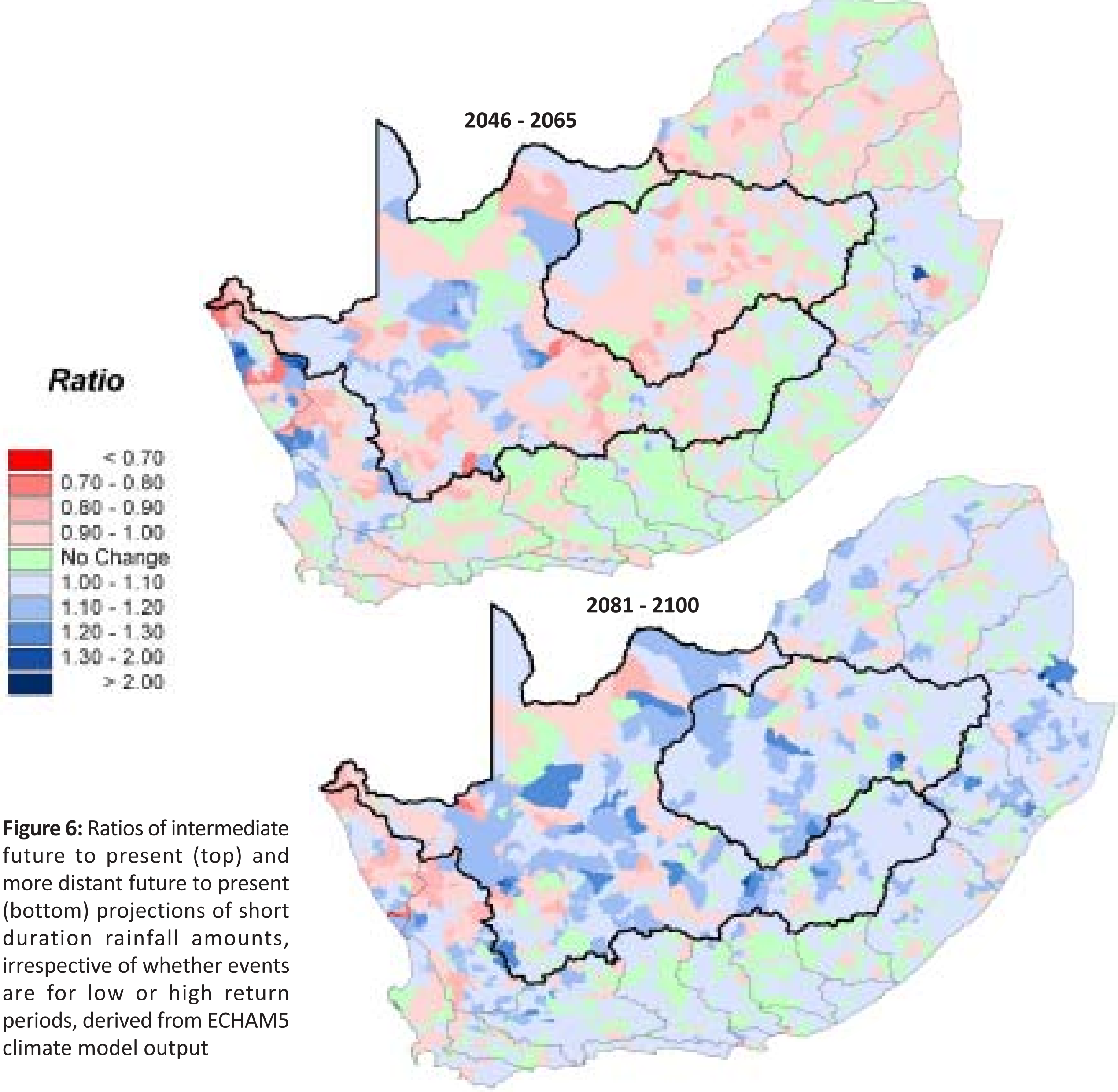


Figure 6: Ratios of intermediate future to present (top) and more distant future to present (bottom) projections of short duration rainfall amounts, irrespective of whether events are for low or high return periods, derived from ECHAM5 climate model output

In the period 2046 to 2065 approximately 40% of the Orange-Senqu River basin is likely to experience an increase in the amount of rainfall per short duration (i.e. less than 24 hour) event, while 38% of the basin is projected to experience a decrease. In the more distant future, however, about 72% of the basin is projected to show an increase in the amount of rainfall per short duration event, irrespective of whether the events are for low or high return periods.

Table 2: Percentage area of the Orange-Senqu River basin projected to experience an increase, a decrease, or no significant change in amounts of rainfall per short duration extreme event in the intermediate and more distant future.

Percentage Area of the Orange-Senqu River Basin		
Ratio	Intermediate Future	More Distant Future
No Change	22	12
Decreasing (i.e. <1)	38	16
Increasing (i.e. >1)	40	72

Long duration rainfall

Rainfall amounts from long duration rainfall extreme events are also likely to increase. In addition, as the duration of the long duration rainfall event is increased from one day to seven days, a greater area of the Orange-Senqu River basin could be affected by increases in rainfall per event.

Figure 7 depicts ratios of intermediate future to present amounts of extreme rainfalls for one and seven day durations for the 10 year return period. As with the short duration rainfall, the blue areas represent increases in amounts per long duration rainfall event while the pink areas represent decreases. The maps show that as the duration of the extreme events increases, so a greater proportion of the Orange-Senqu River basin will experience extreme events that are more severe.

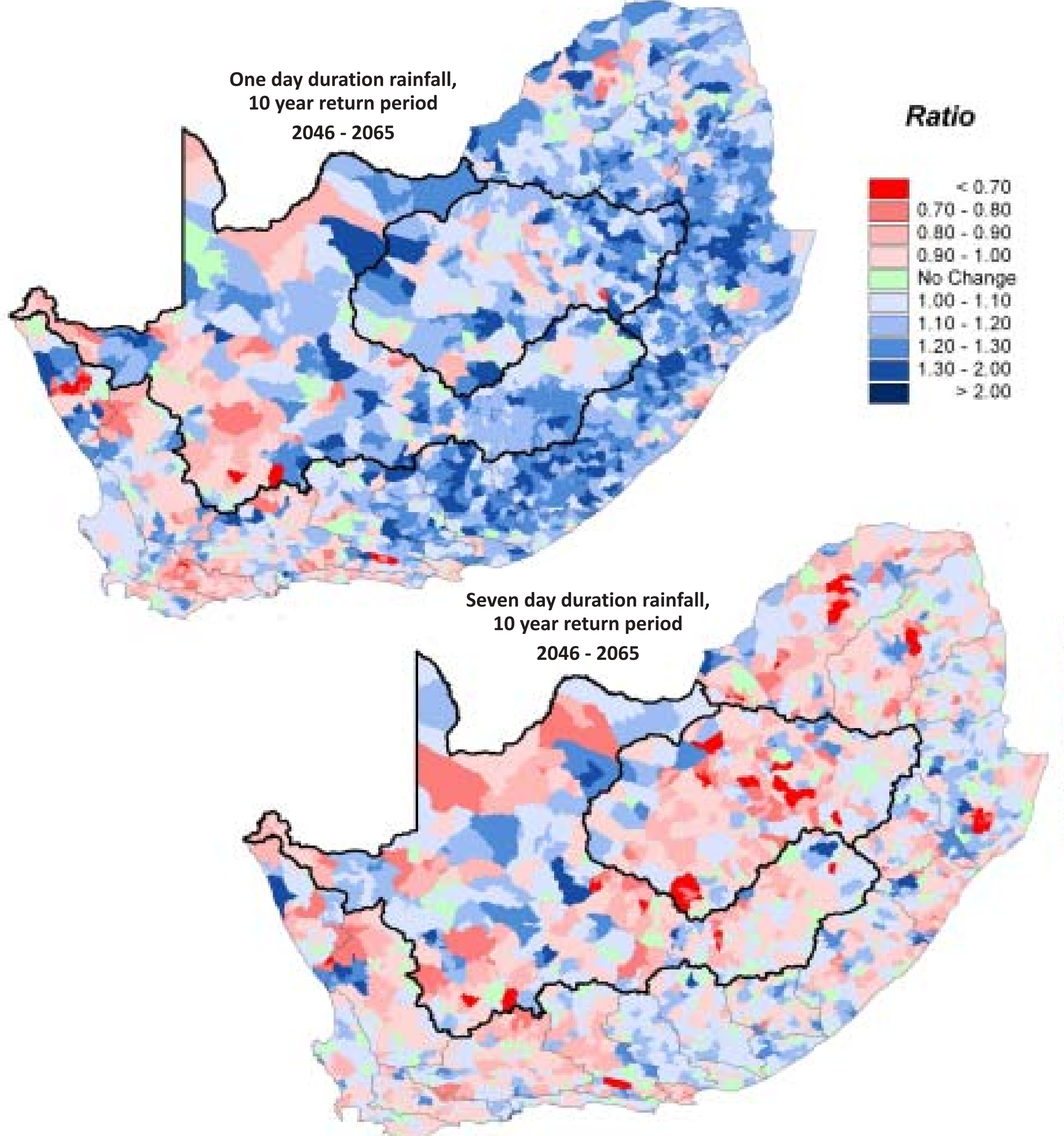


Figure 7: Ratios of intermediate future to present one day (top) and seven day (bottom) duration rainfalls for the 10 year return period, as derived from the ECHAM5 climate model

Another characteristic of extreme long duration rainfalls is that their magnitudes are projected to increase more in the distant future than in the intermediate future. Around the turn of this century approximately 83% of the basin is projected to experience larger extreme rainfall events of seven days' duration and with a recurrence interval of two years than at present. In the intermediate future this percentage is 67%. Increases in the eastern parts of the basin will be of most concern to water managers in the future, as currently these areas already experience the highest rainfall in the basin. This will have important implications for the safety of existing structures.

The ratios of intermediate future to present, and distant future to present, seven day duration rainfalls for the 2 year return period are shown in Figure 8 on the top and bottom respectively. Dark blue areas represent an increase in the magnitudes of heavy rainfall events while pink areas represent a decrease.

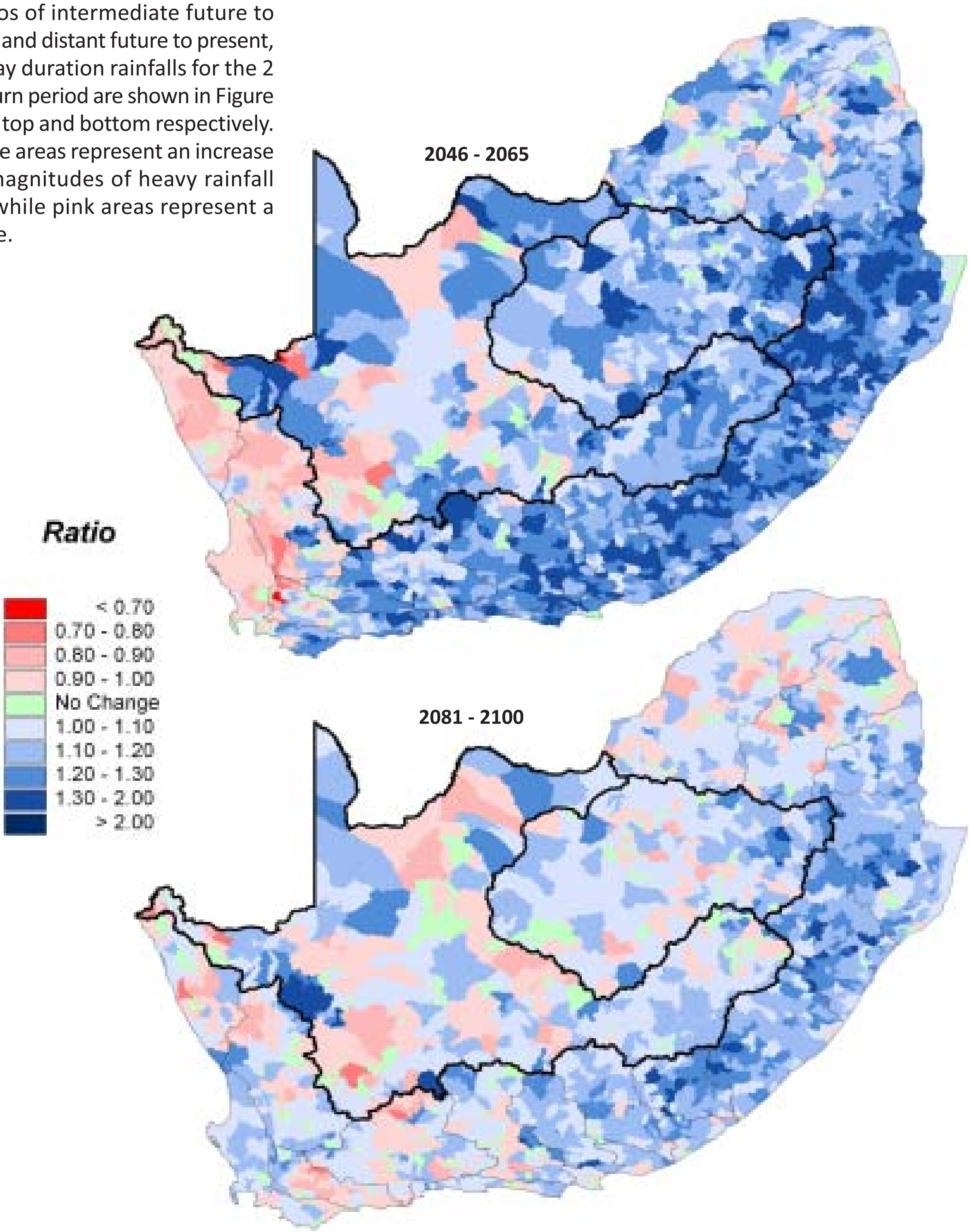
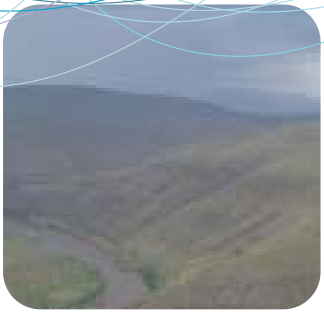
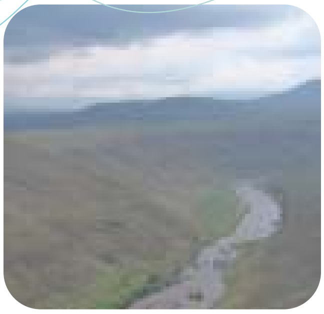


Figure 8: Ratios of intermediate future to present (top), and more distant future to present (bottom) magnitudes of seven day duration rainfall with a 2 year recurrence interval, derived using output from the ECHAM5 climate model





How certain are we of future changes in rainfall in the Orange-Senqu River basin?

Only one General Circulation Model (ECHAM5/MPI-OM) was used to generate the results presented thus far. However, the levels of agreement between this GCM and several other GCMs (Table 3) have also been assessed, but details for each of the other GCMs are not shown here. The key results of this assessment include the following:

- GCMs show greater agreement as the duration of projected extreme rainfall increases

Thus, in the Orange-Senqu River basin, the longer the duration of the rainfall (e.g. seven days as against one day), the greater the confidence in the prediction.

- GCMs show less agreement on increases in extreme rainfalls as the return period is increased from 2 to 50 years

Thus, in the Orange-Senqu River basin, there is less consistency in the results for increases in extreme rainfalls for longer return periods (e.g. 50 years) than for shorter return periods (e.g. 2 years).

- GCMs show more agreement in the distant future than they do in the intermediate future that extremes of rainfalls will increase

Thus, in the Orange-Senqu River basin there is more consistency in the results that larger areas are likely to experience increases in rainfall in the more distant future than the intermediate future.

INSTITUTE	GCM
Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	**Name:** CGCM3.1(T47) **First published:** 2005 **Website:** http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml
Meteo-France/Centre National de Recherches Meteorologiques (CNRM), France	**Name:** CNRM-CM3 **First published:** 2004 **Website:** http://www.cnrm.meteo.fr/scenario2004/indexenglish.html
Max Planck Institute for Meteorology (MPI-M), Germany	**Name:** ECHAM5/MPI-OM **First published:** 2005 **Website:** http://www.mpimet.mpg.de/en/wissenschaft/modelle.html
NASA/Goddard Institute for Space Studies (GISS), USA	**Name:** GISS-ER **First published:** 2004 **Website:** http://www.giss.nasa.gov/tools/modelE
Institut Pierre Simon Laplace (IPSL), France	**Name:** IPSL-CM4 **First published:** 2005 **Website:** http://mc2.ipsl.jussieu.fr/simules.html

Table 3: Information about GCMs the climate change scenarios of which were regionally downscaled by the University of Cape Town to point scale for application in this project (From Lumsden *et al.*, 2009)

Streamflow

Naturally, as the projections are generally for higher rainfall to occur, particularly in the high altitude eastern parts of the basin, so to the mean annual streamflow is likely to increase for both the intermediate and more distant future climates. Yet, despite these widespread projected increases in rainfall, there are a number of areas within the Orange-Senqu River basin which are likely to experience decreases in annual streamflows. However, projected increases in mean annual streamflows are likely to be significantly larger than those projected for mean annual precipitation because changes in rainfall are amplified in both positive and negative directions by the hydrological system.

Results also show that variability in streamflows is projected to increase more in the distant future than the intermediate future. This is of concern, as increased variability makes it difficult for water managers to plan for future streamflows and may also result in increased numbers of extreme events such as floods and droughts.

Figure 9 shows the ratios of intermediate future to present, and more distant future to present, mean annual streamflows generated with the *ACRU* model. The dark blue areas represent an increase in projected streamflows while the pink areas denote a decrease.

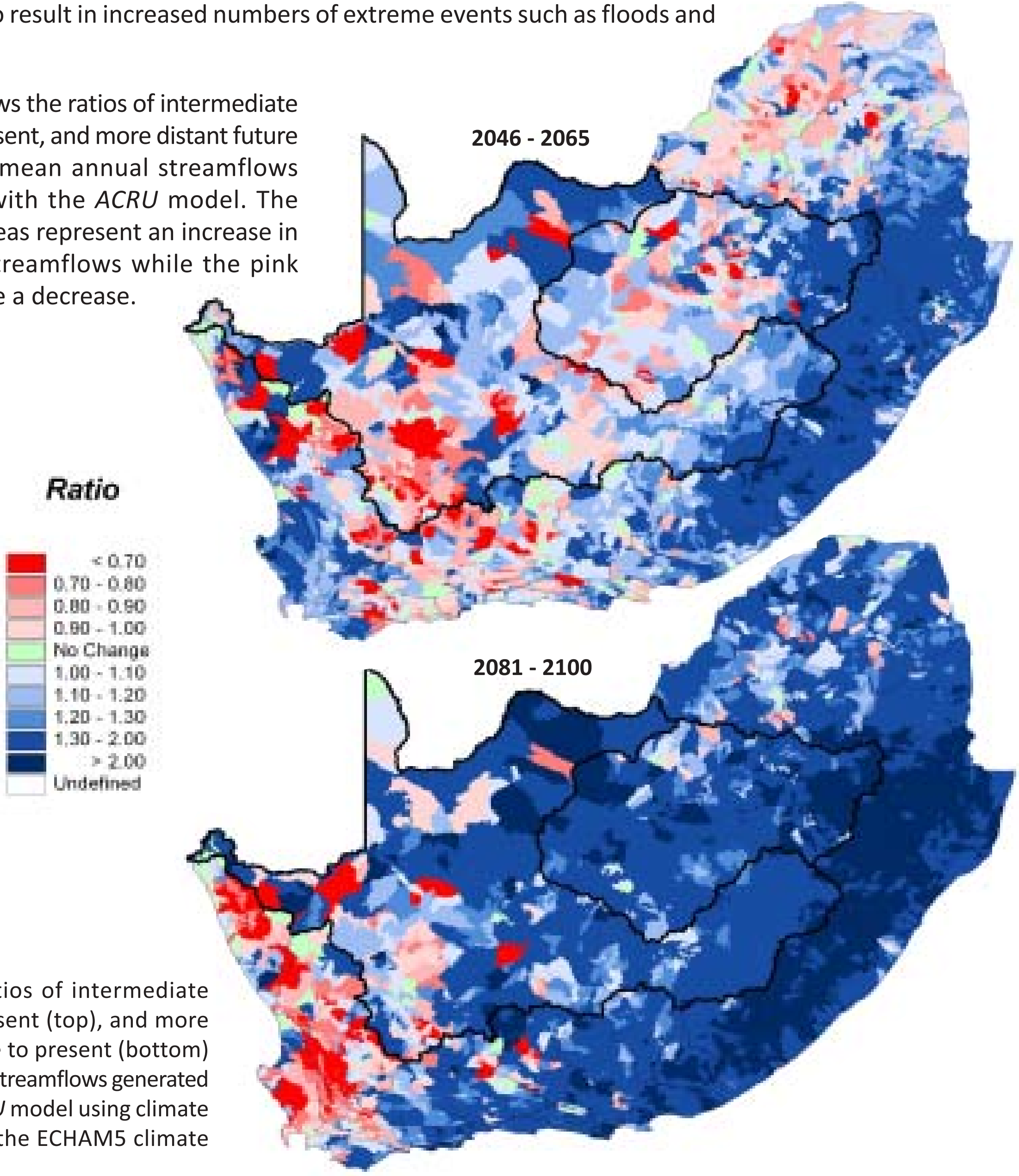


Figure 9: Ratios of intermediate future to present (top), and more distant future to present (bottom) mean annual streamflows generated with the *ACRU* model using climate output from the ECHAM5 climate model

Floods

What are floods?

Floods occur when water overtops the existing channels of streams and rivers, or overflows stormwater drains at high flows. Floods can be divided into different categories depending on their duration. Flash floods are usually associated with severe thunderstorms and occur as a result of high intensity rainfall of short duration. Short duration floods affect particularly smaller basins, urban areas and arid lands. Large scale floods are initiated by prolonged rainfall events, especially when the soils are already wet. These floods are often associated with rainfalls of longer duration and have the potential to impact a greater area. The likelihood of a flood occurring at a given interval of time is indicated by its ‘return period’ or ‘recurrence interval’. Return periods of 2, 10 and 50 years have been used in these analyses.

How do we model floods?

Reliable information on floods is often not available. In the absence of this information, rainfall data, in conjunction with hydrological models such as *ACRU*, are used to estimate floods. With the rainfall data the so-called depth, duration and frequency of rainfall can be calculated. The amount of rainfall for a given duration and probability of recurrence (return period) is known as ‘design rainfall’, and when combined in a hydrological model with basin characteristics such as slope, area, land use and soils can be used to generate a flood hydrograph.

Magnitude of floods

Results suggest that the total area subjected to higher flood magnitudes in the Orange-Senqu River basin could increase into the future. These trends are modelled to be more pronounced in the more distant than the intermediate future and for shorter return periods more so than for longer ones. As the return period increases, more of the Orange-Senqu River basin is projected to experience floods of lower magnitude.

Figure 10 shows the ratios of intermediate future to present (top) and more distant future to present (bottom) one day floods with a two year return period. Dark blue areas depict an increase in flood magnitude while areas in pink represent a decrease.

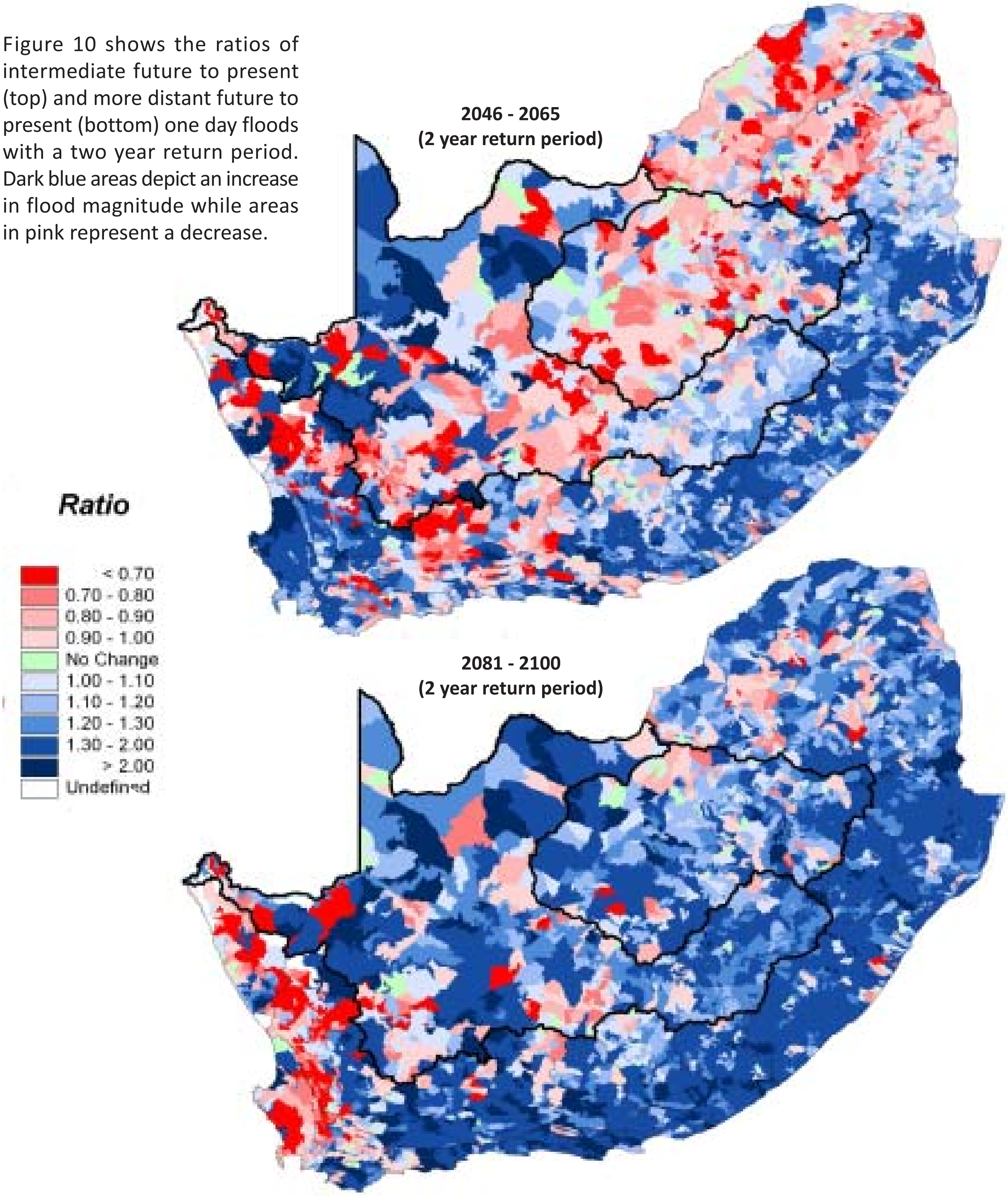


Figure 10: Ratios of intermediate future to present (top), and more distant future to present (bottom) one day flood magnitudes for the two year return period, modelled using input derived from the ECHAM5 climate model

Link between rainfall and floods

Indications are that any changes in rainfall in the future will be significantly amplified in the hydrological system. This amplification is depicted by the more intense colours in the map of floods (Figure 11, bottom) compared to that of rainfall (Figure 11, top) for the same duration and return period. Thus, an area may experience a small change in rainfall (light blue) while the same area may experience a large change in floods (dark blue). A one day duration and 2 year return period was used in both scenarios. Although only 10% of the basin is projected to experience a change in rainfall of a magnitude greater than 20%, 45% of the basin is likely to experience a change in floods of a magnitude greater than 20% for this duration and return period.

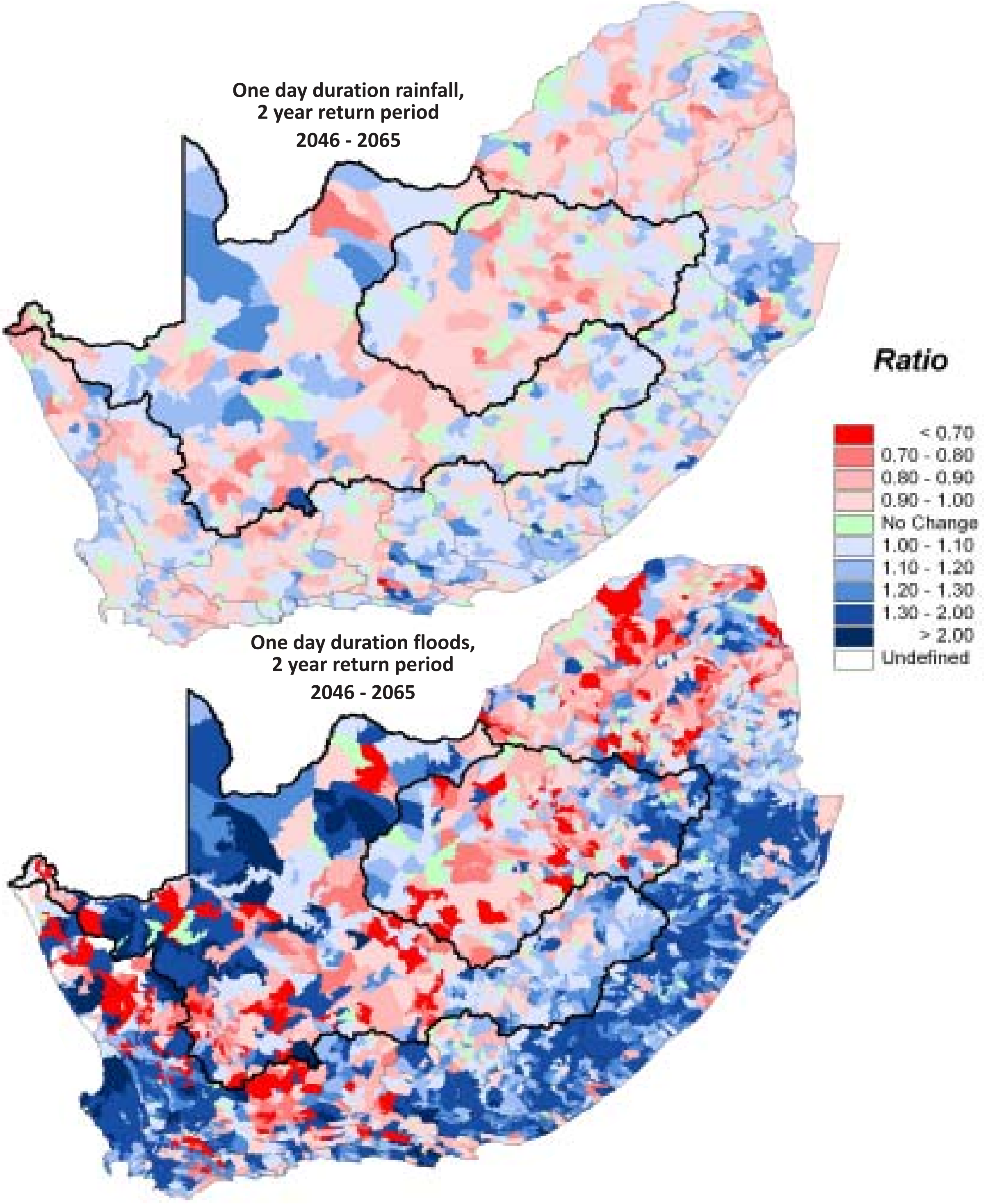


Figure 11: Ratios of intermediate future to present rainfalls (top) and floods (bottom) for the same duration and return period, generated using output from the ECHAM5 climate model

Extent of changes in floods

The results indicate that as the return period increases from 2 years to 50 years so the area that shows decreases in design floods becomes bigger, mainly in the upper reaches of the Orange-Senqu River basin. Figure 12 illustrates this increase in area of lower one day floods in the intermediate future. Similar results were obtained for 3 and 7 day floods for both the intermediate and more distant futures.

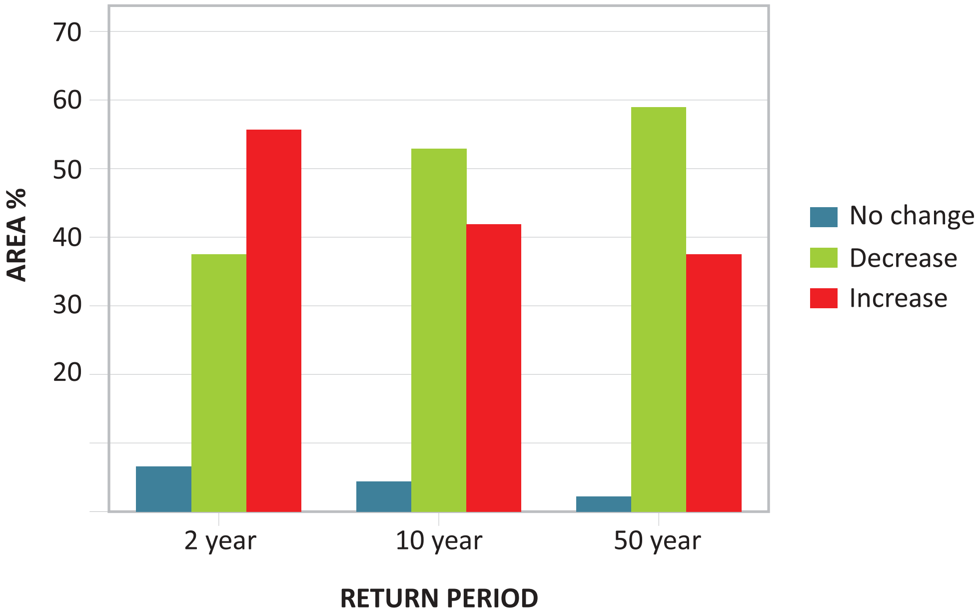
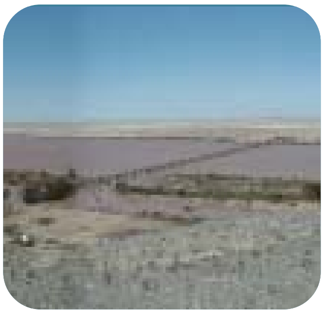
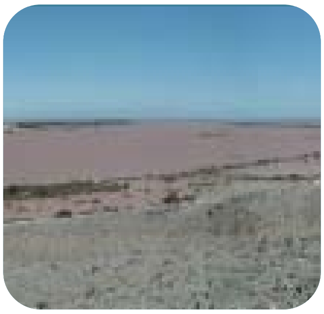


Figure 12. Total area (%) within the Orange-Senqu River basin projected to experience a decrease, increase or no significant change in one day flood magnitudes in the intermediate future for different return periods





Droughts

What are droughts?

A drought occurs when an area or place experiences a shortage of water in some form or other for an extended period of time, usually months or years, and generally as a consequence of below average precipitation. Droughts may be classified into meteorological, agricultural and hydrological droughts.

- Meteorological droughts usually precede the other types of droughts and occur when precipitation is below "normal" or average for a prolonged period.
- Agricultural droughts occur when there is insufficient water in the soil to grow a particular crop at a particular time.
- Hydrological droughts occur when surface and ground water resources such as aquifers, rivers, dams and/or reservoirs are in a below average depleted state for a prolonged period, usually in response to below average rainfall .

Droughts in this study

The focus of this study is on meteorological and hydrological droughts. Drought periods of single or consecutive multiple years (two and three) were analysed. Drought severity is classified here in terms of the return frequency of a drought. The term 'mild drought' is used in reference to a drought which occurs on average every three years or less frequently, 'moderate drought' refers to a drought occurring on average every five years or less frequently and a 'severe drought' occurs only once in ten years or more seldom.

Meteorological droughts

Overall, the area covered by droughts of different durations is projected to decrease in the Orange-Senqu River basin. This is certainly the case with shorter (one to two year) droughts, irrespective of their severity (indicated on the accompanying maps by the dark blue areas, where dark blue indicates fewer severe droughts in an intermediate future climate). However, areas experiencing longer (three consecutive years and longer) moderate or severe droughts may not change at all in future. Figure 13 indicates the ratios of the intermediate future to present conditions for droughts of different durations.

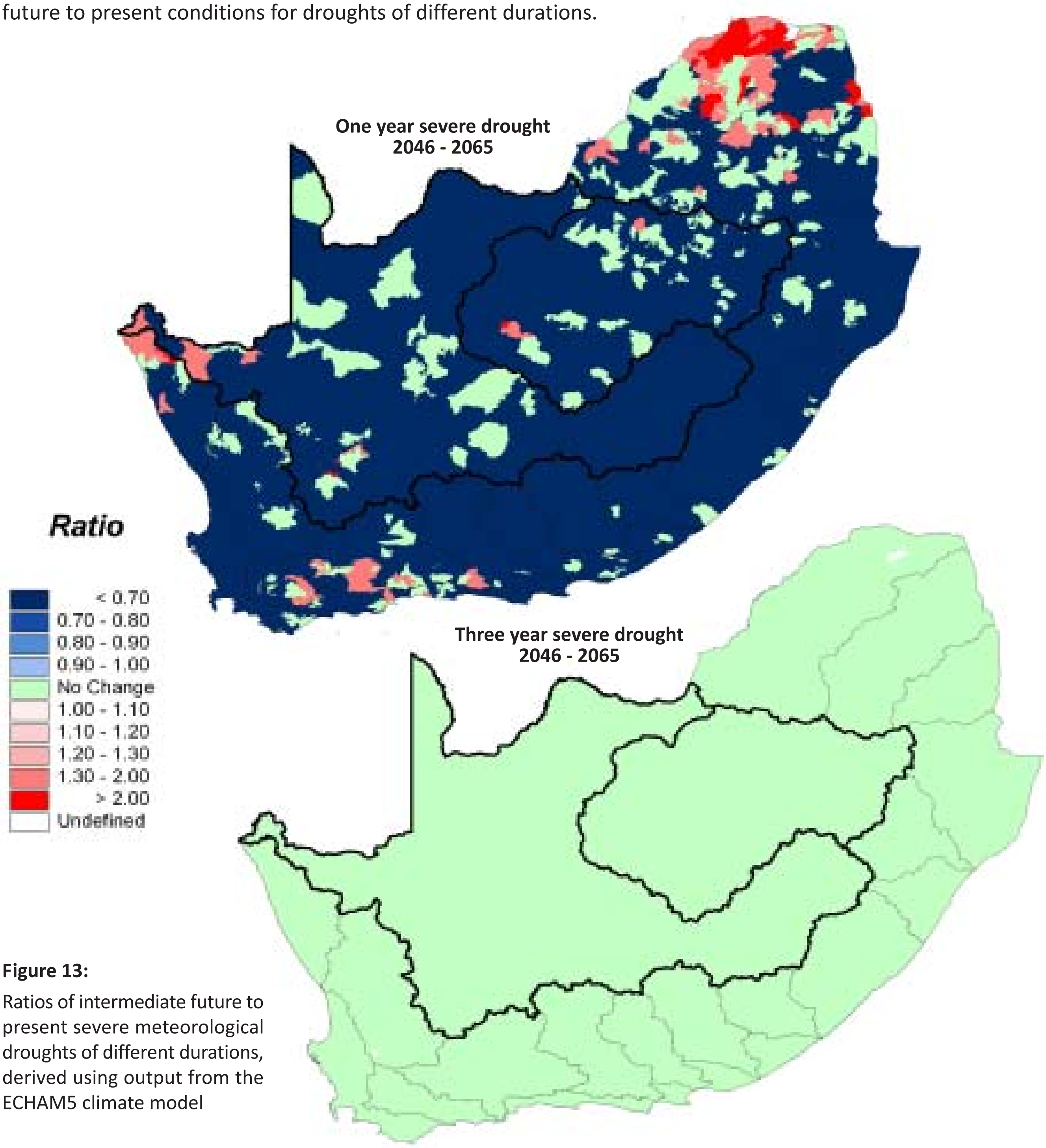


Figure 13:

Ratios of intermediate future to present severe meteorological droughts of different durations, derived using output from the ECHAM5 climate model

Projections also indicate that there are likely to be fewer mild droughts of long duration (three years) in future, but no change in severe meteorological droughts that span three years or longer. Similar trends are evident for changes in the frequencies of drought between the intermediate and distant future climates. The only areas that may experience an increase in the frequency of meteorological drought are the western drier areas of the Orange-Senqu River basin.

Figure 14 shows the ratios of intermediate future to present (top) and more distant future to present (bottom) mild droughts of one years' duration. Dark blue areas indicate a decrease in drought occurrences (i.e. more rainfall in future) while pink areas represent an increase (i.e. less rainfall).

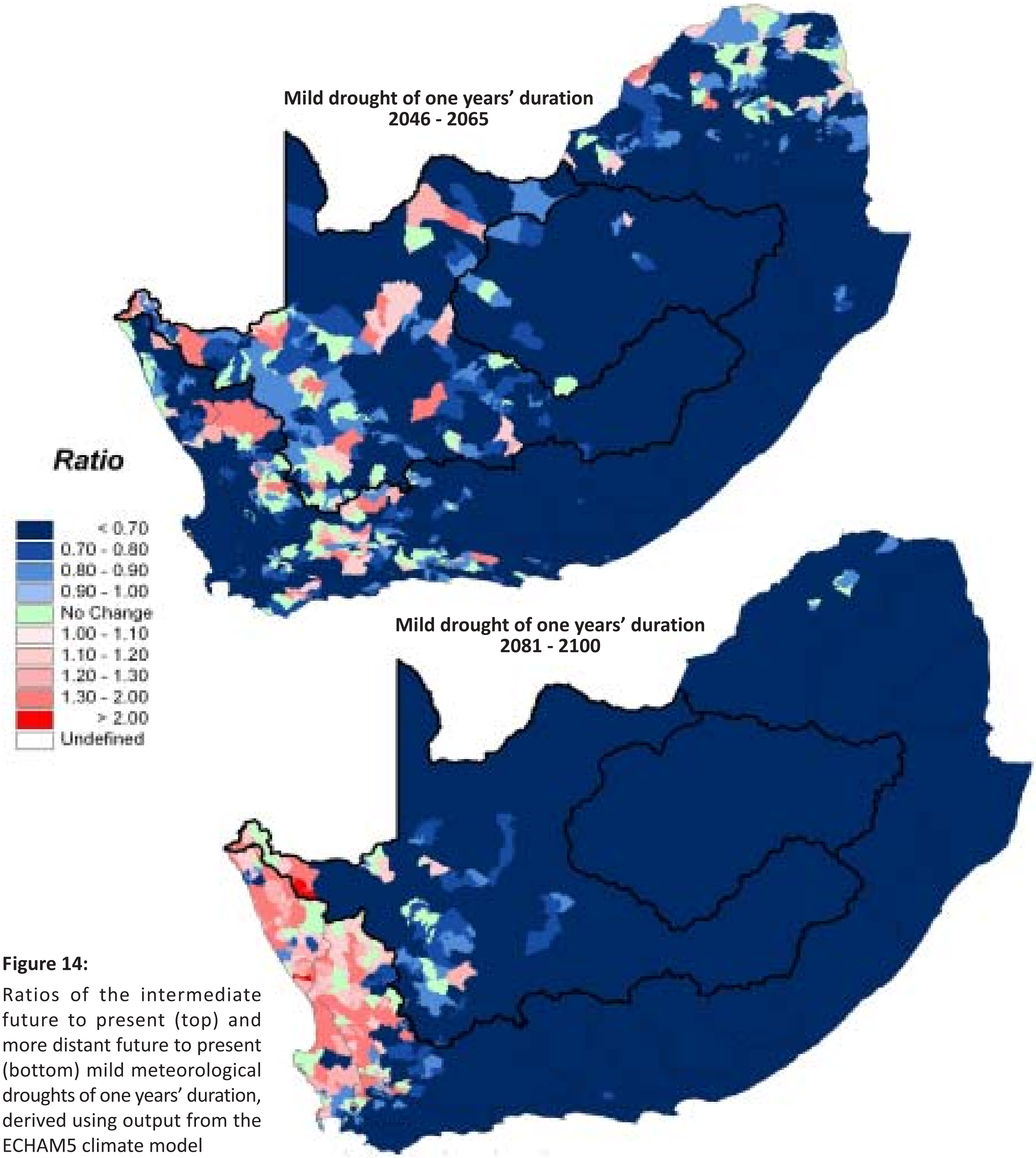


Figure 14:
Ratios of the intermediate future to present (top) and more distant future to present (bottom) mild meteorological droughts of one years' duration, derived using output from the ECHAM5 climate model

How certain are we of future changes in meteorological droughts in the Orange-Senqu River basin?

Projections from the five different GCMs listed in Table 3 show that there is a high level of confidence that the area experiencing meteorological droughts of one years' duration in the Orange-Senqu River basin will decrease in both the intermediate and distant future. However, comparisons between GCMs indicate that for longer drought periods (e.g. two or three years) and for severe droughts, the area exposed to these droughts will generally remain the same in the future as at present.

Hydrological droughts

Results from the study indicate that the total area in the Orange-Senqu River basin presently experiencing hydrological droughts of one years' duration is projected to decrease in both the intermediate and more distant future climates derived from the ECHAM5 GCM. This decrease is more pronounced in the one and two year droughts, with little change from the present in the three year droughts.

Figure 15 indicates the ratio of moderately severe hydrological droughts projected to occur in the intermediate future to those presently experienced for different durations of drought. The dark blue areas represent a decrease in the frequency of hydrological droughts (i.e. more water in streams), the red an increase and the green areas represent areas of no significant change in drought frequencies from the present.

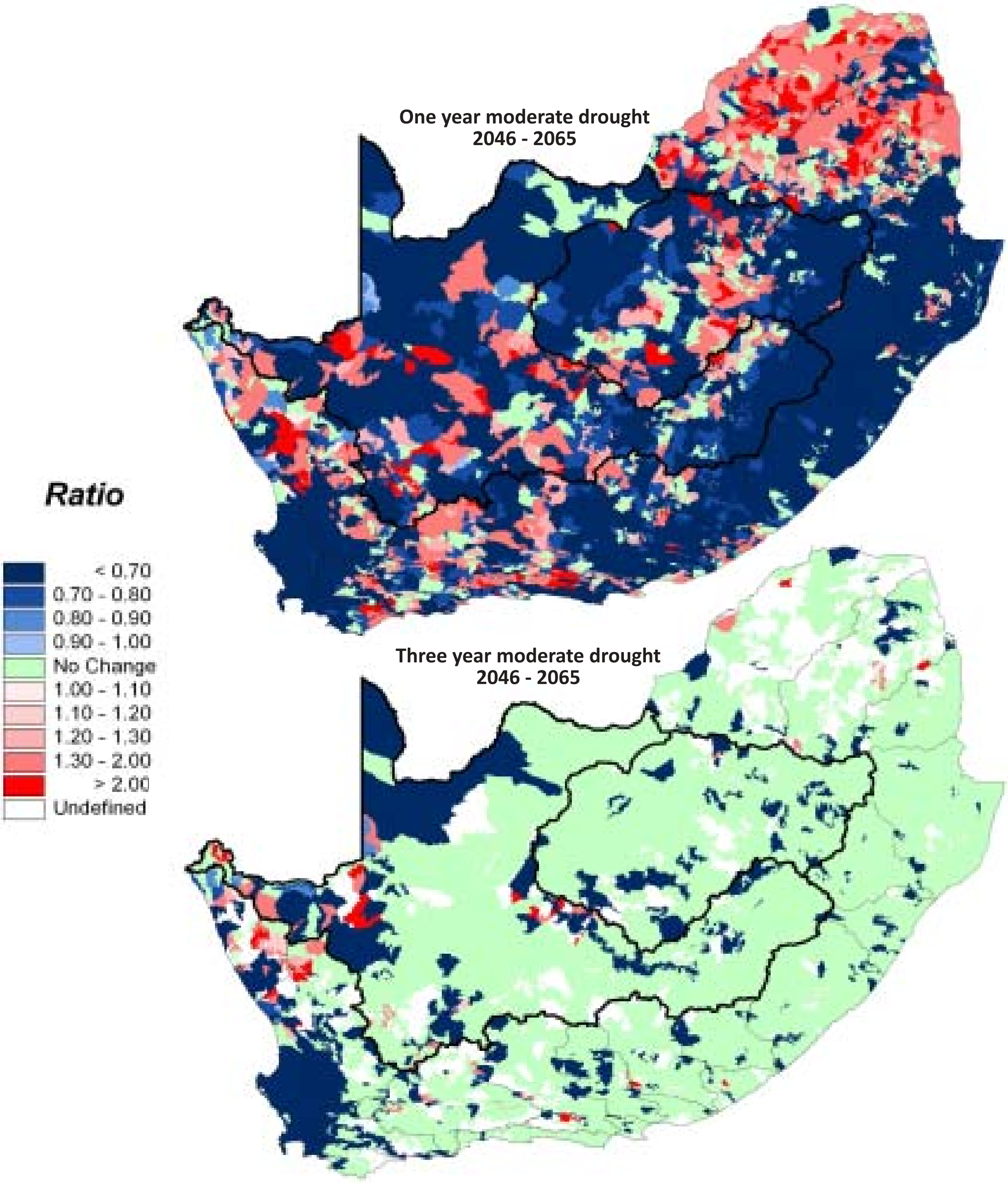


Figure 15: Ratios of intermediate future to present moderate hydrological droughts of different durations, derived using output from the ECHAM5 climate model

For droughts of three years' duration, the area affected by more droughts decreases substantially as the severity of the drought increases (Figure 16).

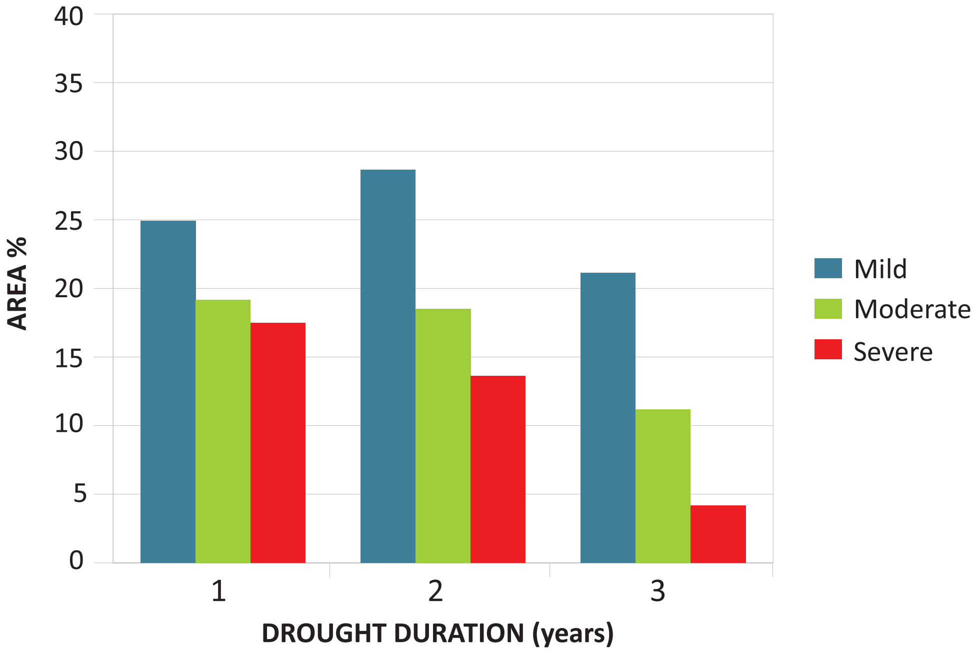


Figure 16: The total area (%) within the Orange-Senqu River basin projected to experience increases in mild, moderate and severe hydrological droughts of different durations.

Approximately 25% of the basin is projected to experience more frequent one, two and three year mild hydrological droughts in the intermediate future. However, trends show that in the more distant future less of the Orange-Senqu River basin will be afflicted by longer, more severe hydrological droughts compared to the intermediate future.

Differences in projections of hydrological and meteorological droughts

Spatial patterns between the meteorological and hydrological droughts are very different. Results for the meteorological drought analysis show that less than 10% of the Orange-Senqu River basin is projected to experience an increases in mild droughts and less than 2% of the basin is affected by increases in moderate or severe annual droughts. However, hydrological droughts are projected to increase over almost 25% of the Orange-Senqu River basin for mild droughts, while approximately 20% and 15% of the basin is projected to be affected by increases in moderate and severe annual hydrological droughts, respectively. This trend of projected hydrological droughts being more extensive in area than the corresponding projected meteorological droughts also holds true for multi-year droughts.

The reason for this amplification may be due to the projected increases in temperature in the intermediate future climate which, in turn, increases rates of evaporation. These factors may lead to drier soil moisture conditions before rainfall events. As a result, larger rainfall events are required in order to replenish some of the soil water content before runoff is produced.

This observation is illustrated in Figure 17 which reflects the ratios of annual meteorological (top) and hydrological (bottom) droughts of mild severity for the intermediate future to present climate scenarios. The dark blue areas indicate a decrease in the projected number of droughts while the red areas indicate an increase.

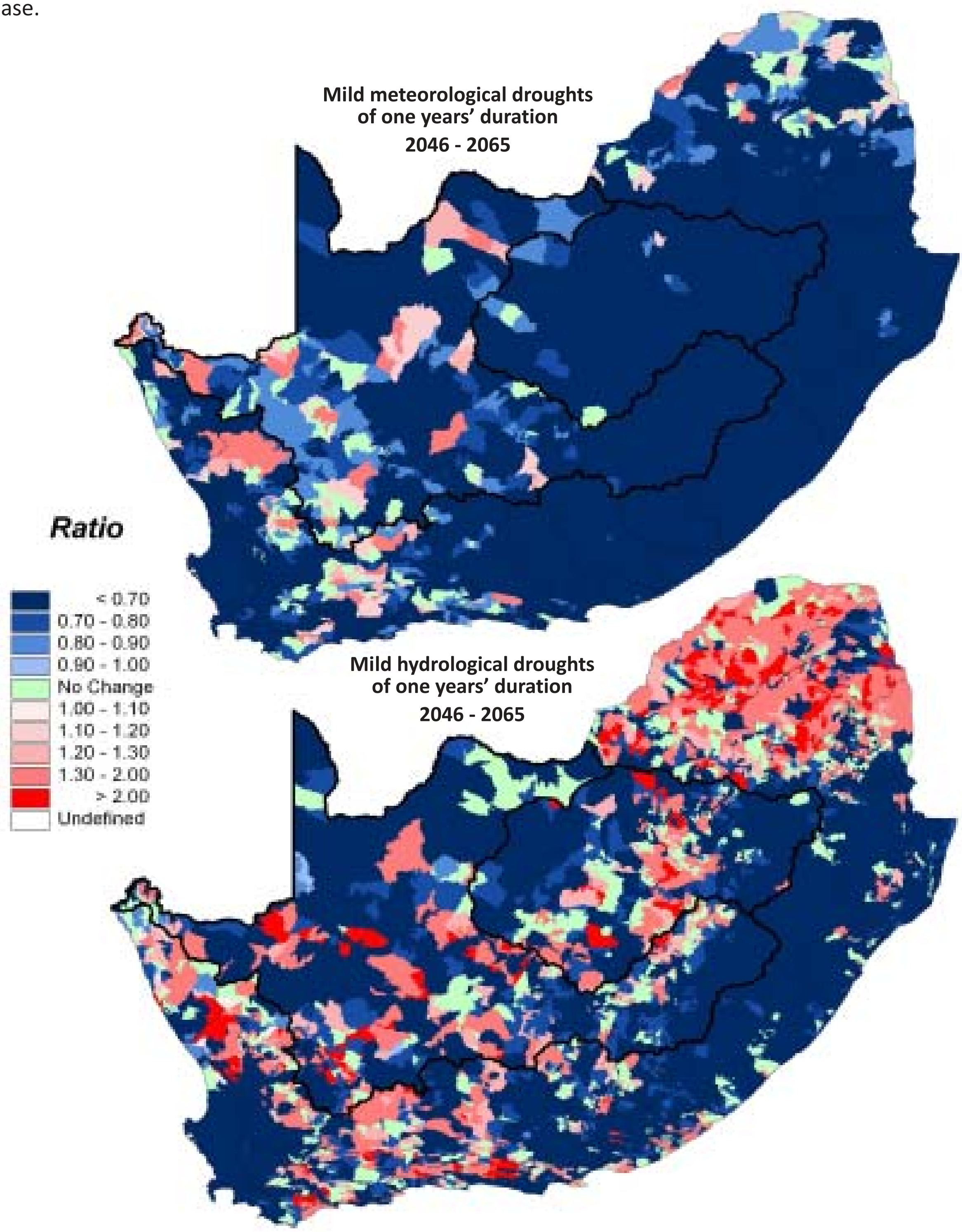


Figure 17. Ratios of intermediate future to present meteorological (top) and hydrological (bottom) one year droughts of mild severity, derived using output from the ECHAM5 climate model

SUMMARY OF RESULTS AND POSSIBLE IMPACTS FOR WATER MANAGERS

	Intermediate Future	Distant Future	Notable Observations
Temperature	↑	↑↑	Possible increases of 3.5°C and more than 7°C
Reference Crop evaporation	↑	↑↑	
Rainfall	↑	↑↑	Possible increases of 20%, and up to 100% with increased variability
Raindays	↑	↑↑	Possible increases of 20%, up to 100% for events >10 mm
Short duration rainfall	↑	↑↑	Possible increases in 40% and 72% of the basin
Long duration rainfall	↑	↑	Increases become larger with longer duration
Frequency of heavy rainfall	↑	↑↑	Increases possible in 67% and 83% of the basin
Agreement in rainfall predictions	↑	↑↑	GCMs agree more in the distant future, and as rainfall duration increases
Streamflow	↑↑	↑↑↑	Mimics rainfall increase; amplified streamflow changes
Streamflow variability	↑	↑↑	
Meteorological droughts (<3 years)	↓	↓	No change for longer (≥3 years) and more severe droughts
Hydrological droughts (<3 years)	↓	↓	No change for longer (≥3 years) droughts

Results confirm the widely accepted notion that climate change will cause increases in temperatures and evaporation in the future. Rainfall in the future, is projected to generally increase over the Orange-Senqu basin, with consequential amplified increases in streamflow and the occurrence of flooding, especially for shorter return periods. The upper reaches of the basin in the east could be particularly affected since this area has the highest historical rainfall already. Areas experiencing meteorological and hydrological droughts could generally decrease, especially those of shorter duration (one to two year). Rainfall and streamflows are predicted to become more variable in future. Although water planners may welcome the possibility that climate change may have some positive effects for water resources, there are several key threats that must be highlighted:

- An exception to this general trend occurs over a small area in the extreme west where more frequent short duration hydrological droughts are predicted for the future;
- Increased variability will reduce the ability to predict the future, hence water planners will need to improve their water planning capabilities;
- Mitigation of the possible effects of flooding should be investigated, for example to determine whether current infrastructure has been designed and built to withstand projected future increased streamflows;
- Second order impacts of an increase in water resources need further investigation. These could include the determination of the impact of additional water resources on water yield, on the region's key sectors such as food production and industry, and on the potential for increased sediment yield with knock on effects on dam storage capacity and water quality.

Other studies using different climate models, emission scenarios, and downscaling methods could well suggest impacts that are contradictory to those presented here. However, the state of the art approach used in this study, together with the high level of agreement between the climate models used, instils confidence in the results of this study. Nevertheless, any initiatives to adapt to the possible impacts of a changing climate should proceed with caution, in order to minimise the risk of erroneous adaptation.

Bibliography

Bohensky, E., Reyers, B., van Jaarsveld, A. & Fabricius, C. (eds.) 2004. Ecosystem services in the Gariep Basin. Sun Press, Stellenbosch.

Diederichs, N., O'Regan, D., Sullivan, C., Fry, M., Mander, M., Haines, C.-J. and McKenzie, M. 2005. Orange River Basin: Baseline Assessment Report - Draft: November 2005. NeWater.

FAO, 1992. Expert Consultations on Revision of FAO Methodologies for Crop Water Requirements. Land and Water Development Division, Food and Agriculture Organisation of the United Nations, Rome, Italy. pp 60.

Ghile, Y.B. 2008. Development of a Framework for an Integrated Time-Varying Agrohydrological Forecast System for Southern Africa. Unpublished PhD Thesis. University of KwaZulu-Natal, Pietermaritzburg, RSA. pp 234.

IPCC, 2007: Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996pp.

Kabat, P., Schulze, R.E., Hellmuth, M.E. and Veraart, J.A. 2003. Coping with Impacts of Climate Variability and Climate Change: A Scoping Paper. International Secretariat of the Dialogue on Water and Climate, Wageningen, Netherlands, DWC Report DWCSSO-01(2003). pp 112.

Knoesen, D.M. 2009. Integrating Hydrological Hazards and Climate Change as a Tool for Adaptive Water Resources Management in the Orange River Catchment. Unpublished PhD thesis, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Lehner, B., Döll, P., Alcamo, J. Henrichs, H. and Kaspar, F. 2006. Estimating the impact of global change on flood and drought risks in Europe: A continental, integrated analysis. Climatic Change, 75, 273–299.

Lumsden, T.G., Kunz, R.P., Schulze, R.E., Knoesen, D.M. and Barichievy, K.R. 2009. Methods 4: Representation of Grid and Point Scale Regional Climate Change Scenarios for National and basin Level Hydrological Impacts Assessments. In: Regional Aspects of Climate Change and Their Secondary Impacts on Water Resources. Water Research Commission Report 1562/1/09, Pretoria, RSA, WRC. Chapter 8.

Lynch, S.D. 2004. Development of a Raster Database of Annual, Monthly and Daily Rainfall for Southern Africa. Water Research Commission, Pretoria, RSA, WRC Report 1156/1/04. pp 78.

Penman, H.L. 1948. Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society A193, London, UK, 120 - 146.

Schmidt-Thomé, P. 2006. Integration of Natural Hazards, Risk and Climate Change into Spatial Planning Practices. Unpublished PhD Thesis. University of Helsinki, Finland. pp 31.

Schulze, R.E. 1995. Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System. Water Research Commission, Pretoria, RSA, Report TT 69/9/95. pp 552.

Schulze, R.E. 2003. The Thukela Dialogue: Managing Water Related Issues on Climate Variability and Climate Change in South Africa, University of Natal, Pietermaritzburg, South Africa, School of Bioresources Engineering and Environmental Hydrology, ACRUcons Report, 44. pp 152.

Schulze, R.E. 2005a. Setting the Scene: The Current Hydroclimatic "Landscape" in Southern Africa. In: Schulze, R.E. (Ed) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05. Chapter 6, 83-94.

Schulze, R.E. 2005b. Looking Into the Future: Why Research Impacts of Possible Climate Change on Hydrological Responses in Southern Africa? In: Schulze, R.E. (Ed) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05. Chapter 1, 3-17.

Schulze, R. E. 2008. Potential Evaporation: General Background. In: Schulze, R. E. (Ed). 2008. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/08, Section 13.1.

Schulze, R.E. and Maharaj, M. 2004. Development of a Database of Gridded Daily Temperatures for Southern Africa. Water Research Commission, Pretoria, RSA, WRC Report 1156/2/04. pp 83.

Schulze, R. E. and Smithers, J.C. 2008. One Day Design Rainfall. In: Schulze, R. E. (Ed). 2008. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/08, Section 6.8.

Schulze, R.E., Lumsden, T.G., Horan, M.J.C., Warburton, M. and Maharaj, M. 2005. An Assessment of Impacts of Climate Change on Agrohydrological Responses Over Southern Africa. In: Schulze, R.E. (Ed) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05. Chapter 9, 141-189.

Schulze, R. E., Lynch, S.D. and Maharaj, M. 2008. Annual Precipitation. In: Schulze, R. E. (Ed). 2008. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/08, Section 6.2.

Schulze, R.E. and Horan, M.J.C. 2009. Methods 1: Delineation of South Africa, Lesotho and Swaziland into Quinary basins. In: Regional Aspects of Climate Change and Their Secondary Impacts on Water Resources. Water Research Commission Report 1562/1/09, Pretoria, RSA, WRC. Chapter 5.

Smithers, J.C. and Schulze, R.E. 2003. Design Rainfall and Flood Estimation in South Africa. Water Research Commission, Pretoria, RSA, WRC Report 1060/1/03. pp 156 plus CD-Rom.

Acknowledgements

European Union for funding the NeWater Project

The Water Research Commission of South Africa, which, through climate change related projects K5/1562 and K5/1843, has enabled all the climate change impacts compilations to be done at the University of KwaZulu-Natal

The University of Cape Town, which, through research by Prof. B.C. Hewiston and Dr M. Tadross and their team have provided the downscaled climate scenarios to the University of KwaZulu-Natal team for application in this study

Caroline Sullivan (Oxford University Centre for Environment) and Myles Mander (Futureworks!) for valuable inputs to the visioning of this process

Layout: Tracy Freese, Purple Boa Creations, purbleboa@mweb.co.za

Photos: Ramogale Sekwale, Cobus Botha, Georg Wandrag, Douglas Macfarlane, Chris Dickens

Introductory map of Orange-Senqu River basin: Leo Quayle

Printing: Teeanem Printers, Pietermaritzburg

Further copies available on request from

Institute of Natural Resources

Tel (+27) 033 346 0796
Fax (+27) 033 346 0895
P.O. Box 100396, Scottsville, 3209
South Africa
www.inr.org.za