Dynamic, Evidence-Based, Ecosystem Services Decision-Support Model for Climate Change Adaptation: exploring a method to provide credits to water users in dry climates.

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by

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Executive Summary

In South Africa there exists a large reliance of socio-economic systems on aquatic ecosystems. DWA studies has shown for instance that more than 70% of the Olifants WMA economy depends directly on water resources, and similarly, the future economy of the Lephalale energy node will likely more than 80% be reliant on water for its GDP production. There is also strong anecdotal evidence that most peri-urban communities, where the bulk of South Africa's poor people reside, have various forms of direct dependence on water and other aquatic ecosystem services.

Yet there exists inadequate analytical and evidence-based understanding, at a local level, of the nature, extent and impact of climate change on aquatic ecology infrastructure and the aquatic ecosystem services that it delivers into the socio-economy. Little understanding also exists on what adaptation measures are relevant and what the costs and benefits of these measures are.

The IPCC's Fifth Assessment Report (AR5), published in September 2013, provides the most recent evidence of climate change, based on many independent scientific analyses from observations of the climate system, paleoclimate archives, theoretical studies of climate processes and simulations using climate models.

The AR5 concludes that the warming of the climate system is unequivocal.

Since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

The climate change effect starts with the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide. These concentrations have increased to levels unprecedented in at least the last 800,000 years. AR5 reports that carbon dioxide concentrations have increased by 40% since pre-industrial times. This results primarily from fossil fuel emissions.

In order to estimate the future impacts of climate change, the IPCC has defined a set of future scenarios, the so-called Representative Concentration Pathways (RCPs). The RCPs estimate climate effects for the next 80 years. The IPCC estimates that global surface temperature change for the end of the 21st century is likely to rise for all RCP scenarios. Changes in the global water cycle in response to the warming will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions. Extreme precipitation events over most of the mid-latitude land masses will likely become more intense and more frequent.

How will climate change affect aquatic ecosystems? UNEP has conducted a systematic review of risks of climate change to ecosystems.

UNEP anticipates significant changes in the distribution of some ecosystems, principally due to increasing temperature and altered precipitation regimes. Likely distribution changes include firstly pole-ward shifts, especially in mid-latitude regions like South Africa, and secondly upward shifts, especially in montane systems. UNEP also anticipates changes in species composition. This in turn could result in changes in the physical and trophic structure of ecosystems, with resulting further effects on system function and composition.

This could affect human well-being through the effect of climate change on the ecosystem services that aquatic ecosystems provide to people. These include provisioning services such as fisheries, water provisioning, timber production or fibre and fodder production. UNEP notes that these changes may vary in distribution, with some instances of increases and some of decreases in production. Possibly more critically, climate change may also affect the ability of ecosystems to regulate flows of ecosystem services. Water purification and water flow are of particular concern. Another impact may be on the ecosystem service of carbon sequestration. Climate change may reduce the ability of many different ecosystems to sequester and/or retain carbon which can feedback to climate change.

The question then emerges how to deal with these risks.

The concept of vulnerability is central to dealing with risk. Tubi et al. (2012) defines vulnerability to climate change to be comprised of two factors: impacts (i.e. the expected damages due to climate change) and adaptive capacity (i.e. the ability of people to adjust to these damages).

The most recent glossary of the IPCC defines vulnerability (to climate change) as follows. "*The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity*. "

There are two fundamental response options to dealing with vulnerability. This includes *mitigation* of climate change and *adaptation* to climate change. *Mitigation* refers to limiting global climate change through reducing the emissions of greenhouse gases (GHGs) and enhancing their sinks. *Adaptation* refers to moderating the adverse effects of climate change through a range of actions that are targeted at the vulnerable system.

Mitigation has traditionally received much greater attention than adaptation in the climate change community, both from a scientific and from a policy perspective (Teri, 2009). The principal reason for this is that mitigating climate change helps to reduce impacts on all climate-sensitive systems, whereas the potential of adaptation measures is limited for many systems. In addition, reducing GHG emissions applies the polluter-pays principle whereas the need for adaptation measures are likely be greatest in developing countries, which have contributed relatively little to climate change. GHG emission reductions are also relatively easy to monitor against an established baseline. It is much more difficult to measure the effectiveness of adaptation in terms of impacts avoided.

UNEP proposes an adaptation-based approach to dealing with the climate risks to aquatic ecosystem services. There are a number of reasons for this. Firstly, given the amount of past GHG emissions and the inertia of the climate system, we are already bound to some level of climate change, which can no longer be prevented even by the most ambitious emission reductions. Then, the effect of emission reductions takes several decades to fully manifest, whereas adaptation measures may have more immediate benefits. In addition, adaptations can be effectively implemented on a local or regional scale, whereas mitigation of climate change requires international cooperation. Finally, most adaptations to climate change also reduce the risks associated with current climate variability, which is a significant hazard in many world regions (Campbell et al., 2009).

The relationship between aquatic ecosystems and climate change is characterised by two perspectives.

First, there exists a conservation perspective. As climate change increasingly puts a strain on ecosystems and species populations, it is important to find ways to increase their resilience to current and future climate change. This is important for protecting ecological infrastructure and for ensuring the protection of ecosystem services dependent upon this infrastructure. (Table 0-1)

Second, there exists a Green Economy perspective. The conservation and restoration of biodiversity and aquatic ecology infrastructure and the safeguard of ecosystem services can play a key role in helping societies to adapt to climate change. Ecosystem-based approaches to adaptation integrate the use of biodiversity and ecosystem services into an overall strategy for helping people adapt to climate change (Munroe et al., 2011). Accordingly, ecosystems are therefore regarded as the first line of defence against impacts of climate change. (Table 0-2)

Adaptation considerations requires of us to have an understanding of a number of issues.

Firstly, we need to understand what to adapt to. Here it is important to note that adaptation strategies designed to address the projections of climate change in the future, will benefit the Southern African social-ecological system in the present. These strategies may be refined as necessary once they have been implemented, and they offer the opportunity to focus on improving the quality of life of South African citizens in the near term. Thus climate change adaptation strategies will help us to adapt also to other, more immediate hazards than climate change.

Secondly, we need to understand how to adapt and what resources are required to implement the adaptation measures. South Africa's National Climate Change Response White paper identifies a range of broad adaptation measures. These include:

- Strengthen biodiversity management and research institutions so that they can monitor, assess and respond effectively to existing anthropogenic pressures together with the additional pressures that climate change presents.

- Conserve, rehabilitate and restore natural systems that improve resilience to climate change impacts or that reduce impacts.

- Prioritise impact assessments and adaptation planning that takes into account the full range of possible climate outcomes, in conjunction with plausible scenarios of other stresses.

- Enhance existing programmes to combat the spread of terrestrial and marine alien and invasive species, especially in cases where such infestations worsen the impacts of climate change.

- Expand the protected area network where it improves climate change resilience, and manage threatened biomes, ecosystems, and species in ways that will minimise the risks of species extinction. A regulatory framework to support investment in conservation or land rehabilitation as a way of offsetting the environmental impacts of new property developments will be explored.

- Encourage partnerships for effective management of areas not under formal protection, especially freshwater ecosystem priority areas, critical biodiversity areas, ecological support areas and threatened ecosystems.

- Expand existing gene banks to conserve critically endangered species that show increasing vulnerability to climate change trends.

These adaptation recommendations are of a highly strategic nature and much more work is required to support local decision makers understand potential local impacts, and how to make long-term plans under a new range of uncertainty about future hydrologic conditions. Water resource managers would also need to consider the local impacts of climate change as they deal with other challenges – including water use licences, population growth, land use changes, economic transformation priorities, economic constraints, and a variety of stressors to the quality and quantity of water resources.

The key to the additional work required is the linkage between climate change and aquatic ecosystems: aquatic ecosystem services. The vulnerability of people, especially local communities, lies in their dependence on provisioning and cultural ecosystem services. It is here that the conservation perspective is of importance, as various adaptation measures may be applied to protecting aquatic ecology infrastructure, which, in turn, protects the delivery of the provisioning and cultural ecosystem services. From the Green Economy perspective, the protection of aquatic ecology infrastructure in itself provides an adaptation mechanism. This happens through the regulating services. The function of the regulating services is to regulate, moderate and insure the delivery of a range of services that secure aquatic ecosystem functioning. Key amongst these are services relating to flow and water quality regulation.

Although an increasing amount of work is being done in South Africa on ecosystem services, there is still woefully inadequate analytical and evidence-based understanding, at a local level, of the nature, extent and role of aquatic ecosystem services in the socio-economy. Even less understanding exists on how these services are vulnerable to climate change and what adaptation measures are relevant.

An adequate analytical and evidence-based understanding requires a systems analysis capability that would internalise:

- The composition and functionality of aquatic ecosystems;

- The production of aquatic ecosystem services from these systems;
- The communities dependent on these ecosystem services;
- The vulnerability of these aquatic ecosystem services to climate change (and near term hazards);
- The cost and benefit implications of the ecosystem services (direct values and insurance values) to beneficiaries.

Such a systems analysis would enable the evidence-based assessment of practical adaptation measures such as:

- Aquatic biodiversity conservation investments;
- Rehabilitation interventions
- Payments for ecosystem services schemes;
- Insurance schemes.

Table 0-1. ***A critical assessment of the evidence of the hazards for South and southern Africa.***

Impacts			**Vulnerability to the hazards of climate change**		**Examples of other Ecosystem Services vulnerable to the hazard, and activities of the SES which will increase the vulnerability**
Phenomenon and direction of trend	**Prediction**	**Trend (southern Africa)**	**Water resources likely to be affected**	**Ecosystem Services likely to be affected**	
Atmospheric carbon levels will continue to increase		Globally, increased by 37.5% since the beginning of the industrial era (from 280ppm to 385ppm)	Wetlands; lakes; estuaries;	Primary production (evapotranspiration)	Poor land management (overgrazing, loss of top soil); invasive biota;
Temperature: Warmer and/or more frequent hot days and nights over most land areas; Warm spells/heat waves. Frequency and/or duration increases over most land areas	Will increase by 0.2°C (low scenario) - 0.7°C (high scenario) per decade	1900-2009; mean min increased by 2°C, mean max by 1.5°C;	All surface water resources (e.g. increased evaporation)	Nutrient cycling Primary production Climate regulation Disease regulation	Poor land management; unbalanced nutrient mix in waste discharge, change in plant species; invasive biota; poorly planned or uncontrolled development; Change in management of human health or management of ecological infrastructure;
Average rainfall	Will increase along the East Coast and decrease along the West coast, by ca. 10% in each case.	Uncertain over southern Africa due to the high natural variability.	Surface and groundwater resources will be affected.	Soil formation Nutrient cycling Primary production Fresh water Disease regulation Water regulation Water purification: Pollination	Poor land management (erosion, invasive biota, change in the capacity of the terrestrial and aquatic ecosystem to sequester nutrients and pollutants). Poorly planned or Uncontrolled development; Certain changes in management institutions.
Increased incidence and/or magnitude of extreme high sea level	Sea levels likely to increase		Estuaries	Fish production Aesthetic services Water purification Natural hazard regulation	
Increase in extreme weather events: Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation; Increases in intensity and/or duration of drought	Rainfall events will become less frequent and more violent. Droughts will become more frequent and last longer	Apparent increase in extreme events such as cyclones and severe droughts.	All water resources	Soil formation Nutrient cycling Primary production Fresh water Climate regulation Disease regulation Water regulation Water purification Pollination	Poor land management (erosion, invasive biota, change in the capacity of the terrestrial and aquatic ecosystem to sequester nutrients and pollutants). Poorly planned or Uncontrolled development; Management institutions not adapted to take account of changing conditions. Poor or non-existent disaster management planning.

Table 0-2. Sectoral Vulnerabilities and Adaptive Capacity (Adapted from McKenzie et al., 2011)

Impact	Sectoral Vulnerabilities	Adaptive Capacity
Temperature Higher warming throughout the continent and in all seasons compared with global average. Drier subtropical regions may become warmer than the moister tropics. **Precipitation** Decrease in annual rainfall in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached. Decrease in rainfall in Southern Africa in much of the winter rainfall region and western margins. Increase in annual mean rainfall in East Africa. Increase in rainfall in the dry Sahel may be counteracted through evaporation. **Extreme Events** Increase in frequency and intensity of extreme events, including droughts and floods, as well as events occurring in new areas.	**Water** Increasing water stress for many countries. 75-220 million people face more severe water shortages by 2020. **Agriculture and food security** Agricultural production severely compromised due to loss of land, shorter growing seasons, more uncertainty about what and when to plant. Worsening of food insecurity and increase in the number of people at risk from hunger. Yields from rain-fed crops could be halved by 2020 in some countries. Net revenues from crops could fall by 90% by 2100. Already compromised fish stocks depleted further by rising water temperatures. **Health** Alteration of spatial and temporal transmission of disease. Vectors, including malaria, dengue fever, meningitis, Cholera, etc. **Terrestrial Ecosystems** Drying and desertification in many areas particularly the Sahel and Southern Africa. Deforestation and forest fires. Degradation of grasslands.	Aquatic ecosystems and the ecosystem services that emanate from them are identified by UNEP as key to enabling and insuring adaptive capacity

Table of Contents

1 Introduction

Atmospheric carbon dioxide concentrations before the industrial revolution were stable at around 280-290 ppm. The first industrial revolution (1800-1870) saw the increased use of coal, particularly in industry and rail transport. This, combined with an increase in the population growth rate resulting from better agricultural and sanitation practices, started the increase in the concentration of CO_2 and other GHG in the atmosphere (Weart, 2008). The Swedish scientist Svante Arrhenius (1859-1927) was the first to recognise that the combustion of fossil fuels may result in global warming. He proposed a relation between CO_2 and atmospheric temperature which he called the natural greenhouse effect. However, this was forgotten and during a period of cooling between the 1940s and the 1970s, through the media, fear began to develop that a new ice age may be approaching. During the 1980s the mean global temperature began to rise and, again through the media, people began to question the idea of an ice age. Media coverage convinced people that the world was on the brink of significant climate change which would have many negative effects (Maslin, 2009).

The IPCC was formed in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). Its mission is to provide comprehensive scientific assessments of current scientific, technical and socio-economic information worldwide about the risk of climate change caused by human activity, its potential environmental and socio-economic consequences, and possible options for adapting to these consequences or mitigating the effects. The IPCC has published a number of reports since its formation and, through its reports, has successfully formed a focal point for our knowledge of climate change and its likely effects on the global social ecological system. The integrating structures provided by the IPCC through its working groups and task force offer the global climate change community the platform from which to gauge the state of knowledge and identify gaps in the knowledge base.

Development of the national economy has in part been dictated by the availability of natural resources and water availability is a central consideration. Infrastructure has been built to support the economy at a high level of assurance. This has created a delicate balance between resource availability and the commitments that must be met from the resource. Even a slight change in the spatial or temporal climate will have implications for the level of assurance of supply and so for the economy, both because the existing infrastructure will not necessarily cope with the change and the increased variability will mean that planning new infrastructure will be more difficult.

The increasing level of GHG, particularly CO_2, was identified as the main cause of climate change and so has been the main target of the mitigation strategies. As first noted by Arrhenius and his contemporaries, the main source of CO_2 is from the combustion of fossil fuels to provide the energy that drives the modern economy. A number of other GHG have also been identified, all of which are linked either to the industrial economy or to the simple increase in the global population numbers and their needs and the waste products that are generated from these.

The United Nations Framework Convention for Climate Change (UNFCCC), an international environmental treaty negotiated in 1992 during the Earth Summit held in Rio de Janeiro and came into effect in 1994. This convention encourages industrialised countries to stabilise GHG emissions to a level that would prevent dangerous anthropogenic interference with the global climate system. This was followed in 1997 (effective 2005) by the Kyoto Protocol which set binding targets for signatory states to reduce their GHG emissions (UNFCCC).

Mitigation: In the developed world, carbon has been targeted as the mechanism to control global warming. This is because the most commonly occurring green-house gasses (GHG) are carbon compounds. In the north-western hemisphere sophisticated policies and international agreements are being developed to reduce carbon emissions to a level which, it is considered, will minimise the negative effects of GHG and so bring the projected change in climatic conditions under control. This initiative is currently enshrined in the Kyoto Protocol. The UNFCCC and the Kyoto Protocol have set the agenda for mitigation which has dominated the international response to global warming. Much of the focus in climate change mitigation has been on how to maintain the growth of an energy-hungry economy while reducing the carbon footprint. This suited the industrialised nations but did not help the developing nations very much for two reasons. Firstly, most of the GHG emissions from burning fossil fuel are from the industrialised nations and secondly, many of the people in the developing nations are poor and, as a result, more vulnerable to the vagaries of climate change. At the same time, the tropical forests, which are important carbon sinks, are being felled for agriculture, timber and other reasons. The felling and burning of this deforestation is estimated to account for nearly 20% of the global greenhouse gas emissions making land cover change the second biggest contributor to global GHG emissions after power generation (UN-REDD, viewed 2012; Parker et al., 2009).

Having accepted the veracity of this, the developed world is imposing the concept of GHG reduction on developing countries as well. However, apart from the BRICS (Brazil, Russia, India, China, South Africa) countries, carbon emissions are generally low in developing countries.

A recent mitigation strategy, pioneered by the FAO, UNDP and UNEP, which offers the developing world a way of mitigating GHG emissions is the REDD (**R**educing **E**missions from **D**eforestation and **D**egradation) programme. The REDD Programme provides policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries. REDD also provides policy approaches and positive incentives for the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (Parker et al., 2009). It is estimated that there will be a substantial North-South flow of finance which could reward a meaningful reduction in carbon emissions and also support a new, pro-poor development, help conserve biodiversity and secure vital ecosystem services (UN-REDD, viewed 2012). However, not all countries have forests, so alternate methods of generating credits may profitably be investigated.

REDD+ covers, in addition to deforestation and degradation, other activities such as the sustainable management of forests and the enhancement of forest carbon stocks. REDD+ also has the potential to offer developing countries substantial financial benefits for protecting their forests, and may be more cost-effective than other emission-reduction policies (REDD-net, viewed 2012).

In summary, although the predicted effects of climate change will be felt globally, early mitigation strategies have focused on issues of concern to the industrialised nations. Developing countries were, by and large, not considered. REDD+ is an initiative that extends mitigation activities to tropical, largely developing, countries which receive high rainfall. However, much of the landmass lying on or just outside the tropics, both North and South, is arid or semi-arid and so the REDD+ programme (or mechanism) will not benefit these countries. A large number of people live in these areas, many of them in extreme poverty. The high level of poverty means that these people are vulnerable to the vagaries of the weather. A different mechanism needs to be developed to address the mitigation of climate change in arid and semi-arid areas.

Climate change mitigation is an important objective, but certain choices, such as the greater use of hydropower or biofuels, will consume substantially more water and may impact negatively on the overall basket of ES (Pittock, 2011). Mitigation strategies, thus, require the integration of a range of disciplines if the most effective option is to be developed.

Adaptation: Effective adaptation to climate change needs resilient social-ecological systems and effective policies and institutions. This is especially important for poor, vulnerable communities. The design of effective mechanisms require the linkages between projected changes, ecosystem services (ES) and the socio-economy to be explicitly developed and integrated. This will be particularly important in fragile arid or semi-arid regions. The projections of increased climate variability are superimposed on the already high variability found in South Africa. In this situation it is difficult to separate the effects of climate change from the inherent climatic variability of the region. Thus, people living in these regions may already be facing the conditions of variability projected for other parts of the world.

This exploratory project will focus in particular on the need to increase the resilience and robustness of, and to achieve water equity for, vulnerable, poor communities in an uncertain future. The high natural climatic variability in arid and semi-arid southern Africa means that policies and strategies developed to increase the resilience and robustness of social-ecological systems in the face of climate change in the medium to longer term are likely to be immediately relevant in the face of the natural variability. This will give governments the opportunity to fine-tune their policies and strategies aimed at adaptation to future climate change.

2 Assessment of climate change models for SA

2.1 IPCC Fifth Assessment Report

The IPCC's Fifth Assessment Report (AR5), published in September 2013, provides the most recent evidence of climate change, based on many independent scientific analyses from observations of the climate system, paleoclimate archives, theoretical studies of climate processes and simulations using climate models.

The AR5 concludes that the warming of the climate system is unequivocal.

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The climate change effect starts with the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide. These concentrations have increased to levels unprecedented in at least the last 800,000 years. AR5 reports that carbon dioxide concentrations have increased by 40% since pre-industrial times. This results primarily from fossil fuel emissions.

The IPCC estimates that global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, and *more likely than not* to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit inter-annual-to-decadal variability and will not be regionally uniform.

It is highly likely that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase. It is very likely that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur.

Similarly, changes in the global water cycle in response to the warming will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

Projected changes in the water cycle over the next few decades show similar large-scale patterns to those towards the end of the century, but with smaller magnitude. Changes in the near-term, and at the regional scale will be strongly influenced by natural internal variability and may be affected by anthropogenic aerosol emissions.

Changes in the global water cycle in response to the warming will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases.

2.2 The South African perspective

Professor Roland Schulze (pers. comm.) notes that uncertainty and variability are two factors that we in southern Africa, together with Australia, have to live with. The co-efficient of variability of the climate, rainfall in particular, of these countries is amongst the world's highest, and the variability of runoff varies by two to five times that of the rainfall. He notes that it is the temperature or precipitation events, not the averages, which have the impact and recommends that critical variables should be recognised. With precipitation, for instance, a rainfall event of 10mm will generate runoff and an event of 25mm will generate sediment yield. He notes that climate change is an event-driven process and that the large events are likely to become more frequent.

Schulze (pers. Comm.) recommends using data generated by several models for downscaling. He notes that there are a range of 23 Global Climate Models available, but the newer models are better than the older ones and there is a need to standardize on selected models so that the results of studies may be comparable.

Global Climate Models (GCM) simulate the climate response at a comparatively low resolution and so do not lend themselves to examining local-scale response to global climate change. Due to the complexity of the modelled process and constraints of CPU power, GCMs typically resolve the earth's surface in a grid of about 80 to 500 km (ORASECOM, 2010). Hewitson and Crane (2005) noted that there was a continuing demand for robust downscaling techniques and present a methodology that utilized the advantages of existing techniques while minimizing their disadvantages. The aim was to derive precipitation statistics that could have immediate application in the formulation of adaptation and mitigation strategies in South Africa. Simulations from three GCMs provided the data, CSIRO Mk2, ECHAM4.5 and HadAM3. Application of the methodology to the data derived from these three models showed general agreement in the projected climate change between the 3 models that there would be increased summer rainfall in the interior and East of South Africa and a decrease in winter rainfall in the Western Cape, although there were large areas of inter-model disagreement.

ORASECOM (2010) and Schulze et al. (2011) both used data generated by the ECHAM-5/MPIOM GCM, the first results from this model were published in 2005. It is one of the most prominent GCMs and generates an output between the wetter and drier models. ORASECOM (2010) based projections on Scenario A1B (an economically driven future governed from a global perspective and using a balance of fossil and non-fossil derived energy). Schulze et al. (2011) based their projections on scenario A2 (worst case scenario). The ORASECOM (2010) projections were downscaled using the STAR (a statistical model based on historical weather records) and the CCLM (a dynamic model that uses the output of the GCM ECHAM5).

Schulze et al. (2011) found that quaternary catchments were too coarse a scale to model the detailed hydrological response and so have divided each of southern Africa's quaternary catchments into 3 quinary catchments which show a greater degree of hydrological homogeneity, giving a total of 5 838 quinary catchments in the southern African region. Schulze et al. (2011) used the ACRU model to model the runoff per quinary. This was modelled for the baseline (1971-1990), the intermediate future (2046-2065) and the distant future (2081-2100). The coefficient of dispersion was also calculated per quinary (Figure 2-1).

There is no clearly defined trend, although the drier west of the country tends to become drier and the wetter East of the country tends to become wetter. This is most clearly seen in the south western Cape where the projected runoff in the distant future is between 0.5 and 0.75 of the baseline runoff. The high coefficient of variability in the drier west of the country is apparent, although there are quinaries across the region which show a high coefficient of dispersion.

The January runoff figures show a mixture of areas of increased and decreased runoff across the drier regions of the county with a consistently more moist south-east area (Figure 2-2). The coefficient of dispersion is very high in the Kalahari Desert in January although there are areas of the lower Orange River basin where the coefficient of dispersion does not change much from the baseline. The distribution of runoff during July (Figure 2-3) shows a similar pattern of change to that of January in that quinaries showing increased or reduced runoff are mixed, showing no distinct trend.

There is apparent agreement that in the distant future the Western Cape is projected to realize a decrease in runoff. However, this is not realized progressively. In the intermediate future the projection is that runoff in this region will be higher than the baseline.

Using the Thukela Basin as a case study area, water temperatures were modelled per quinary for the whole basin. This was not done for the region although the model used was shown to be sufficiently robust to perform the task. Modelling the change in water temperature was based on the modelled change in air temperature. Air temperature was modelled using the GCM ECHAM5 which projected an overall increase in temperature from baseline where few quinaries in the lower basin reached a mean annual maximum of 21.99°C to a situation where, in the long term future, the majority of quinaries will experience a mean annual temperature of up to 23.99°C.

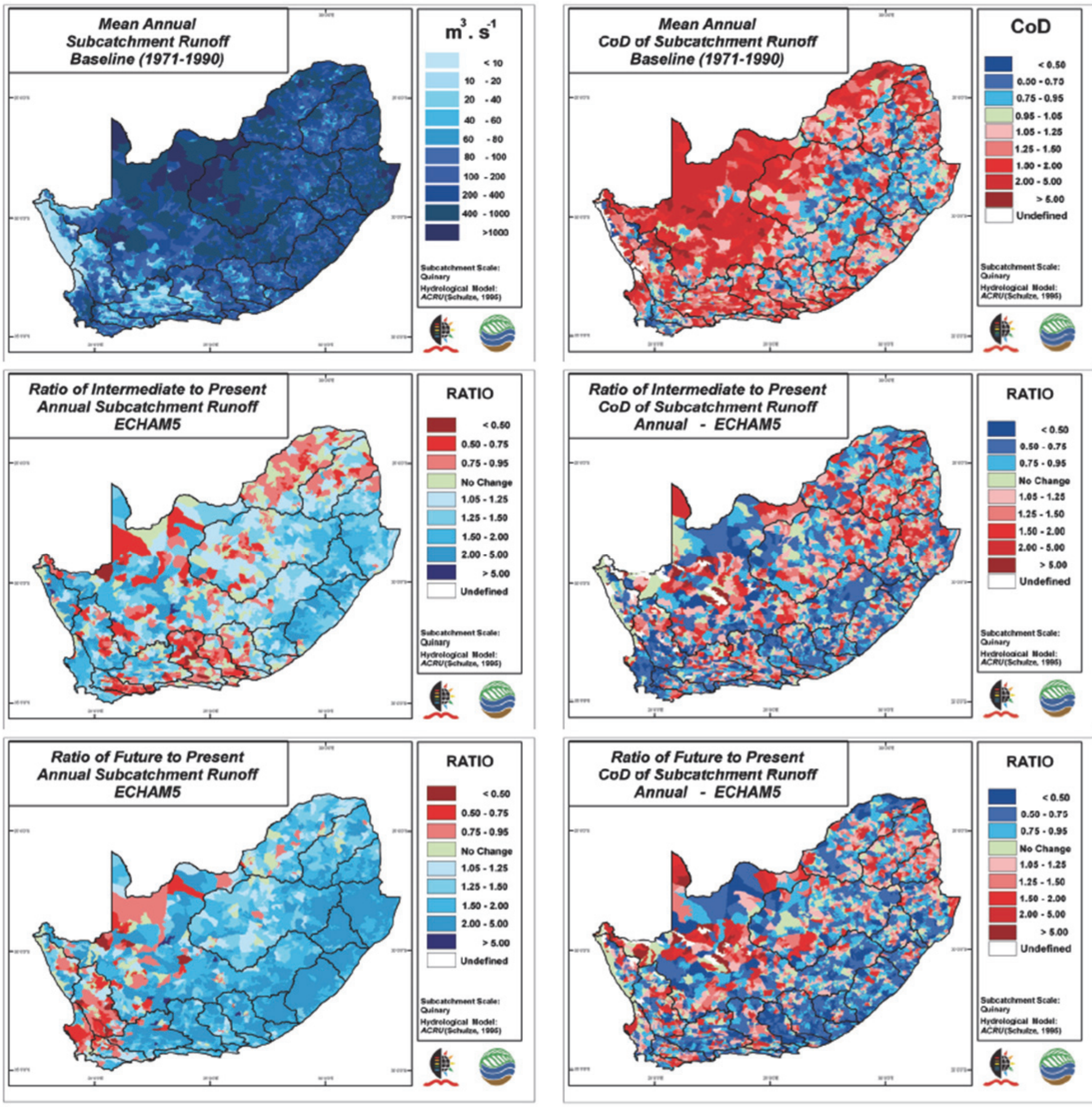

***Figure 2-1**. Mean annual individual sub-catchment runoff (m3.s-1) under baseline climatic conditions, as well as ratios of the intermediate future (2046-2065) to present and more distant future (2081-2100) to present sub-catchment runoff derived with the ACRU model from ECHAM5 climate input (left hand maps), together with their respective Coefficients of Dispersion (right hand maps) (From Barichevy et al., 2011).*

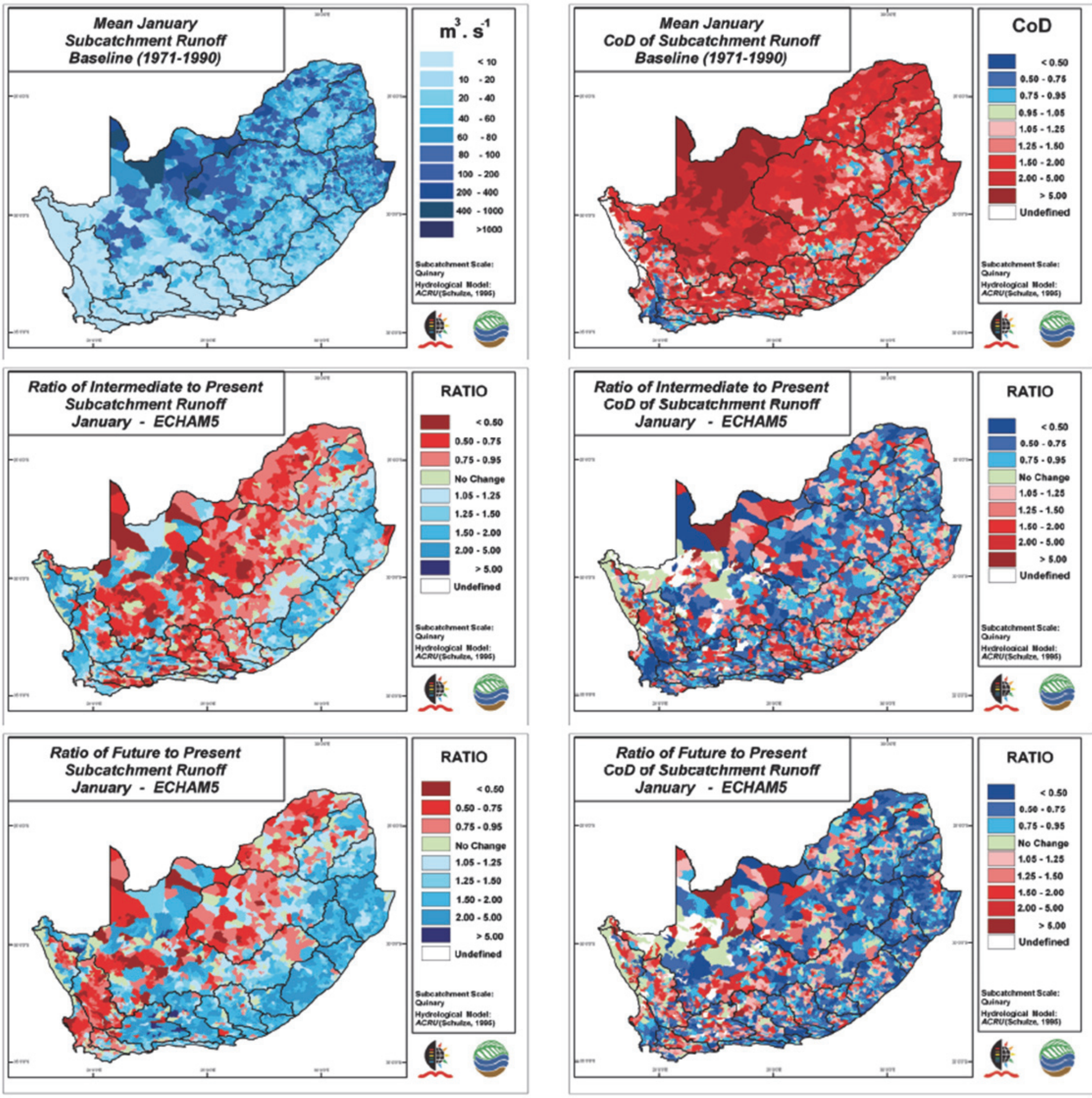

Figure 2-2. ***Mean January individual sub-catchment runoff (m3.s-1) under baseline climatic conditions, as well as ratios of the intermediate future to present (2046-2065) to present and more distant future (2081-2100) sub-catchment runoff derived with the*** **ACRU** ***model from ECHAM5 climate input (left hand maps), together with their respective Coefficients of Dispersion (right hand maps) (From Barichevy et al., 2011).***

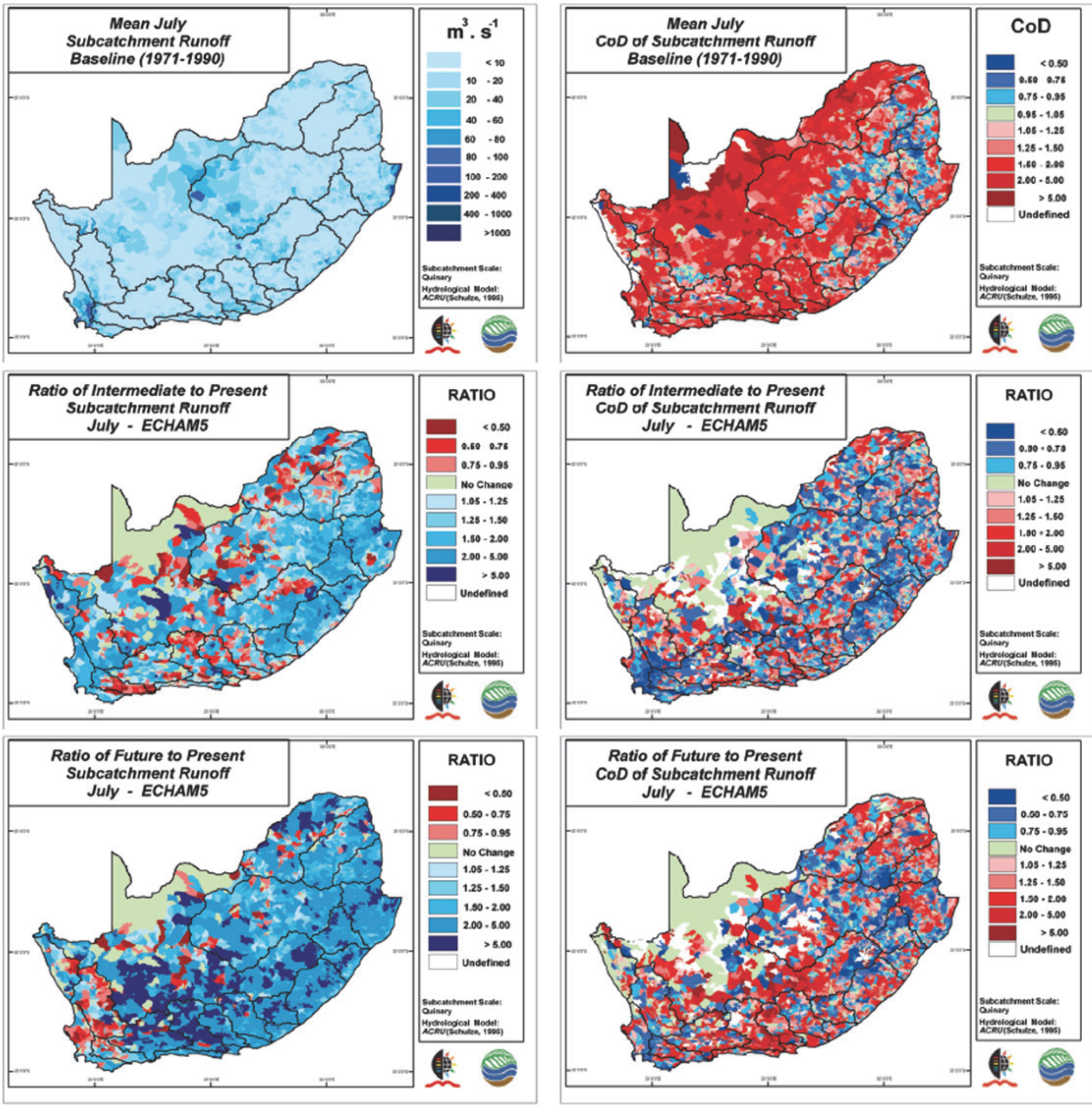

Figure 2-3. ***Mean July individual sub-catchment runoff (m3.s-1) under baseline climatic conditions, as well as ratios of the intermediate future to present (2046-2065) to present and more distant future (2081-2100) sub-catchment runoff derived with the* ACRU *model from ECHAM5 climate input (left hand maps), together with their respective Coefficients of Dispersion (right hand maps) From Barichevy et al., 2011).***

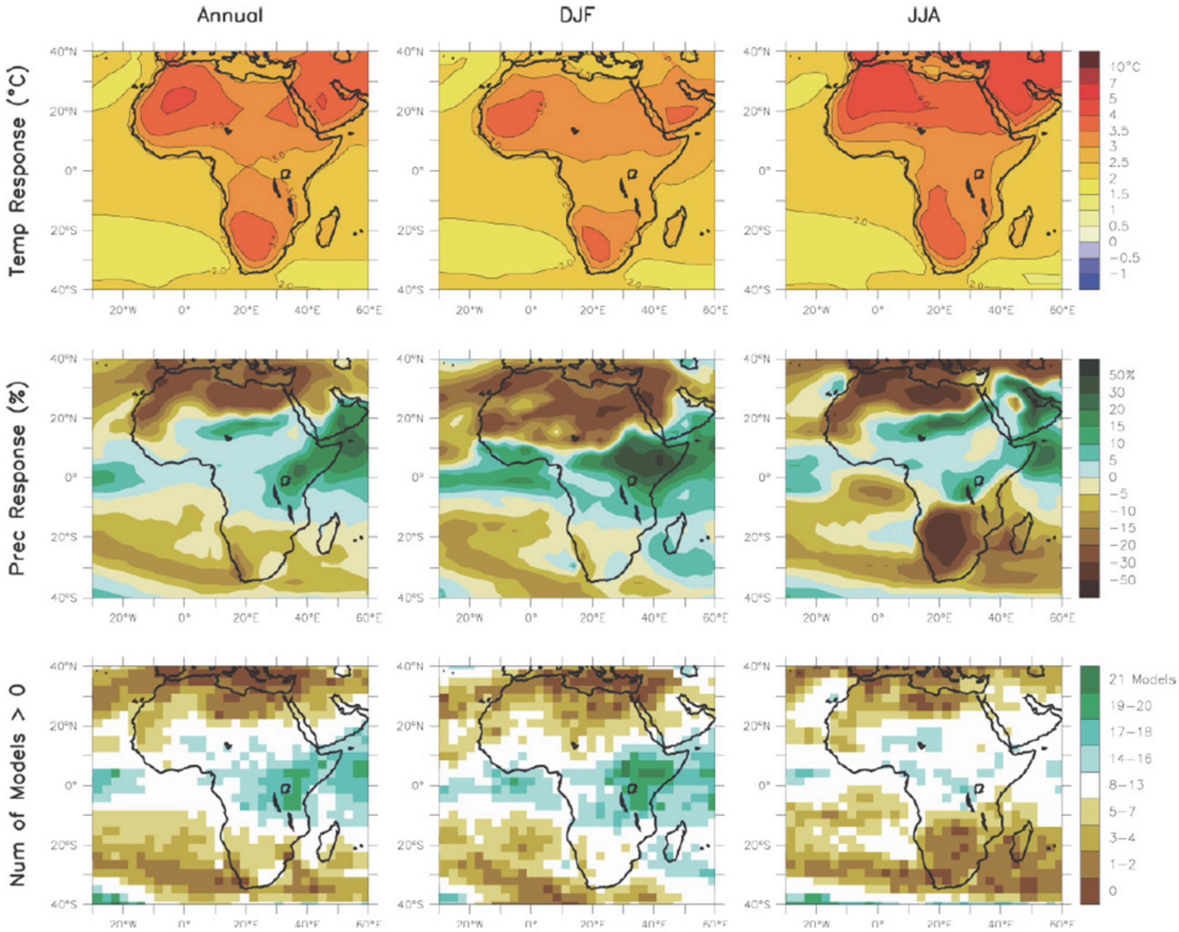

Figure 2-4**. **Predictions of Climate Change over the African Continent from 21 different GCMs. Average values for 2080-2099 compared to 1980-1999 (A1B Emissions scenarios) (From ORASECOM, 2010).

Projected changes in the Orange River Basin shown in Figure 2-4 are at a coarser scale, being a composite of 21 different GCMs. Figure 2-4 indicates that the southern African interior, centring on the Kalahari Desert, will become generally hotter and drier. It also indicates that there is a level of agreement between the models concerning the increase in temperature in southern Africa as well as a decrease in precipitation in the south west of the continent. But this trend is less well defined for the Kalahari than it is for the western Cape.

The downscaled projections for the Orange River Basin (ORASECOM, 2011) indicate that there will be warming of over 2°C across the basin and the central Kalahari (Figure 2-5) with a decrease in precipitation under both the wet and dry realisations over the same area (Figure 2-6).

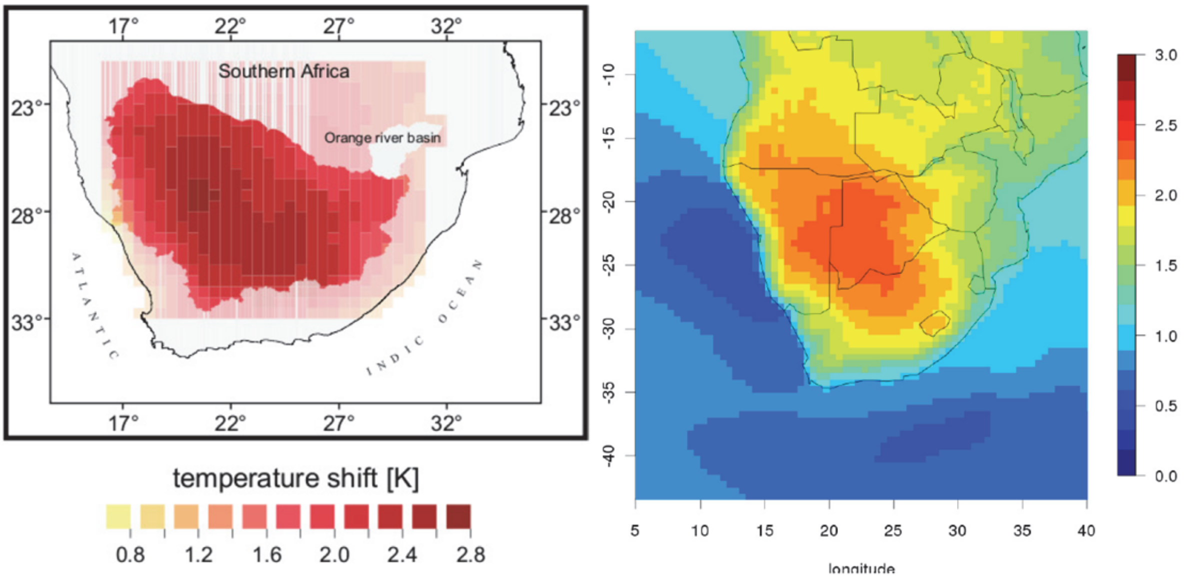

Figure 2-5. ***Temperature shift between present and future (2031-2060) under the A1B emissions scenario using the STAR (left) and CCLM (right) models (ORASECOM, 2011).***

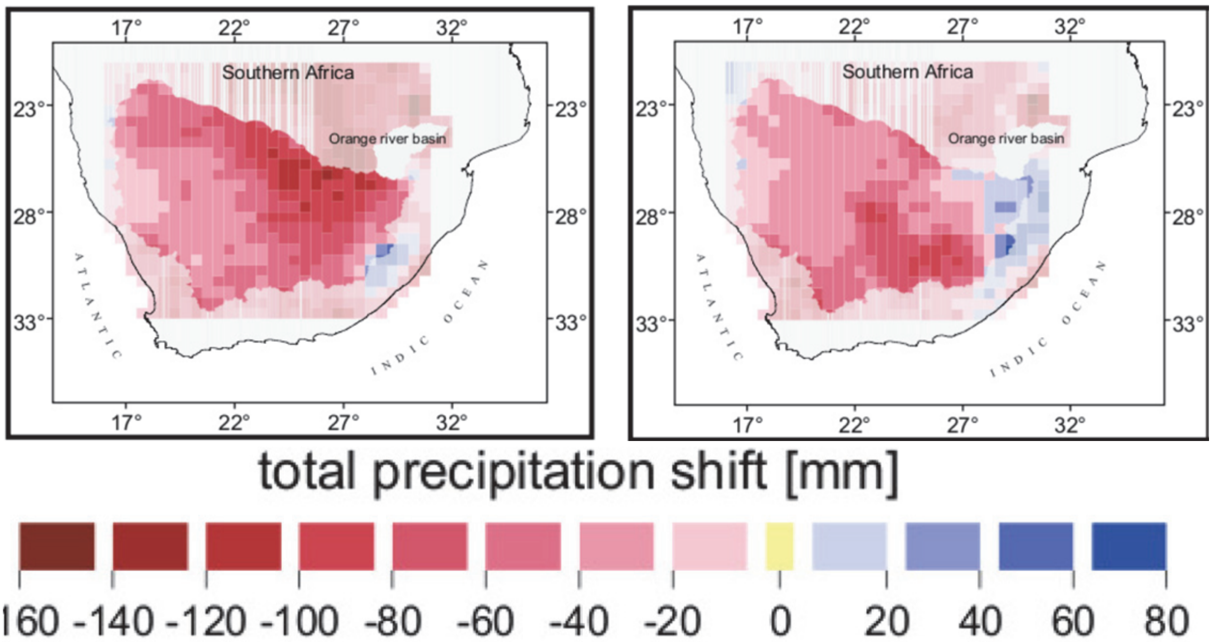

Figure 2-6. ***Total precipitation shift under the dry (left) and wet (right) realisations (ORASECOM, 2011).***

What will this mean?

The projections for southern Africa are that the following changes will occur:

- Temperature change
- Precipitation change
- Change in the variability of events.

Table 0-1 and 0-2 provide a brief overview of some of the consequences resulting from these changes.

How certain can we be?

There are several changes which have been measured over the recent past.

The concentration of CO_2 in the atmosphere has risen from 280 parts per million (ppm) at the dawn of the industrial age when the use of fossil fuel became widespread to the current level of 385 ppm. The Swedish scientist Arrhenius was the first to recognize that the relationship between CO_2 and atmospheric temperature could cause a greenhouse effect.

Globally, temperatures are increasing. The increase is greater in the polar regions but is currently happening globally.

Sea level is rising. The average rate of sea level rise between 1961 and 2003 was 1.8 $\pm$ 0.5 mm/year, and the projections are that this rate will increase. An estimated 70-75% of this rise was caused by thermal expansion of sea water and without any further atmospheric warming the thermal expansion of sea water is likely to continue for more than a century (Bates et al., 2008).

Glaciers are in decline globally. Although glaciers have been in retreat since the end of the little ice age, the current rate of melting has increased substantially (WWF, undated).

Extreme weather events are on the increase. Figure 2-7 below shows number of natural disasters reported between 1900 and 2013 (From http://www.emdat.be/natural-disasters-trends). The country profile for South Africa shows that nine of the top ten disasters by number of people affected were climate related, predominantly droughts and floods, but the figures of people affected also reflect that the national population had increased more than 10-fold during the period, affecting many more people in recent years. This increase in population combined with an overall increase in technology may, to an undetermined extent, account for greater numbers of events being registered more recently but the exponential increase which started in about 1950 (Figure 2-7) would indicate that the numbers recorded are greater than simply an increased ability to record and communicate the occurrence of these events.

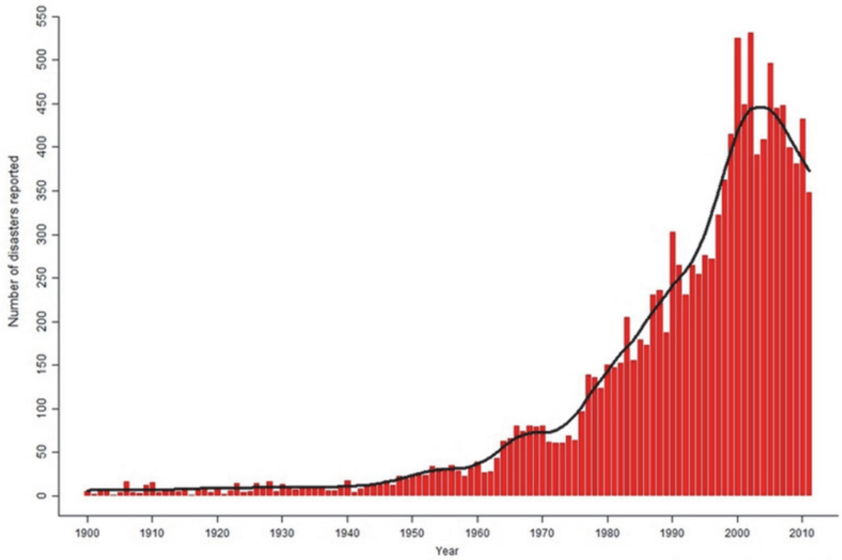

Figure 2-7. ***The number of natural disasters reported between 1900 and 2013 (downloaded from http://www.emdat.be/natural-disasters-trends).***

What are the immediate concerns?

Projections of change are being made for 15 to 80+ years into the future and there is uncertainty concerning these projections. While the management of the likelihood of global warming is a long term goal, managing the vulnerability of the socio-economy, particularly those whose daily survival depends on ecosystem services for their livelihoods, is a more immediate concern.

As has been stated above, southern African climate is highly variable, so much so that effects of global warming cannot be separated from the natural inter-annual variability at this stage. Policies and institutions put in place now to cope with this variability would increase the resilience of the social-ecological system to the longer term projected changes while at the same time reducing the vulnerability of society and the economy to the variability that is currently experienced.

3 Background: the impacts of climate change to water resources in South Africa

3.1 UNEP on climate change and aquatic ecosystems

UNEP anticipates significant changes in the distribution of some ecosystems, principally due to increasing temperature and altered precipitation regimes. Likely distribution changes include firstly pole-ward shifts, especially in mid-latitude regions like South Africa, and secondly upward shifts, especially in montane systems. UNEP also anticipates changes in species composition. This in turn could result in changes in the physical and trophic structure of ecosystems, with resulting further effects on system function and composition. Examples of such effects may include the invasion of temperate grasslands by woody plants, or disappearance of trees as a result of drought.

This could affect human well-being through the effect of climate change on the ecosystem services that aquatic ecosystems provide to people. These include provisioning services such as fisheries, water provisioning, timber production or fibre and fodder production. UNEP notes that these changes may vary in distribution, with some instances of increases and some of decreases in production. Possibly more critically, climate change may also affect the ability of ecosystems to regulate flows of ecosystem services. Water purification and water flow are of particular concern. Another impact may be on the ecosystem service of carbon sequestration. Climate change may critically reduce the ability of many different ecosystems to sequester and/or retain carbon which can feedback to climate change.

Modelling and experimental studies further suggest that ecosystem function may change due to the combined effect of climate change and changes in ecosystem composition and structure. For instance, some models suggest that global net primary production has already started to change (increases in some regions and decreases in others) as a result of changes in temperature and precipitation.

At the species level, UNEP anticipates that climate change has already caused changes to the distribution of many plants and animals. The key concern here relates to possible distributional changes in the form of range contractions and extinction of some species. Changes occurring for aquatic ecosystems may for instance include shifts in spring events, species distributions and community structure. It may also include changes in functioning and productivity, including shifts from cold-adapted to warm-adapted communities, phenological changes and alterations in species interactions.

The composition of many ecosystems are also of concern. Site level reductions in species richness are of concern because under changing environmental conditions, species diversity plays a role in regulating ecosystem processes. Climate change can also facilitate the spread and establishment of invasive species.

3.2 The South African perspective

The climate in South Africa has a high inter- and intra-annual variability and the records do not go back far enough to enable the use of statistics to detect trends in climate change. The coefficient of variation of rainfall in South Africa is amongst the world's highest. One of the projections of climate change is an increase in variability which will cause an increase in the vulnerability of the socio-economy, but particularly the poor, as a result of the increasing variability of precipitation. South Africa has developed coping mechanisms to provide stability to this variability by developing the water resources in a way that has been able to provide a high assurance of supply. But there have been a number of developments in recent decades which indicate that something additional needs to be done. The country's economic growth and increasing population have put increasing demands on the water resource. The more so since the democratic elections of 1994, after which many people were able to improve their quality of life, with the concomitant increased use of resources. In addition, a number of the river basins have reached closure in that there is no more water to allocate for additional uses. This pressure has resulted in the degradation of the water resource and the stream of benefits provided by the ecosystem services to the socio-economy. This has increased the vulnerability of the socio-economy to the vagaries of the climate. In particular, it has increased the vulnerability of the rural poor whose livelihoods depend, at least in part, directly on the benefits provided by ecosystem services.

Water flow and quality are key inputs in the production of aquatic ecosystem services and the economy (Ginsburg et al., 2010; SA Government, 2011) and these, particularly flow, are dynamic in nature. South Africa is dependent on natural resources and water requirements of the economy and this requirement is not variable. The times of greatest need do not necessarily coincide with the times of greatest availability. The National Climate Change Response Whitepaper outlines a number of responses which need to be taken. Amongst these are institutional, human resource, planning and initiatives to increase the country's resilience to water related impacts.

The solution to the global climate change problem lies in mitigation and its funding, amidst a continued need for developing countries to achieve development imperatives. The management of carbon emissions is the route chosen by the developed world to mitigate the projected changes. But carbon markets alone will not provide adequate mitigation funding, less so in the more arid climates. Thus, new mitigation mechanisms are needed, and one such example is reducing emissions from deforestation and degradation in developing countries (REDD+), which in recognition of the carbon sequestration by forests is the first global system for the payment for ecosystem services to be implemented (Dr Thierry de Oliveira and Dr Ravi Prabhu, pers. com.). In drier countries where the forest cover may be small some alternate means is required for the payment for ecosystem services.

A challenge noted by the SADC (Lesolle, 2012) is how to couple climate change mitigation and development. Per capita CO_2 emissions from Africa are lower than from all the other continents. Recognising that wealthier societies are more resilient to the projected changes, the generally higher levels of poverty found in African countries compared to others indicate the importance of strategies for adaptation. The effect of rainfall on a society dependent largely on renewable natural resources is illustrated by the effect of rainfall variation on the GDP of Zimbabwe over the period of a decade and a half (Figure 3-1). Scarcity of water and its critical importance to all sectors of the South African economy raise the question 'what are the risks to on-going development, and where do they lie?' An understanding of the risks to the various sectors of society will guide the formulation and prioritisation of adaptation strategies to cope with the projected increase in variability.

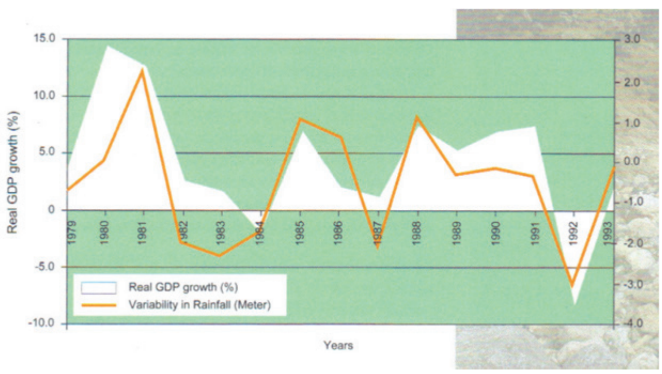

Figure 3-1. Rainfall variability and GDP growth in Zimbabwe between 1979 and 1993 (from SADC, 2011).

However, we are already living in a natural laboratory of variability so we should not wait for the onset of climate change projections. We need to start now with the identification, prioritisation and implementation of strategies to increase society's resilience to variability. The first step in this process is to identify the hazards and the risks that each hazard carries. *Water is a key resource for sustaining life and society. No community and economy will prevail without water of sufficient quality or quantity. With a large part of the population lacking access to clean and safe water as well as a high dependence of water-intensive sectors, water is the nexus of Africa's development challenges* (SADC, 2011).

The overarching hazard is climate change. Sub-hazards presented by climate change are:-

- Increase in temperature
- Change in precipitation
- Increase in the occurrence of extreme events

The influence of each of these will be assessed against the aquatic ecosystem services on which society depends.

3.3 The hazard – Climate change

There is an increasing awareness of the manifestation of global climate change. Atmospheric CO_2 concentrations have increased from 280 ppm at the beginning of the industrial revolution to about 385 ppm at present and the indication is that concentrations will continue to increase. One manifestation is that, globally, there has been an increase in temperature. This temperature increase has been more marked in the Polar Regions, but the global average increase is approximately 0.2 to 0.6°C since the late 19^{th} century. CO_2 is one of the GHG and the increase in concentration of this and other GHG (for instance methane) in the atmosphere is causing this temperature increase (Schulze et al., 2011; IPCC, 2007; MEA, 2005; Hulme et al., 2005; Basset, 2006). A number of global circulation models (GCM) have been developed and these depict climate at a coarse scale.

3.3.1 Risk

Risk of the hazard is a function of its likelihood and its consequence, as shown in the formula below:

$Risk_{ES} = f(L;C)_H$

Where:

- ES = ecosystem service
- L = likelihood

- C = consequence
- H = hazard

In terms of climate change, the consequence of a change in a sub-hazard (as discussed below) may be clear but the likelihood of its occurrence may not be clear.

Refsgaard et al. (2012) developed a framework to characterise the uncertainty in climate change adaptation. The framework gauges uncertainty in three dimensions, the level of uncertainty, the source of the uncertainty and the nature of the uncertainty. They noted that the sources of uncertainty differ greatly between the issues to be assessed, but that most of the uncertainties may be reduced through research. Uncertainties related to ambiguity may be reduced through dialogue, but that uncertainties resulting from the stochastic nature of the factor being assessed, such as climate, cannot be reduced. They also note that the uncertainties around adaptation add a level of complexity to the uncertainties of the climate change events, compounding the overall uncertainty. The framework developed assists in understanding the uncertainties involved when assessing the risks of climate change adaptation.

3.4 Sub-hazard: Temperature change

The historical climate record shows a warming of approximately 0.7°C over most of the African continent during the 20th century and climate change scenarios for Africa indicate future warming across the continent ranging from 0.2°C (low scenario) to 0.7°C (high scenario) per decade. This warming is projected to be greatest over the interior of the semi-arid regions of the Sahara and the Kalahari deserts. Davis (2011) presents data for southern Africa showing that, between 1901 and 2009, the average minimum annual temperature has increased by 2°C and the average maximum annual temperature has increased by approximately 1.5°C. Temperature records from the Sandveld area of the South African West Coast show that there has been an increase in the average temperature of 'about 1°C' over the last 50 years (C.A.P.E., downloaded 2012). Midgly et al. (2002) project that by 2050, depending on the climate change scenario used, there will be a loss of Fynbos biome area of between 51 and 65%. The ranges of roughly 10% of the endemic Proteaceae are restricted to this area and will be lost, and projections indicate that a third of the species could suffer complete range dislocation by 2050.

Plants, invertebrates and vertebrates with invasive phenology will be the quickest to take advantage of the projected changing conditions. Burgiel and Muir (2010) state that invasive species present one of the two greatest threats to biodiversity, the other being climate change. On their own, invasive species cause damage estimated at US$1.4 billion annually, 5% of the global economy, with impacts on sectors such as agriculture, forestry, aquaculture, transportation, trade, power generation and recreation. Combined, the complexity of the interaction of these two drivers increases substantially. Evidence is growing that climate change is compounding the impacts of invasive species, and climate change is likely to exacerbate the problem because invasive species have a broader tolerance and adaptability to change (Burgiel and Muir, 2010).

An increase in temperature is also likely to increase evaporation from open water surfaces.

3.5 Sub-hazard: Change in precipitation

The predictions of rainfall changes across Africa are less certain. Hulme et al. (2005) point out that while Africa will not escape the human-induced changes in climate, climate change scenarios for Africa based on GHG warming remain at a low level of confidence as the natural inter-annual variability combined with the role of land cover in modifying regional climates masks the effect of longer term trends. There is, however, general agreement between the GCMs that south eastern Africa will become wetter with the precipitation coming as more frequent and bigger events. This would result in more runoff than is currently the case. There is also general agreement between the GCMs that south western Africa will become drier, with a possibility of a slight increase in inter-annual variability. In this case there would be a decrease in runoff, as changes in precipitation are amplified by the hydrology (Schulze, pers. comm.; Lumsden et al., 2009; Lehner, 2005).

Until recently the tools to downscale these GCMs to regional or local scale did not exist. Hewitson and Crane (2005) present an empirical downscaling technique based on self-organising maps, and have applied this to South Africa. This downscaling reveals a similarity in the projected climate change between models, with projected increased summer rainfall in the interior and the eastern part of the country and a decrease in the winter rainfall in the Western Cape.

3.6 Sub-hazard: Increased variability of events

There is a third change predicted by the various scenarios and that is that the nature and frequency of the events is expected to change. Higher rainfall is projected for the east of southern Africa and this would be in the form of more rain days and more days with heavier rainfalls. If this scenario is correct, the combination of wetter antecedent conditions and larger rainfall events would result in more runoff being generated and this would have implications for, *inter alia*, filling of dams and water quality. According to all of the GCMs evaluated, less rainfall is projected along the west coast and the adjacent interior, with the possibility of a slight increase in inter-annual variability. If correct, this would result in a decrease in flows and an increase in flow variability, since changes in precipitation are amplified in the hydrological cycle (Schulze, pers. comm.; IPCC, 2007; Lumsden et al., 2009). Overall, the increased inter-annual variability is expected to result in an increase in extreme events such as floods and droughts.

Projections indicate that there will be a change in the nature and frequency of events. Projections indicate that heat waves will become more frequent and intense (Schulze, pers. comm.) and that rainfall events will become more intense. They will become more frequent in areas where an increase in precipitation is projected and less frequent in areas where a decrease in precipitation is projected. Schulze also noted that while the averages may not change much, it is the events (such as heat waves, droughts, floods, etc.) which have the impact and it is these events which should be noted.

As convergence in climate-change scenarios with the existing variability becomes apparent, there is now an arguable basis for developing appropriate response strategies for incorporation into adaptation policy. A challenge is now to explore the issues of uncertainty and probability in order to develop a more rigorous basis to enable proactive responses (Lumsden et al., 2009). Climate is one of the most important drivers of hydrology, determining both the quantity of water available and its temporal distribution. Even relatively small shifts in climate are likely to affect the quantity, timing and variability of runoff. The nature of the rainfall events will also impact on water quality, particularly the sediment load carried by rivers.

Although there are now tools available to simulate the changes at a finer scale, the effect of the projected changes in temperature and precipitation on the water resource and the ecosystem services that the water resource delivers remains to be quantified.

National policies and legislation, however, do not have the flexibility to cope with the projected variability in the hydrology. The Department of Water Affairs has calculated the water yield for the country at 98% assurance of supply although some sectors of the economy may receive water at a lower assurance of supply (NWRS, 2004). However, once a river basin is 'closed', then all the water currently available is committed. While this may not be an issue in the East of the country where rainfall may increase, the challenge will be to service these commitments in the face of reduced water resource availability in the West where the projections are that rainfall will decrease.

The environmental reserve, for instance, is set against present status and is determined for both 'normal' and 'drought' seasons. But the reserve determination method does not, as yet, accommodate the projected variability of climate change.

South Africa shares six river basins with neighbouring countries. These six basins drain more than 50% of the country. Each of these river basins is heavily exploited in South Africa and investigators (e.g. Mohamed, 2003; Turton, 2003) have reported that some residents of the neighbouring countries resent the fact that South Africa already uses a large (and therefore possibly inequitable) portion of the water resources in the shared river basins (Ashton et al., 2008). While recognising the challenges imposed by the climatic variability of the region, a decrease in the available water resource will increase the pressure on the resource and so the need for countries to work together to 'stretch' the available water.

3.7 Water management areas in South Africa

Initially there were 19 Water Management Areas planned for South Africa. However, this has now been reduced to 9, which are accommodated in Climate Water Zones (Figure 3-2).

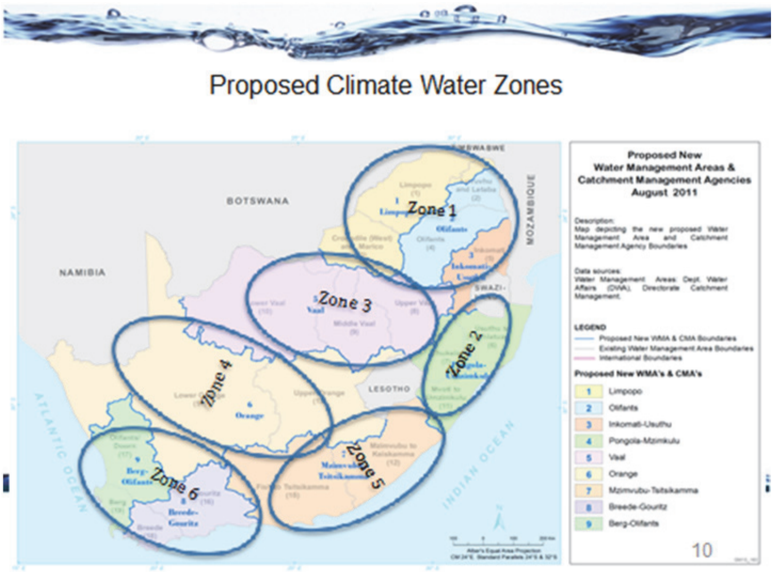

Figure 3-2. ***Proposed Climate Water Zones for South Africa (Mgquba, 2012).***

These zones, as demarcated on the map, broadly match the climate zones of the country and so group the regions by the changes predicted to occur as a result of climate change.

3.8 The Evidence

A critical assessment of the evidence of the hazards described above in South and southern Africa is given in Table 0-1.

4 The impact of climate change on Aquatic Ecosystem Services and Water Resources

4.1 Aquatic ecosystem services at risk

A major weakness of many environmental and resource economics (ERE) studies is an inconsistency in the classification of environmental goods and services. The Millennium Ecosystems Assessment (MEA, 2005) proposes a consistent and standardised classification of environmental goods and services, which it collectively refers to as ecosystem services.

The MA defines the term ecosystem services, which encompasses environmental goods and services (and renders this term redundant). Ecosystem services as classified by the MA are comprehensive and built on earlier work by authors such as De Groot, Costanza, as well as the total economic value (TEV) approach.

The MA classifies ecosystem services into supporting (basic ecosystem functions and processes that underpin all other services), regulating (covering the absorption of pollutants, storm buffering, erosion control and the like), provisioning services (covering the production of foods, fuels, fibre etc.), and cultural services (covering non-consumptive uses of the environment for recreation, amenity, spiritual renewal etc.). Figure 5-1 illustrates the conceptual model relevant here, and the sections below provide the necessary detail.

The concept of ecosystem services applied is that ecosystems are considered to incorporate assets (the natural capital) that yield a flow of services of benefit to people, much like other capital stocks. A change in the ecosystem (asset) would cause a change in the system as a whole and impact upon the delivery of ecosystem services in some way.

It is important to recognize that the utilitarian values (the benefits consumed, used or enjoyed) of these services are not additive. Supporting and regulating services can be considered to be similar to intermediate consumption in the economic sense. Provisioning and cultural services are those that enter final consumption. In order to avoid double accounting, only the final consumption services should be valued.

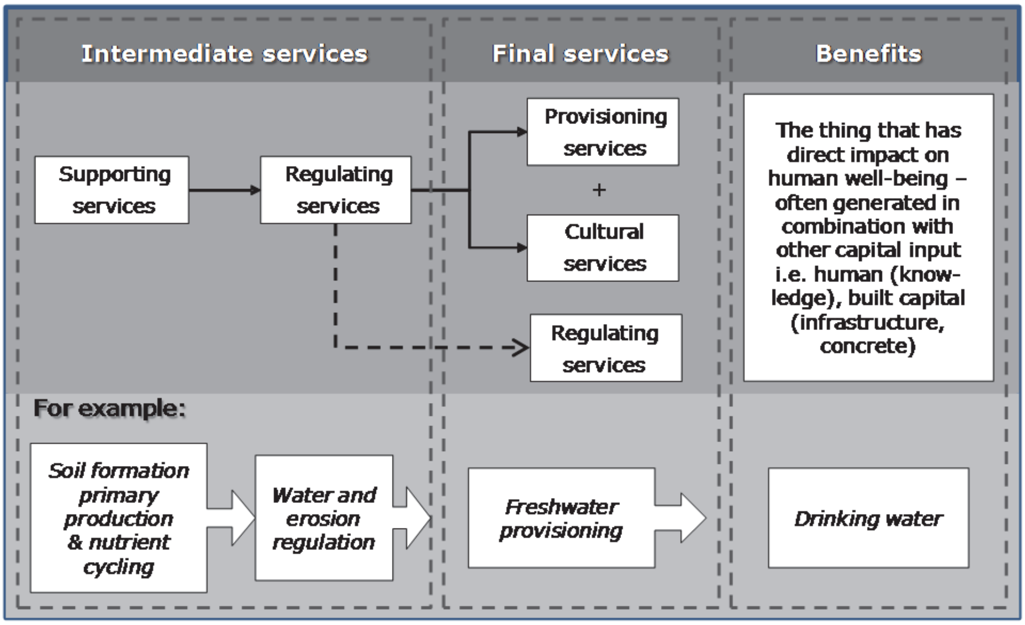

Figure 4-1. ***The distinction between intermediate services, final services and benefits (adapted from Fisher et al., 2008) illustrated by the stylised relationship between supporting, regulating, provisioning and cultural services as defined by the Millennium Ecosystem Assessment (MA) (Ginsburg et al., 2010) and simplified example.***

4.2 Ecosystem services

Ecosystem services (ES) are the benefits that people obtain from ecosystems. In the framework provided by the Millennium Ecosystem Assessment (2005), ES are classified into 4 categories as follows:

- Supporting – Services necessary for the production of other ecosystem services;
- Provisioning – Products obtained from ecosystems;

- Regulating – Benefits obtained from regulation of ecosystem processes; and

- Cultural – non-material benefits obtained from ecosystems.

Biodiversity, the variety of life, underpins all ecosystem services in part through providing resilience to shocks from changes and extreme events. A change in temperature or rainfall could cause the range of protected species to move away from protected areas, compromising conservation goals (O'Malley, 2006), such as predicted for certain Fynbos species by Midgley et al. (2002).

These ES, together with many other factors, contribute to human well-being.

The focus of this section is on ES, mainly aquatic ES, at risk to climate change.

4.2.1 Supporting services

Soil formation:

Intact wetlands will accrete through the capture of sediment. This ES is one of reducing soil loss rather than soil formation. It is, nevertheless, an important ES delivered by wetlands as it recovers some of the soil lost to erosion and reduces the sediment load in the river, thereby improving the water quality (Russell, 2006).

Nutrient cycling:

This is the storage, processing and acquisition of nutrients within the biosphere. Nitrogen and Phosphorus are the most important both in the increase in these elements introduced into the N- and P-cycles by human activity and in their effect on ecosystems. Too little limits biological productivity and too much will cause eutrophication in aquatic systems. Both of these will reduce biodiversity. Aquatic systems, including the biota, play an important role in the redistribution of these nutrients (De Groot et al., 2002. Esbenshade, 2006). Nutrients are mobilised and distributed by aquatic systems (including soil water), but an overload or an imbalance of nutrients will cause eutrophication in aquatic systems and will lead to a loss of biodiversity.

Primary production:

Increased CO_2 levels make more carbon available for photosynthesis. But although CO_2 levels are increasing the biological impacts are not yet entirely clear. It can result in higher net primary production but in the presence of increased carbon other factors or nutrients may become limiting. For instance, the oceans are a major carbon sink, but increased CO_2 will cause pH to decrease, causing a shift in carbon speciation. The effect of this is uncertain and difficult to model, but the shift from carbonate to bicarbonate is already impacting organisms which use carbonate for shell formation, for instance. Acidification of waters will also decrease the capacity of these waters to absorb CO_2 in the future. However, concomitant with rising CO_2 levels is rising temperature and the heat wave experienced in Europe in 2003 led to a 30% decrease in primary production across Europe and recovery from this stress did not occur immediately the stress was removed (Parliamentary office for S&T, 2009; Basset, 2006; Laabermeier, 2006). This decrease in primary production with an increase in temperature was not anticipated, indicating the complexity of the changes ecosystems are likely to undergo in the future. Another predicted effect is that higher CO_2 levels will mean that plant stomata will not need to remain as wide open and so this may reduce evapotranspiration, so using less water, but this has yet to be tested. Primary production provides the food for direct human consumption as well as the food for grazers, both for human consumption or cultural experience (bird or game viewing). It also sequesters carbon, mainly through phytoplankton in aquatic systems. However, when the phytoplankton is dominated by cyanobacteria (blue-green algae) there is a possibility that toxins will be produced. These are costly to remove from freshwater during the treatment process.

4.2.2 Provisioning services

Fresh water:

Fresh water is a limiting resource in South Africa as it is in other semi-arid countries. The fresh water provided by ecosystems forms the basis of the services of water regulation and water purification which will be covered under Regulating services below. Freshwater is essential for all life and also for all human endeavours. South Africa is the 29^{th} driest country out of 193 countries assessed, with an estimated 1110 m^3 of water per person yr^{-1} in 2005. Those countries which are drier are either oil-rich middle eastern states or small islands (Muller et al., 2009). If the population of neighbouring countries which share river basins are included in the assessment this per capita water availability may be even lower. But I have not seen figures on this.

4.2.3 Regulating services

Climate regulation:

Climate regulation is essential for human wellbeing, and plays out through a variety of ES such as favourable temperature and precipitation for human habitation (Costanza et al., 1997; De Groot et al., 2002; MEA, 2005). Locally, the effect of climate regulation is seen in the temperature and precipitation which in turn influence such human activities as agriculture.

Disease regulation:

Temperature and water availability determine the distribution of the vectors of diseases such as malaria and bilharzia. But the relationship is not simple. For instance, a reduction in precipitation will lead to less surface water, but could also lead to a reduction in stream velocity may lead to a relative increase in habitat availability for the vectors. In a drying scenario, an overall decrease in standing water in the environment will reduce mosquito breeding habitat. In a more humid scenario and increase in stream velocity will reduce the habitat available to snail vectors. But, an increase in temperature will expand the geographical range of vectors of disease, so causing the range of the diseases to increase (Malan et al., 2009).

Water regulation:

Water regulation is the regulation of hydrological flows and is the driver of the drought / flood cycle. As an ES, water regulation may be defined in many ways. It is essential for human life and is harnessed for drinking, agriculture, hydropower generation, industrial, sanitation services and a variety of other uses. Its distribution is generally uneven across the world and people have gone to great lengths to move it to areas where use has exceeded supply. As a resource it has also been severely degraded (Tedson, 2006; Costanza et al., 1997). Water may be impounded to assure supply during periods of natural low flow. It may be moved from areas of plenty to areas where it is needed for human activities. These and other activities (such as irrigation, power generation, urban and industrial use) will redistribute the existing ES, impacting negatively on the natural ecosystems and the rural poor who depend on these ES. Intact wetland and riparian areas will buffer the effect of floods and droughts. Impoundments and other interventions may increase the loss of water through evaporation, but may also reduce this loss (e.g. the Jonglei Canal bypassing the Sudd, South Sudan; Mitchell, 2013).

Water purification:

This important ES is primarily the filtering, retention and storage of fresh water in compartments such as wetlands (using the Ramsar definition). The quality of the water is improved when the ecosystem is healthy. This is achieved through the capture sediments, pathogenic bacteria and certain pollutants. Sediment capture is a physical process. Pollutant capture may happen through one of several processes. Nutrients are taken up by plants. The anoxic / anaerobic zones of wetlands may denitrify and also immobilise heavy metals. Organic pollutants may adsorb onto organic material or clay particles. This sequestration of pollutants is not permanent and draining or erosion of the wetland or riparian zone may re-mobilise the pollutants (Esbenshade, 2006).

Pollination:

The provisioning ES of pollination ensures the reproduction of many plant species. Pollination is estimated to be directly or indirectly be responsible for 15-30% of global food production and as the world population grows so does the need for more food. A healthy ecosystem contributes to food security. Insect pollinators in particular are sensitive to poor water quality and aerosols (Haber, 2006).

4.3 Water resources at risk

The assets of the system may be naturally bounded by the physical characteristics of the systems.

4.3.1 Physical characteristics

Physically, the systems may be bounded by the individual river basins. Within the basins the assets of the system may be categorised, following the definition of the National Water Act (NWA, 1998), as '*a river or spring; a natural channel in which water flows regularly or intermittently; a wetland, lake or dam into which, or from which, water flows; and any collection of water which the Minister* *may, by notice in the Gazette, declare to be a watercourse. A reference to a watercourse includes, where relevant, its bed and banks*'. Each of these assets provides specific benefits in terms of the ES that they deliver.

Precipitation can take one of three routes once it reaches the ground. Some will quickly evaporate, some will run off as surface flow and some will infiltrate into the soil. The latter two categories form the resource that is available to the social-ecological system. The relative distribution of the precipitation through these three main routes is dependent on a number of factors such as the geology, temperature, relative humidity, nature of the event, etc.

4.3.2 Groundwater

Groundwater is available in two different zones. Precipitation that is infiltrating into the ground passes through the vadose zone. Water in the vadose zone is available to plants but not for abstraction by borehole or well because the soil interstices are not saturated. The water in the vadose zone is generally moving towards the phreatic zone (water table) or towards a spring. The phreatic zone (water table) is where the soil interstices are saturated and this water is available for abstraction. Recharge of the phreatic zone depends on several factors, with the nature of precipitation events, soil type and degree of soil surface compaction being some of the factors.

The timescale over which groundwater flows is always longer than surface water runoff and may be very long.

The groundwater quality is influenced by land use and once pollutants have got into the groundwater they may take centuries to clear, depending on the dynamics of the particular system.

4.3.3 Springs

A spring is where groundwater daylights. Springs may be large (e.g. the dolomite eyes of Molopo or Kuruman) or small, and may be permanent or ephemeral. Springs reflect the effect of land use practices on the ground water, for instance over abstraction of groundwater will lower the water table and the spring will cease to flow. Springs tapping the vadose zone tend to be ephemeral while those tapping the phreatic zone tend to be permanent. The quality of natural spring water depends on the geology of the area, but land use activities overlay this, and any pollutants or nutrients not adsorbed to the soil will find their way into the groundwater and so affect the quality of the spring water.

The acid mine drainage decant may be regarded as a man-made spring.

4.3.4 River Channel (including riparian zone)

Common usage of the term 'river' implies a channel or conduit for surface water which may be perennial or may be ephemeral. The term includes the water flowing in the channel, but also the riparian zone and the ecosystem of the flowing water and the riparian zone. The riparian zone may serve as a short term storage of water and is in direct contact with the surface water. The riparian zone is also able to protect the river in that it has the capacity to capture some of the nutrients and pollutants and sediment contained in the surface runoff. The riparian zone needs to be in good condition to perform this function effectively.

4.3.5 Wetland

Wetlands deliver a number of benefits. Amongst these are the attenuation of floods, the regulation of water supply, the enhancement of water quality, erosion control, the maintenance of biodiversity and food security. Delivery of the benefit of food security depends on the integrity of the wetland. For instance, where the ES have been redistributed through engineering interventions such as dams constructed for irrigation or hydropower generation, the quantity of flood water reaching the wetland will be reduced and the capacity of the wetland to deliver food security to the people who depend on it is reduced proportionately (Mitchell, 2013).

Despite the fact that wetlands are clearly valuable, freshwater ecosystems are amongst Africa's most undervalued resources. As a result, the services the wetlands provide continue to be degraded either from lack of understanding or for short-term economic gain (Mitchell, 2013).

4.3.6 Lake (natural or artificial)

South Africa has few natural lakes, unlike tropical Africa. However, a large number of impoundments have been built in order to provide the high level of assurance of supply required by the sophisticated economy. Combined, these give the country the capability to store 66% of the mean annual runoff (King et al., 2012). They also, of course, provide a range of ecosystem services as provided by natural lakes. In addition to the benefit of ensuring a high assurance of supply, these lakes capture sediment and nutrients, mitigate floods and provide opportunities for recreation. An ES seen as a dis-benefit is the response of lakes to excess nutrients which lead to excessive growth of algae or higher plants. This makes the lake unsightly and can lead to extra expense for water purification, particularly when the algal blooms are composed of the toxin-producing cyanobacteria.

5 Vulnerability

The term 'vulnerability' is used in many different ways by various research communities, such as those concerned with secure livelihoods, food security, natural hazards, disaster risk management, public health, global environmental change, and climate change. Various definitions for the term have raised various questions: whether vulnerability is the starting point, an intermediate element, or the outcome of an assessment; whether it should be defined in relation to an external stressor such as climate change, or in relation to an undesirable outcome; whether it is an inherent property of a system or contingent upon a specific scenario of external stresses and internal responses; and whether it is a static or a dynamic concept.

The concept and assessment of livelihoods and their vulnerability gained traction in the late 90's and early 2000's through work conducted for and on behalf of DfID (British Government's Department for International Development). "*A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities* *and assets both now and in the future, while not undermining the natural resource base."* (DfID, 1999). The loss of this capacity renders individuals and societies vulnerable to change.

While the concept of livelihood is more narrowly defined than that of well-being, it is apparent that they are complimentary – in achieving livelihood options one achieves many of the constituents of well-being. An important advance in the development of the livelihoods concept was the recognition that cash (financial capital) was only one constituent of a basket of capital (or assets) that were required to fulfil livelihoods objectives. The narrower definition of livelihood also lent itself to a fairly objective framework for analysis that is illustrated below (Figure 5-1).

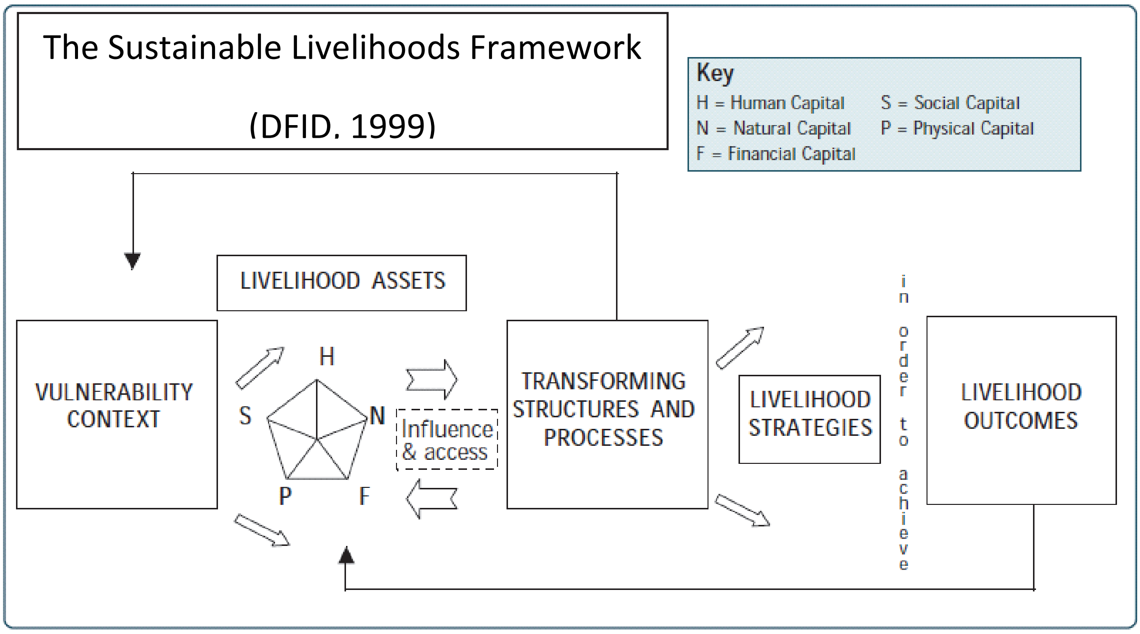

***Figure 5-1**. The Sustainable Livelihoods Framework (DfID, 1999).*

Both the concept of well-being and the livelihoods framework are useful in guiding our thinking and our analysis, primarily because they force us to think far beyond the material. While the economic value of the ecosystem services is self-evident, their value is much more than that. They have significant spiritual, cultural, ecological, social and recreational values which need to be factored into decision making on the allocation of benefits from these services. For instance, societies may be vulnerable to impacts such as misdirected policies or fragmentation of their traditional homes.

But what is vulnerability? Tubi et al. (2012) defined vulnerability to climate change as being comprised of two basic factors: impacts (expected damages due to climate change) and adaptive capacity (the ability of people to adjust to these damages). The South African vulnerability Atlas (2010) notes that South Africa is exposed to many other risks in addition to the highly variable climate and notes that these, together with the low adaptive capacity, must be taken into account in planning and decision-making. Davis (2011) presents a case study on the vulnerability of a village in northern Lesotho where there was an inverse relationship between vulnerability and natural capital, social capital, human capital, physical capital and financial capital (in the form of cattle). Those most vulnerable had the weakest livestock assets and cultivated a limited range of crops. They also did not belong to any community groups, so had very low social capital.

Davies et al. (2010) examined variables representing exposure and sensitivity as a measure of potential impact of climate change on populations in the SADC region. This, when combined with adaptive capacity, is an indicator of vulnerability. They found that, under present day conditions the area with the highest sensitivity and exposure to climate risk was the sub-tropics at latitudes between 12 and 25°S. Under projections for 2050, this area extended to 30°S and also northwards into northern Angola and parts of the DRC. However, the risk of impact from climate change would depend on the adaptive capacity of the individual countries in the region. They noted that countries with a high capacity adaptation were Mauritius, South Africa, Botswana and Namibia and those with the lowest capacity for adaptation were Mozambique, Madagascar, Malawi.

Dong et al. (2011) examined agro-ecosystem resilience, livelihood options and institutional capacity in a series of ten case studies on six continents. They found that climate variability and climate change was an important factor in forcing fragile pastoral systems into an increasingly vulnerable position.

Dougill et al. (2010) recognised the importance of managing agroecosystems in the arid Kalahari that may cease functioning because of changing climate or land degradation. They examined ecosystem resilience in the face of drought, the adaptive capacity of rural communities' in the face of drought as mediated through their access to other assets and the ability of institutions and policy interventions (socio-political governance) to play a role in mediating drought-related crises. This study highlighted how greater sharing of land management knowledge and practices between private and communal land managers can provide 'win-win-win' benefits of reducing system vulnerability, increasing economic income and building social capital.

Four case studies of interventions which re-established the security of livelihoods are presented in the Africa Environment Outlook (2004), two of which are referred to here. Salem (2004) described the increase of vulnerability of Moroccan herders after a multi-year drought and how the establishment of cooperatives increased their capacity for self-organisation and ecosystem management. He notes that the capacity of self-organisation infused by traditional institutions can be pivotal in reversing environmental degradation. In a study on the system of managing wildlife in Africa Waithaka (2004) noted how policies which reserve the wildlife for recreation can bring about poverty and vulnerability, but adopting appropriate land-use policies which allow use of the resource by communities can reverse environmental degradation.

6 Aquatic ecosystems and climate change – two perspectives

The relationship between aquatic ecosystems and climate change is characterised by two perspectives.

Firstly, there exists a conservation perspective. As climate change increasingly puts a strain on ecosystems and species populations, it is important to find ways to increase their resilience to current and future climate change. This is important for protecting ecological infrastructure and for ensuring the protection of ecosystem services dependent upon this infrastructure.

Table 0-1 in the executive summary sets out this perspective. The conservation perspective is of importance not only from a biodiversity conservation perspective, but also from a perspective of preserving and maintaining provisioning and cultural ecosystem services. Provisioning services cover the renewable resources that are mostly directly consumed and that generally have well-defined property rights. The cultural services captures many of the non-use (or passive use) values of ecological resources such as spiritual, religious, aesthetic and inspirational wellbeing.

A second and often not well understood perspective, relates to the conservation and restoration of biodiversity and ecological infrastructure and the safeguard of ecosystem services can play a key role in helping societies to adapt to climate change. Ecosystem-based approaches to adaptation integrate the use of biodiversity and ecosystem services into an overall strategy for helping people adapt to climate change (Munroe et al., 2011). Accordingly, ecosystems are therefore regarded as the first line of defence against impacts of climate change. Of special interest here are the regulating services.

Regulating services are indirect services that determine the capacity of ecosystems both to regulate the impact of external shocks, and to respond to changes in environmental conditions without losing functionality. The regulating services affect the distribution of outcomes, and in particular they affect both variation about the mean response and the likelihood of extreme responses. Supporting services capture the main ecosystem processes that support all other services.

This second perspective therefore introduces a Green Economy perspective.

7 Perspectives on adaptation

7.1 General perspectives

Adaptation to climate change will need to cover a range of disciplines but at the same time will need careful coordination from the planning phase onwards. Without thorough coordination there is a real danger that some of the activities will have unexpected consequences which will have negative impacts on other sectors of the socio-economy. In 2011 the Southern African Development Community published their climate change adaptation strategy (SADC, 2011). This broad-based plan is divided into three main areas, water governance, infrastructure development and water management, as set out in Table 7-1. In his foreword, Dr. Tomáz Augusto Salamão, Executive Secretary of the Southern African Development Community, said that the priority for Africa was to improve climate resilience to achieve sustainability and equitable development. Although the list of areas addressed in the strategy (Table 7-1) are recognised as priority areas, the order of the listings in not in order of priority.

Table 7-1. The topics addressed by the SADC climate change strategy for water (SADC, 2011).

Water Governance	Infrastructure development	Water management
• Awareness and communication • Education and capacity building • Research and Development • Stakeholder participation • Water advocacy • Reforms and mainstreaming • International negotiations • Climate financing	• Multi-purpose water storage • Water supply and sanitation • Irrigation and drainage • Groundwater development • Alternative water supply sources • Flood protection structures • Hydrogeo-Meteorological monitoring system	• Data and information • Scenarios and climate modelling • Vulnerability assessments • Precipitation and flow forecasting • Early warning system • Optimisation of dam operation • Water demand management • Groundwater management • Water quality management • Integrated water resource management

This strategy is thorough in that it addresses the existing water resource management activities (business as usual) in a way that will improve the efficiency of the current activities. This is necessary, particularly such activities as optimisation of dam operation, water demand management, groundwater management, water quality management and integrated water resource management (IWRM). Water demand management has the potential to give substantial short term returns on water saving. IWRM, when fully implemented, covers most if not all of the points in the list as well as others which are not listed. It is these other aspects (business unusual) which may offer the opportunity to make some large improvements in the national capacity to adapt to and cope with climate variability and change.

But what are these other aspects? The 1992 Rio conference (UNEP, 1992) initiated a chain of thought on the importance of environmental protection which is still being developed. The concept of ecosystem services making a meaningful contribution to the SES was taken further through the controversial paper by Costanza et al. (1997) in which the authors estimated that ecosystem services contribute USD33 trillion annually to the global economy, 1.8 times the global GNP from the formal economy at the time. The concept of ecosystem services having a value to the SES was further developed through the Millennium Ecosystem Assessment (MA, 2005) which provided a firm structure and categorisation to the concept, setting the scene for in depth research into the value of the ES and how they may be managed to sustain or increase the stream of benefits to the socio-economy. This development has laid the foundation for two further concepts which are relevant to coping with climate variability, and these are Ecological Infrastructure and Ecosystem-Based Adaptation.

The concept of Ecological Infrastructure recognises that the natural environment provides infrastructural support to the SES in much the same way that built infrastructure does. It also recognises that ecological infrastructure needs to be maintained if it is to sustain the flow of benefits on which the SES depends.

The concept of Ecosystem-Based Adaptation (EbA) legitimises recognition of the contribution that the natural environment can make to the resilience of the formal economy. It provides the link between ES and the ecological infrastructure which supports the ES on the one hand and the increased resilience of the SES on the other.

One example of ecosystem-based adaptation is given in the text box below (CASE STUDY: New York's water supply). In a position paper presented to the UNFCCC during the climate change talks held in Bangkok in 2009, the IUCN made three main points regarding the implementation of EbA. They made the point that EbA should not be the sole adaptation mechanism, but should be part of a broader portfolio (see also UNDP-UNEP, 2011). They pointed out that it provides a cost-effective way to protect SES from climate change and the extreme events that are projected to increase (see, for example, the text box on New York's water). They also noted that EbA would promote policy coherence because it integrated the roles of diverse agencies. Artur and Hilhorst (2012), however, when researching the adaptation mechanisms of Mozambicans to floods, and found that successes and failures depended on the cultural and political perceptions, but if adaptation measures are to be accepted then they need to fit in with the local culture and processes. If this was achieved then people incorporated the adaptation responses into their normal behaviour. They noted, however, that those with a better education or more wealth were in a better position to take advantage of adaptation programmes.

7.2 Ecosystem-based adaptation

The concept of Ecosystem-based adaptation is gaining attention as a cost-effective means of protecting human and ecological communities against the impacts of climate variability and change. This is described as building nature's resilience to the impacts of climate variability and change, while also helping to meet people's basic needs, and harnesses biodiversity and ES as part of the overall adaptation strategy to help people adapt to climate change. It uses sustainable management, conservation and restoration of ecosystems to provide services to maintain or increase resilience and reduce the vulnerability of ecosystems and people to the adverse effects of climate variability and change. Ecosystem-based adaptation can generate social, economic and cultural benefits, contribute to biodiversity conservation and build on traditional knowledge where it should form part of a broader portfolio of adaptation. In addition, healthy ecosystems have the potential to mitigate climate change through the storage of carbon in forests and wetlands (IUCN, 2009). In South Africa the DWA publication 'Water for Growth and Development' recognises the importance of the contribution of healthy functioning of aquatic ecosystems to the continued social development and economic growth of the country, but particularly for the well-being of the people who depend directly on the ES for their livelihoods. The concept of the environmental reserve is being implemented to give effect to the need to maintain the balance between social and economic growth on the one hand and maintaining the resilience of aquatic ecosystems on the other (Travers et al., 2012; WfGD, 2009).

Examples of EbA include (after Munroe et al., 2011):

- Related to estuaries: coastal defence through the maintenance and/or restoration of coastal vegetation. The vegetation reduces the strength of waves before they reach the shore and therefore reduces coastal flooding and coastal erosion;

- Sustainable management of wetlands and floodplains for maintenance of water flow and quality, acting as floodwater reservoirs and providing important stores of water in times of drought;

- Conservation and restoration of forests and natural vegetation to stabilise slopes and regulate water flows, preventing flash flooding and landslides as rainfall levels and intensity increases;

- Establishment of healthy and diverse agroforestry systems (the integration of food production into forests) to cope with changed climatic conditions.

According to UNEP (Monroe et al*., 2011*), ecosystem-based adaptation requires more work in specific areas to expand the evidence base include:

- More detailed comparisons between ecosystem-based adaptation and alternative adaptation strategies, taking into account, social, environmental and economic considerations;

- An analysis tool of thresholds, boundaries and tipping points across a range of ecosystem-based adaptation, in varying climatic zones, in order to give decision-makers clearer indication of which type of ecosystem-based adaptation is applicable to their situation, to enable them to make informed, comparative decisions between adaptation options;

- More attention to costs as well as benefits: the literature tends to highlight positive outcomes with comparatively little attention paid to the potential costs of ecosystem-based adaptation. This is not just in relation to economic costs (although this gap needs to be addressed more systematically and across a greater range of ecosystems) but also related to adverse actual and potential environmental and social effects;

- More information on whether ecosystem-based adaptation is being supported by local/national/international policies and on the success of ecosystem-based adaptation projects regarding instigating policy change;

- Greater consideration of the temporal and spatial aspects of ecosystem-based adaptation effectiveness;

- More strategic monitoring of existing ecosystem-based adaptation projects.

CASE STUDY: New York's water supply.

New York had avoided the expense of building large filtration plants to treat drinking water by drawing its water from pristine catchments to the north of the city. By the late 1980's the Croton River catchment had been suburbanised and the water quality had deteriorated to the extent that it needed to be treated. At the same time the farmers in the other catchments were intensifying their activities and this was causing a deterioration in water quality from these catchments. Rather than build a large water purification plant to cope with this poor water quality, city officials entered into negotiations with the farmers during the 1990s to improve their farming practices and so protect the quality of the water. Within 5 years 93% of all the farms in the New York City catchments had joined the voluntary programme and this played a critical role in stabilising and reducing pollution, thereby improving the quality of the water supply to New York. This enabled New York City to avoid the multi-billion dollar cost of a new water treatment plant. At the same time, New York implemented *other measures including a water conservation programme which reduced per capita water consumption by almost 20%.*

The cost of building the water treatment works would have been in the range of six to eight billion dollars with operation and maintenance costs of US$300 million annually. The investment made to protect the ecosystem service of water purification provided by the catchment amounted to US$1.3 billion.

In 2012 Hurricane Sandy hit New York, disrupting services. A characteristic of natural disasters is that services are disrupted, exposing citizens to the risk of disease. A priority intervention is to ensure that people have safe water to drink. But in New York one service remained largely intact and as a result, largely ignored. Mayor Bloomberg tweeted "New York City's water is absolutely safe to drink".

The ecosystem was able to cope with the natural disaster.

Sources: Appleton, 2002; Salzman, 2012

7.3 Biodiversity and invasive species

Invasive species have been responsible for an estimated half to two thirds of all recent extinctions and their cost to the global economy (spread across a wide variety of sectors, e.g. agricultural pests) is estimated at US$1,4 trillion annually, 5% of the global economy. The interaction between climate change and invasive species is complex but evidence is rapidly growing on how climate change is compounding the already devastating effects of invasive species. Invasive species typically have 'weedy' characteristics in that they are able to rapidly colonise newly available opportunities such as habitat change and outcompete other species which have a less robust pattern of growth. Climate change impacts, such as warming temperatures, changes in precipitation or drivers of habitat integrity, are likely to increase opportunities for invasive species because of their adaptability to disturbance and to a broader range of biogeographic conditions and environmental controls. The impacts of those invasive species may be more severe as they increase both in numbers and extent, and as they compete for diminishing resources such as water. Warmer air and water temperatures may also facilitate movement of species along previously inaccessible pathways, both natural and human-made (Burgiel and Muir. 2010). Nel et al. (2004), using the heterogeneity signatures of South African river main stems, found that 44% were critically endangered, 27% were endangered, 11% were vulnerable, and 18% were least threatened. Invasive species can compromise ecosystem functions by taking advantage of habitat disturbance, less competitive species, species under stress or other characteristics of otherwise healthy systems. This affects the multiple roles of ecosystems in providing provisioning, regulating, supporting and cultural services. Such ecosystem-based approaches are thereby not simply about saving ecosystems, but rather about using ecosystems to increase the resilience of society and the resources on which society depends. Variation in ES will have different effects on different communities (urban vs. rural; wealthy vs. poor, etc.) which need to be defined and taken into account in the planning of policy and other interventions (Burgiel and Muir. 2010; MEA, 2005).

7.4 The Green Economy

The Green Economy (UNEP, 2009, 2012) is a United Nations Programme which brings ecosystem-based adaptation into the main stream of society. It provides a new engine for sustainable economic growth in the face climate change through investing in natural capital. The CC DARE Programme (UNEP, undated) has taken the Green Economy from theory to practice. The programme offers a sustainable growth paradigm that is as much a developing country agenda as it is a developed economy one. In South Africa, the natural environment, within the context of the Green Economy, has been shown to have the potential to support substantial growth in the economy, particularly in job creation if its integrity is maintained (Giordano et al., 2012).

7.5 Case study: Niger Delta

It is a given that the quality of ecosystem services that an ecosystem can deliver is correlated to the condition of the ecosystem. It is also a given that ecosystem services are not additive, in other words the decision to use one basket of services may detract from other baskets of services which could also be derived from the ecosystem. For example, the decision to build a dam to provide for irrigation or hydroelectricity generation will provide value to certain sectors of the economy but will detract from other sectors (see the text box on CASE STUDY: Niger Inner Delta below). Seldom have planners considered the full suite of impacts on users when planning an intervention, with the result that there have been unexpected consequences which are often detrimental. This led to the statement in the FAO document reviewing the condition of the Hadejia-Nguru wetlands (in North-Eastern Nigeria, Lake Chad Basin) following the impoundment of waters upstream for irrigation, that *'The economic value of production from the wetlands is very large, many times greater than that of all the irrigation schemes for which the inflowing rivers are dammed, diverted and their waters used'* (FAO, 1997). Planning in a way that considers all the users and assesses the value of the basket of ecosystem services that each user community uses, together with the impact of the use of one basket of ES as opposed to another, is complex. It is, however, important if the benefit to society of the available ES is to be managed equitably.

The quantitative assessment of the change in the value of an ES with a change in one or more of the drivers of ES was pioneered by Ginsburg et al. (2010). This integrative discipline linking the science of the valuation of ES to the impact on the economy of progressive changes in the ES needs to be further developed if it is to become a useful tool in the management of the distribution on ES to achieve the economic growth without losing sight of the equity as envisaged in the DWA policy on Water for Growth and Development (WfGD, 2009).

The equitable and sustainable distribution of ES is made all the more complex by the high degree of climate variability experienced in southern Africa. But the capacity to distribute ES in an equitable and sustainable manner under the current highly variable conditions will prepare decision-makers for any increase in the variability that may come about through the medium to longer term climate change.

What is needed is a tool or framework which will provide planners with the complete picture of the user communities of ES, the value of ES to each community and the impact of each basket of ES on the other baskets that are, or might be, used by the communities. In this way it will be possible to plan for the package of baskets of ES that will sustain the various sectors of the socio-economy into the future.

CASE STUDY: Niger Inner Delta

There is a well-defined relationship between the area of the Niger Inner Delta, Mali, and the tonnage of fish sold through the markets in the delta (Figure 7-1) between 1976 and 2003, dry years in the Sahel (from Kone, 2005). The r2 value of 0.518 is for the relationship of fish marketed during the year of inundation, but in fact the flood level of the previous year should be taken into account in this relationship. For instance, the outlier of 45,000 tonnes from a flooded area of less than 10,000 km^2 followed three consecutive years of high floods. It may be hypothesised that the fish population had built up to a high level and that the low waters concentrated the fish, leaving them vulnerable to the fishermen.

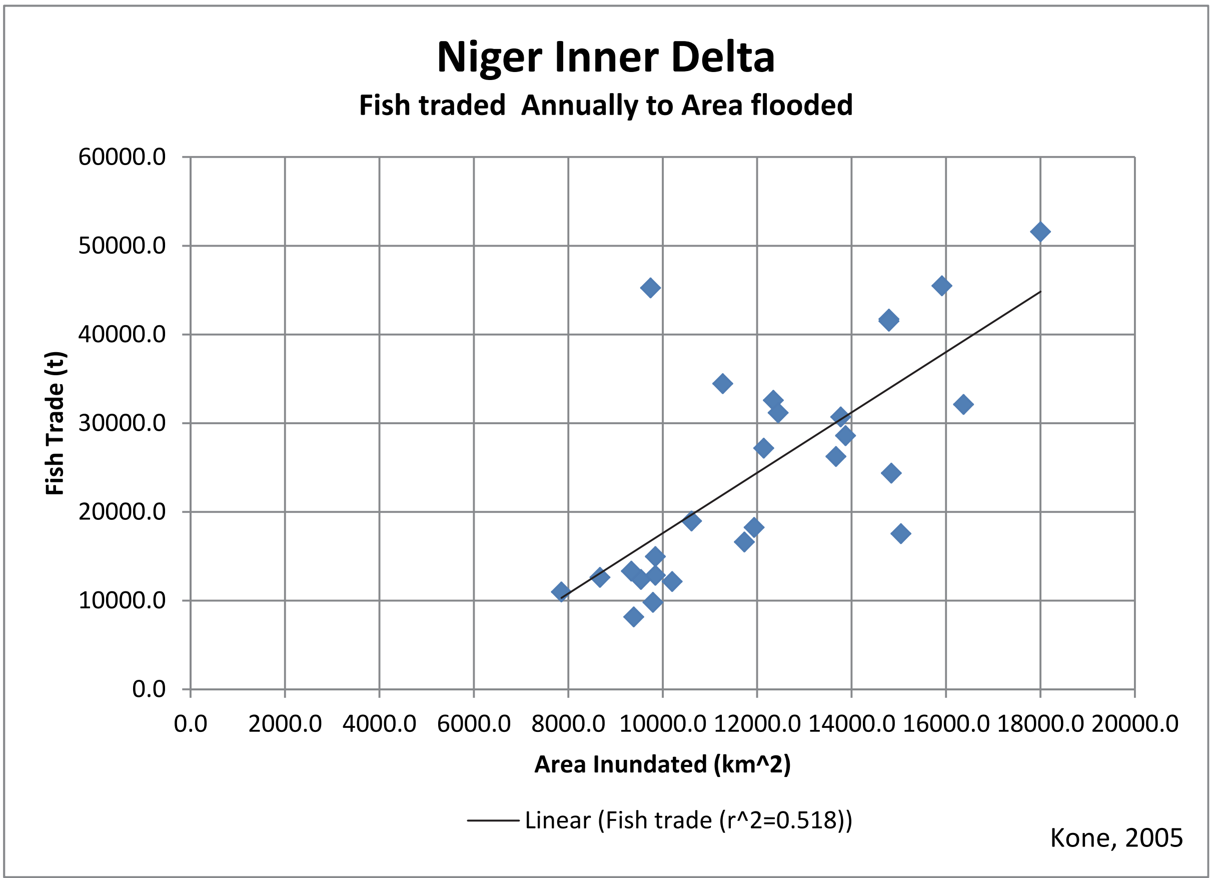

Figure 7-1. The relationship between the area of annual inundation of the Niger Inner Delta, Mali, and the annual tonnage of fish marketed (from Kone, 2005).

Early maps indicate that before the construction of irrigation and hydropower dams redistributed part of the ES generated by the river flow, the delta covered an area of up to 36,000 km^2 (Zwarts et al., 2005). Using the regression relationship developed from the data behind Figure 7-1, the fishery yield would have been in the order of 90,000 tonnes annually when the delta was flooded to this extent. This would provide additional livelihoods not only through increased fisheries but also through flood-recession agriculture and grazing for livestock.

8 Problem Statement

The relationship between aquatic ecosystems and climate change is characterised by two perspectives.

First, there exists a conservation perspective. As climate change increasingly puts a strain on ecosystems and species populations, it is important to find ways to increase their resilience to current and future climate change. This is important for protecting ecological infrastructure and for ensuring the protection of ecosystem services dependent upon this infrastructure (Table 0-1).

Second, there exists a Green Economy perspective. The conservation and restoration of biodiversity and aquatic ecological infrastructure and the safeguard of ecosystem services can play a key role in helping societies to adapt to climate change. Ecosystem-based approaches to adaptation integrate the use of biodiversity and ecosystem services into an overall strategy for helping people adapt to climate change. Accordingly, ecosystems are therefore regarded as the first line of defence against impacts of climate change (Table 0-2).

Adaptation considerations require of us to have an understanding of a number of issues.

Firstly, we need to understand what to adapt to. Here it is important to note that adaptation strategies designed to address the projections of climate change in the future, will benefit the Southern African social-ecological system in the present. These strategies may be refined as necessary once they have been implemented, and they offer the opportunity to focus on improving the quality of life of South African citizens in the near term. Thus climate change adaptation strategies will help us to adapt also to other, more immediate hazards than climate change.

Secondly, we need to understand how to adapt and what resources are required to implement the adaptation measures. South Africa's National Climate Change Response White paper identifies a range of broad adaptation measures. These include:

- Strengthen biodiversity management and research institutions so that they can monitor, assess and respond effectively to existing anthropogenic pressures together with the additional pressures that climate change presents.

- Conserve, rehabilitate and restore natural systems that improve resilience to climate change impacts or that reduce impacts.

- Prioritise impact assessments and adaptation planning that take into account the full range of possible climate outcomes, in conjunction with plausible scenarios of other stresses.

- Enhance existing programmes to combat the spread of terrestrial and marine alien and invasive species, especially in cases where such infestations worsen the impacts of climate change.

- Expand the protected area network where it improves climate change resilience, and manage threatened biomes, ecosystems, and species in ways that will minimise the risks of species extinction. A regulatory framework to support investment in conservation or land rehabilitation as a way of offsetting the environmental impacts of new property developments will be explored.

- Encourage partnerships for effective management of areas not under formal protection, especially freshwater ecosystem priority areas, critical biodiversity areas, ecological support areas and threatened ecosystems.

- Expand existing gene banks to conserve critically endangered species that show increasing vulnerability to climate change trends.

These adaptation recommendations are of highly strategic nature and much more work is required to support local decision makers understand potential local impacts, and how to make long-term plans under a new range of uncertainty about future hydrologic conditions. Water resource managers would also need to consider the local impacts of climate change as they deal with other challenges – including water use licences, population growth, land use changes, economic transformation priorities, economic constraints, and a variety of stressors to the quality and quantity of water resources.

The key to the additional work required is the linkage between climate change and aquatic ecosystems: aquatic ecosystem services. The vulnerability of people, especially local communities, lies in their dependence on provisioning and cultural ecosystem services. It is here that the conservation perspective is of importance, as various adaptation measures may be applied to protecting aquatic ecology infrastructure, which, in turn, protects the delivery of the provisioning and cultural ecosystem services. From the Green Economy perspective, the protection of aquatic ecological infrastructure in itself provides an adaptation mechanism. This happens through the regulating services. The function of the regulating services is to regulate, moderate and insure the delivery of a range of services that secure aquatic ecosystem functioning. Key amongst these are services relating to flow and water quality regulation.

Although increasing amounts of work are being done in South Africa on ecosystem services, there is still woefully inadequate analytical and evidence-based understanding, at a local level, of the nature, extent and role of aquatic ecosystem services in the socio-economy. Even less understanding exists on how these services are vulnerable to climate change and what adaptation measures are relevant.

An adequate analytical and evidence-based understanding requires a systems analysis capability that would internalise:

- The composition and functionality of aquatic ecosystems;

- The production of aquatic ecosystem services from these systems;

- The communities dependent on these ecosystem services;

- The vulnerability of these aquatic ecosystem services to climate change (and near term hazards);
- The cost and benefit implications of the ecosystem services (direct values and insurance values) to beneficiaries.

Such a systems analysis would enable the evidence-based assessment of practical adaptation measures such as:

- Aquatic biodiversity conservation investments;
- Rehabilitation interventions
- Payments for ecosystem services schemes;
- Insurance schemes.

Definitions for the adaptation to climate change vary, with the IPCC defining it as “adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects” (McCarthy et al., 2001). The concept of adaptation to climate change has been developed relatively recently (Horstmann, 2008).

The concept of its implementation through the payment of ecosystem services is explored by van der Sand (2012) who identifies four types of services for which payments are made:

- Hydrological or watershed services,
- Carbon sequestration,
- Biodiversity protection and
- Landscape beauty.

Adaptation is expected to reduce vulnerability to climate change. But if the PES scheme restricts the use of natural resources that form part of traditional adaptation strategies this could increase the vulnerability of various actors to climate variability and change (van der Sand, 2012).

There is a great deal of poverty in sub-Saharan Africa, and while policy mechanisms such as REDD+ have the potential to generate funds for poverty alleviation in some of the areas, there is also a need for strategies which will help poor people adapt to the projected changes that they will face. In South Africa particularly there are two changes occurring which make the implementation of adaptation to water shortage more complex. These are an ongoing increase in human population numbers and increasing aspirations to a better lifestyle. Few countries have de-linked this latter aspiration from water use.

While much research has been done on adaptation to the predicted decrease of available water as a result of climate change, in only a few instances has this has been successfully implemented at a meaningful scale in South Africa. A reason for this is, in part at least, the difficulty of inducing changes of behaviour amongst the general public. This is recognised in the National Climate Change Response Whitepaper (SA Government, 2011) which rates behaviour change (through incentives and disincentives, including regulatory, economic and fiscal measures as well as education, training and public awareness) as a strategic priority in the adaptation to climate change. However, these strategies need to be financed, and sources of funding are often limited in developing countries.

Bearing in mind the highly variable southern African climate and the fact that the conditions under which people live in southern Africa, and that climate variability is projected to increase, the hypothesis that this project addresses is as follows:

Adaptation strategies designed to address the projections of climate change will benefit the Southern African social-ecological system now. These strategies may be refined as necessary once they have been implemented, and they offer the opportunity to focus on improving the quality of life of South African citizens in the short term.

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