Local water resource management strategies for adaptation to climate induced impacts in South Africa

PIERRE MUKHEIBIR

PREPARED FOR THE WORKSHOP:

Rural Development and the Role of Food, Water & Biomass: Opportunities for Development and Climate

Novotel, Dakar

14-16 November 2005

November 2005
ENERGY RESEARCH CENTRE
University of Cape Town

Contents

1 Introduction 1

2 Overview of current South African water sector 2

3 Brief overview of the South African agricultural sector 3

4 Key issues affecting water availability 4
- 4.1 Current climate trends 4
- 4.2 Future climate scenarios 5
- 4.3 Potential impact on municipal water supplies and agricultural production 6
- 4.4 Water management drivers 7
  - 4.4.1 Demand - overview 7
  - 4.4.2 Supply – water security 8

5 Strategies for future sustainable water supplies 8
- 5.1 Policy vision 8
- 5.2 The linkage between climate variability and climate change 8
- 5.3 Supply side management strategies 9
  - 5.3.1 Planning and management 9
  - 5.3.2 Drought relief 12
  - 5.3.3 Rainwater harvesting 12
  - 5.3.4 Desalination 12
  - 5.3.5 Reduction of leaks 12
  - 5.3.6 Control of invasive alien vegetation 13
  - 5.3.7 Rainfall enhancement 13
  - 5.3.8 Control of water pollution / water quality 13
  - 5.3.9 Contingency planning for drought 13
  - 5.3.10 Improved monitoring and forecasting systems for floods and drought 14
  - 5.3.11 Inter-basin transfers 14
  - 5.3.12 Marginal changes in construction of infrastructure 14
  - 5.3.13 Maintain options for new sites 14
- 5.4 Demand side management strategies 14
  - 5.4.1 Water restrictions 14
  - 5.4.2 Tariff structures 14
  - 5.4.3 Changes in agricultural management practices 16
  - 5.4.4 Sanitation systems 16
  - 5.4.5 Water education 16
  - 5.4.6 Re-use of grey water 16
  - 5.4.7 Leak reduction 17
  - 5.4.8 Assistance projects 17

6 Strategy analysis – A case study of municipal water supply 18
- 6.1 Criteria for strategy analysis 18
- 6.2 Multi-criteria strategy analysis 19

7 Barriers to implementing adaptation 20

7.1 Agricultural sector 20
7.2 Municipal water sector 20

8 Conclusions 22

References 23

1 Introduction

In the Third Assessment Report of the Intergovernmental Panel on Climate Change, the following key issues in relation to climate and water were presented (IPCC 2001):

> "Climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources, affecting both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in-stream ecosystems and water-based recreation. Changes in the total amount of precipitation and in its frequency and intensity directly affect the magnitude and timing of runoff and the intensity of floods and droughts; however, at present, specific regional effects are uncertain".
>
> "The impacts of climate change will depend on the baseline condition of the water supply system and the ability of water resource managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social and legislative conditions. In some cases - particularly in wealthier countries with integrated water management systems - improved management may protect water users from climate change at minimal cost; in many others, however, there could be substantial economic, social and environmental costs, particularly in regions that already are water-limited and where there is considerable competition among users".

In response to this, this paper focuses on water resource management strategies in South Africa to meet its development goals. These are based mainly on the analysis of potential coping strategies at local municipal level in response to impacts due to climate variability.

South Africa's rainfall is already highly variable in spatial distribution and unpredictable, both within and between years (DEAT 2004). Thus water is considered a limiting resource for development in Southern Africa and a change in water supply could have major implications for most sectors of the economy. Factors that contribute to vulnerability in water systems in Southern Africa include seasonal and inter-annual variations in rainfall, which are amplified by high run-off and evaporation rates.

Poor distribution of water resources in Southern Africa coupled with climate variability, in the form of frequent droughts and floods, has lead to direct hardship for many people, particularly the poor (SADC 2001). If the occurrence of drought became more frequent, the impact on water resources, and consequently agriculture, would be significant. In light of this, it would be prudent to account for climate change in water resource planning to meet the development objectives of South Africa.

Climate change is expected to alter the present hydrological resources in Southern Africa and add pressure on the adaptability of future water resources (Schulze & Perks 2000). Taking note of the substantial uncertainties around rainfall projections, there is nonetheless a tendency for the majority of models to suggest a decrease in rainfall over the western part of southern Africa in coming decades. Coupled with warming, this implies net drying, with negative consequences on water supplies and agriculture (Fischer et al. 2002).

Climate change response strategies could potentially act as significant factors in boosting sustainable economic and social development. Strategies that are designed to address climate variability and change and address the development objectives of the country are clearly in the national interest, especially if they include poverty alleviation and job creation.

This paper begins with an overview of the current water resource situation in South Africa and then locates water resources in the broader policy context. The key issues affecting water security in South Africa are discussed and include current climate trends, future climate scenarios and water management drivers. Drawing a other published literature and a case studies (Mukheibir & Sparks 2005), various supply side and demand side management strategies are presented and discussed. A methodology for selecting viable strategies is put forward and the set of criteria are proposed for application in a multi-criteria analysis tool. Finally, obstacles hindering the successful implementation of these climate change response strategies are discussed.

2 Overview of current South African water sector

South Africa is generally viewed as a water-stressed country with an average annual rainfall of 500mm., which is approximately 60% of the world average. The greater part of the interior and western part of the country is arid or semi-arid. 65% of the country receives less than 500mm per year and 21% of the country receives less than 200mm per year (DWAF 1994).

Since rainfall displays strong seasonality, the natural availability of water across the country is variable, with stream flow in South African rivers is at a relatively low level for most of the year. This limits the proportion of stream flow that can be relied upon for use. Moreover, as a result of the excessive extraction of water by extensive forests and sugar cane plantations in the relatively wetter areas of the country, only 9% of the rainfall reaches the rivers, compared to a world average of 31% (DWAF 1996).

Groundwater also has an important role to play in rural water supplies, but few major groundwater aquifers exist that can be utilised on a large scale due to high salinity in most parts of the country.

The total average annual available surface water in South Africa is 49 $200x10^6m^3$ (this includes the inflow from Lesotho and Swaziland). Of this, 25% is economically harnessed as usable yield (this includes usable return flow).

Table 1: Available yield in year 2000
(DWAF 2004b)

Source	*Million m^3/a*	*%*
Surface water	10 240	77.4 %
Groundwater	1 088	8.2 %
Usable return flow	1 899	14.3 %
TOTAL	**13 227**	**100 %**

The total amount of water required for 2000 was 12 $871x10^6m^3$, a figure close to the available limits (DWAF 2004b). Agriculture is by far the largest user of water, as shown in Figure 1, while urban and rural requirements make up 25% and 4% respectively. Agriculture and forestry together use two thirds of the available water resources.

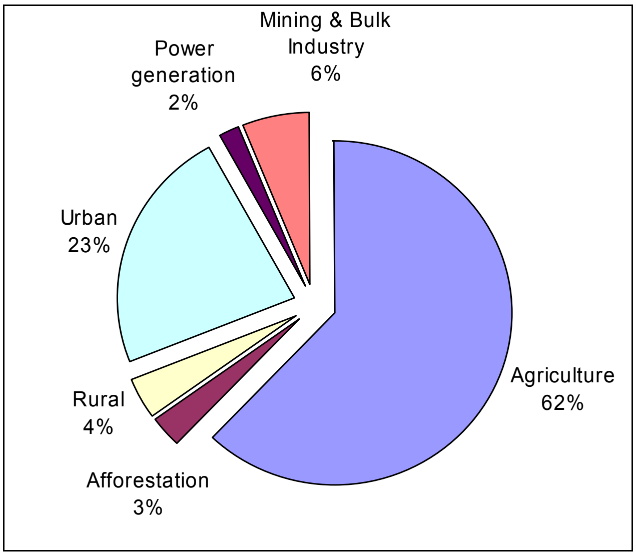

Figure 1: Water demand for 2000 per sector
(DWAF 2004b)

The provision of water is key to a coherent development strategy if it is to be successful. Access to clean water is the most significant resource for reducing poverty and disease, and improving the life of poor South Africans. Available water is also key in promoting rural development and increasing food security.

The legacy of apartheid has left the country with the huge task of providing sustainable water delivery services to its population in order to meet these basic needs. The majority of the people without basic domestic water services live in rural areas. According to the 2001 census, 84% of South Africans have access to piped water, 32% directly into their homes (SSA 2003).

To address the needs of the rural poor, the Growth, Employment and Reconstruction (GEAR) strategy focuses on land reform and associated agricultural development and on the provision of infrastructure, notably water. (DWAF 1997). The two main objectives of GEAR are to attain both equity and economic growth. The combination of these objectives makes it clear that economic development progresses towards some set of social goals – notably more jobs and more equal income distribution. Without adequate supply of water for economic activities, these two objectives will be difficult to achieve. Basic adequate water services are defined by DWAF as potable water supply of 25 litre/person/day within a walking distance of 200m (DWAF 1994). This is considered sufficient for cooking and drinking. To address the issue of affordability, Government has committed itself to providing 25 litres per day, free of charge (the life-line tariff), to be implemented by local authorities (Majola 2002).

In South Africa the National Water Policy for South Africa - White Paper (DWAF 1997) and National Water Act of 1998 (DWAF 1998) are based on the principles of equity, sustainability and efficiency. The country's new laws have instituted a macroeconomic and environmental reform process in the sector in which water rights have been separated from land rights and a water right is limited to a 'use-right'. Water is now deemed a common property source owned by the people of South Africa and managed by the Government (Goldblatt et al. 2002). DWAF has released The National Water Resource Strategy (NWRS) (DWAF 2004b) to address the management of the water resources to meet the development goals of the country (Kasrils 2002). One of the key objectives of the NWRS is to identify areas of the country where water resources are limited and constrain development as well as development opportunities where water resources are available.

3 Brief overview of the South African agricultural sector

As can be seen from Figure 1, agriculture currently uses about 62% of the registered water used in South Africa. South Africa is mainly self-sufficient, but has to supplement its production with imports of rice, wheat and meat. Approximately 70% of the total grain production in South Africa consists of maize.

The agricultural sector also contributes to employment and throughout the food production chain. The social value of agriculture warrants special attention when deciding on competitive allocation of water among sectors since it contributes to food security and job creation. It is interesting to note that irrigated agriculture contributes only 1.5% to the GDP. Rain fed cultivation, livestock farming and afforestation contribute approximately 3%. The secondary contribution to the economy through the provision of raw materials and demand for goods and services should however, not be ignored. It has been estimated that agriculture supports about 25% of the manufacturing sectors contribution to the GDP (DWAF 2004d).

There is a large potential for water saving in this sector given that between 30-40% of the irrigated water is lost through leaks and evaporation. Not all the water abstracted for irrigation by conventional methods reaches the roots systems of the plants. Conveyance losses due to the age of the schemes and leaking canals add to the losses. Irrigation methods, irrigation scheduling, soil type, soil penetration and crop selection all have significant impact on the efficient use of water in agriculture.

An unaccounted proportion of irrigation water returns to the rivers by overland flow and seepage. This return water can be nutrient enriched and polluted with pesticides, herbicides and other pollutants that have an adverse effect on the quality of the river systems (DWAF 2004d).

4 Key issues affecting water availability

Three main issues affect South Africa's water resource management. Firstly, the natural conditions, low rainfall with high evaporation rates, which together create low availability of run-off. Climate variability makes it difficult to estimate the run-off. It is has been projected that climatic change will have notable impacts on the available run off. Secondly, population growth and economic development lead to greater water demand and increased pollution of available resources. Thirdly, the policies pertaining to management of water resources determines the approach taken by relevant authorities to managing the resource and directly impacts other driving forces and pressures.

4.1 Current climate trends

From climate records of the part 50 years, climate variability can be clearly observed. Climate variability results in unpredicted flooding and of importance in this study, drought. Unpredicted drought causes stress to vulnerable agriculture and small scale water resources.

Since the climate projections indicate that the western part of southern Africa will become drier, an analysis of the rainfall trends for this area was made for the past 30 years (Mukheibir & Sparks 2005). As can be seen in the graphs below, no clear trends can be observed for the different seasons for the three representative towns in the area, since they exhibit low correlation factors for the linear regression trend lines. However, what is significant is the high variability of the rainfall data from year to year, with periods of good rainfall followed by periods of drought. This makes planning for times of drought difficult yet essential, since with large interannual variabilities there are no rainfall guarantees in any year.

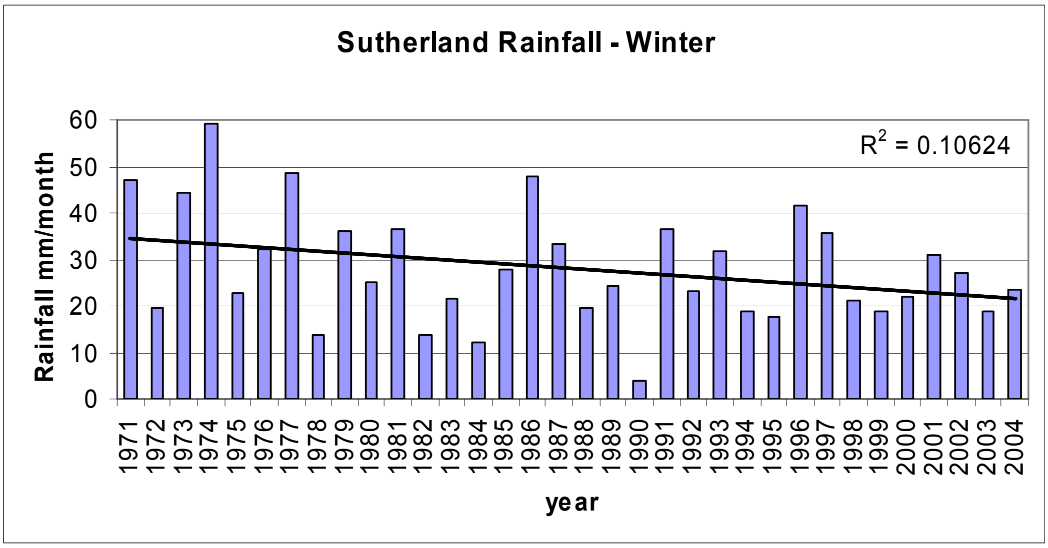

Figure 3: Winter rainfall trends for Sutherland between 1971 and 2004
(Mukheibir & Sparks 2005)

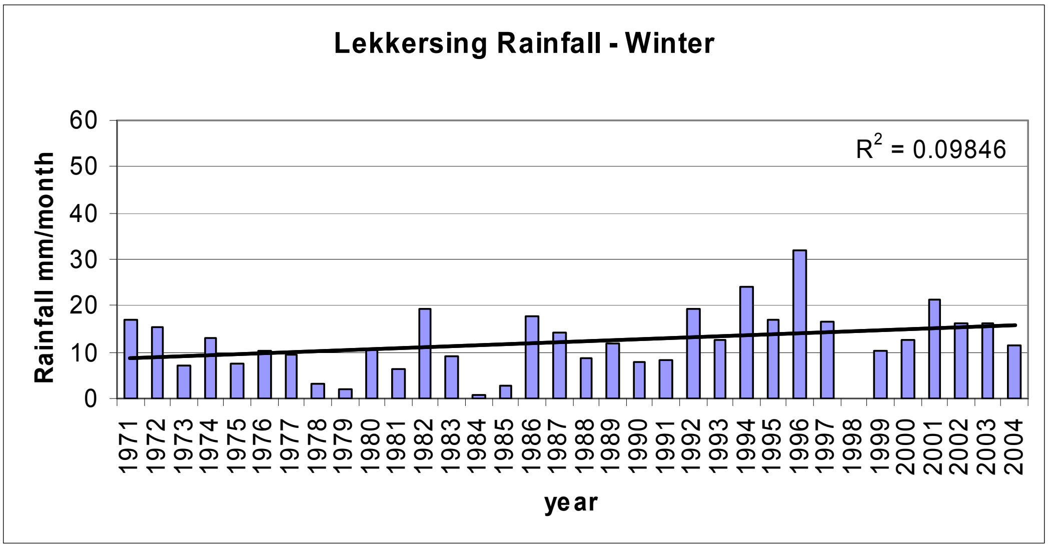

Figure 4: Winter rainfall trends for Lekkersing between 1971 and 2004
(Mukheibir & Sparks 2005)

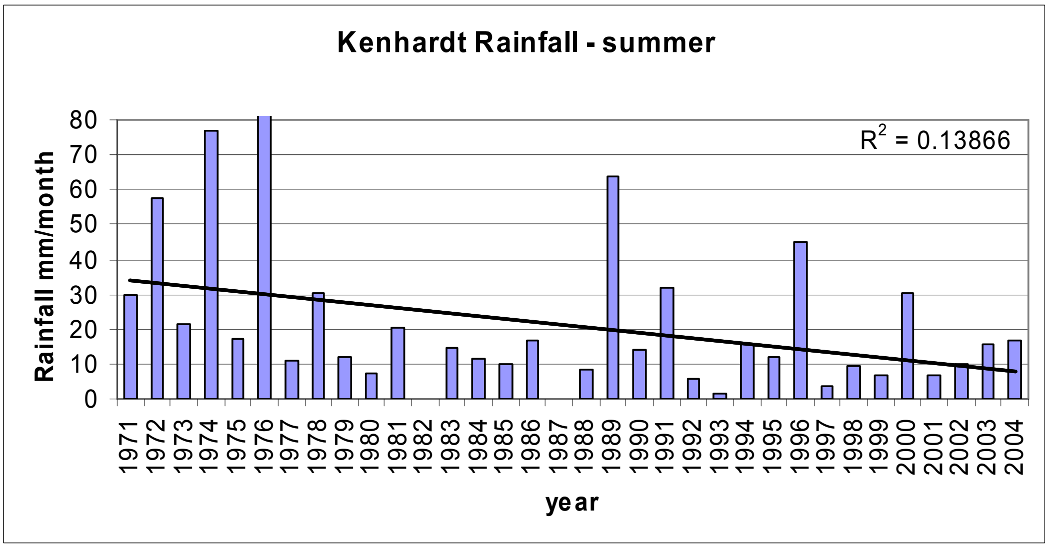

Figure 5: Summer rainfall trends for Kenhardt between 1971 and 2004
(Mukheibir & Sparks 2005)

4.2 Future climate scenarios

It is useful to examine future climate scenarios as they relate in particular to water resources. Despite the wide range of uncertainty, there is an ever-increasing consensus amongst the scientific community that global climate change is a physical reality.

Specifically for South Africa, temperature is expected to increase everywhere, with the greatest increase inland and the least in the coastal regions. Temperature is expected to increase by approximately 1.5° along the coast and 2°-3° inland of the coastal mountains by 2050. Along with temperature increases, changes in evaporation, relative and specific humidity as well as soil moisture are anticipated (Midgley et al. 2005).

Precipitation projections for southern Africa, as provided by empirical and regional climate model-based downscaling tools, indicate a wetter escarpment in the east, a shorter winter season in the southwest, a slight increase in intensity of precipitation, and drying in the far west (Hewitson et al. 2005). The climate change outputs from the models currently being used produced significantly different simulations, however, whilst there are still many uncertainties with regard to the magnitude, the direction of change appears to be consistent.

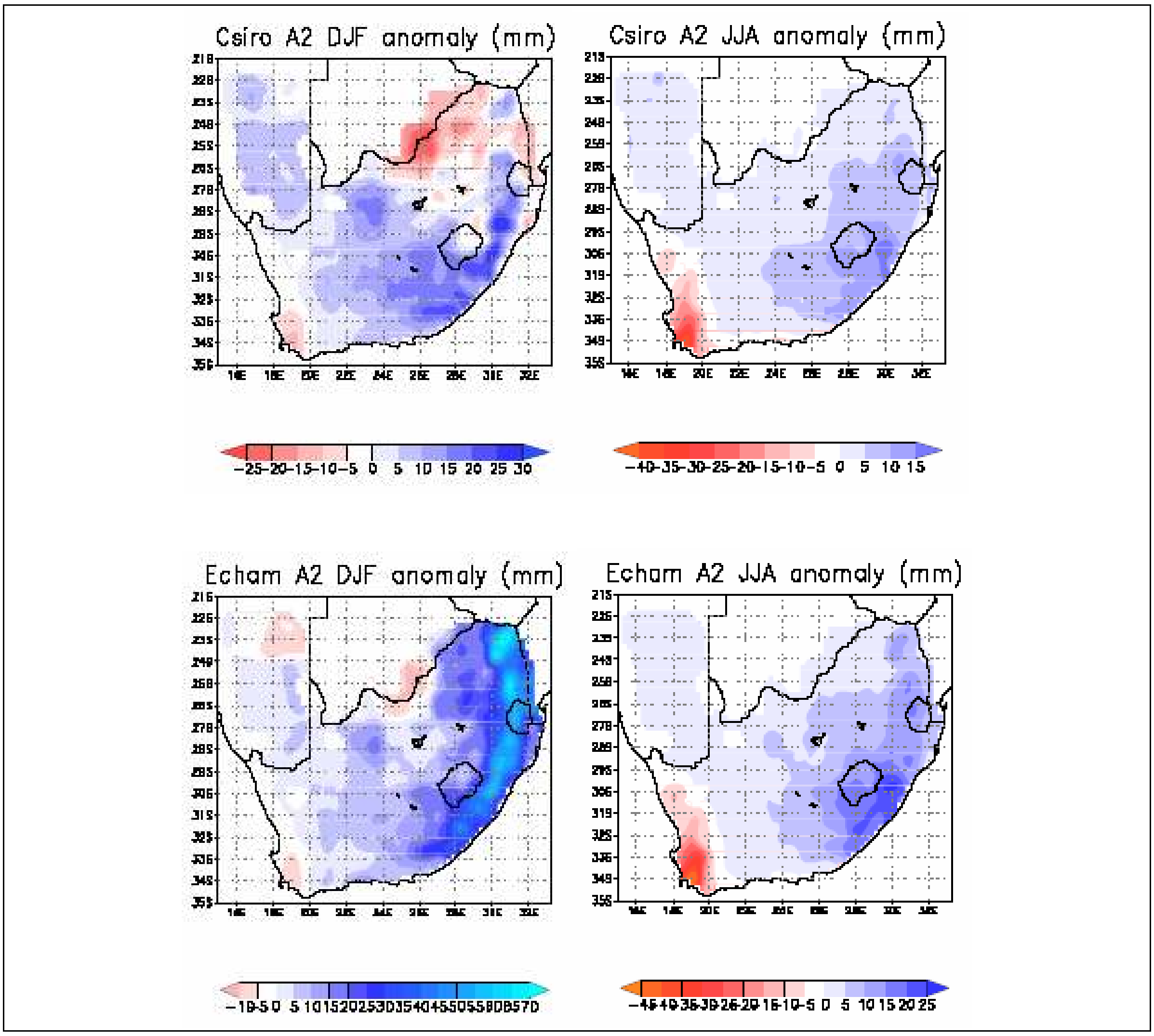

Figure 6: Seasonal mean monthly anomaly of total precipitation downscaled from two Global Circulation Models (Hewitson et al. 2005)

4.3 Potential impact on municipal water supplies and agricultural production

Hydrological responses are known to be sensitive to changes in rainfall. From the threshold study of runoff conducted using the ACRU hydrological modeling system, it was found that runoff was highly sensitive to changes in precipitation and that recharge into the vadose zone is even more sensitive to changes in rainfall (Kiker 2000). It was further found that the western half of the country could experience a 10% decrease in runoff by the year 2015 and by 2060 in the eastern region. Hence groundwater recharge will be more adversely affected than surface water. Towns and farmers reliant on groundwater in the western region of the country, could expect the groundwater stocks to become depleted and unreliable in future.

As is illustrated in Figure 2, the production of agricultural products can be closely linked to the drought patterns of Southern Africa. For example, there has been a steady increase in agricultural production since 1965. However, dips in production can be seen in the early 1970s, 1980s and mid 1990s, which correspond with the occurrence of significant droughts experienced in South Africa and serve to illustrate the vulnerability of agriculture to variations in climate, and potentially to long-term climate change.

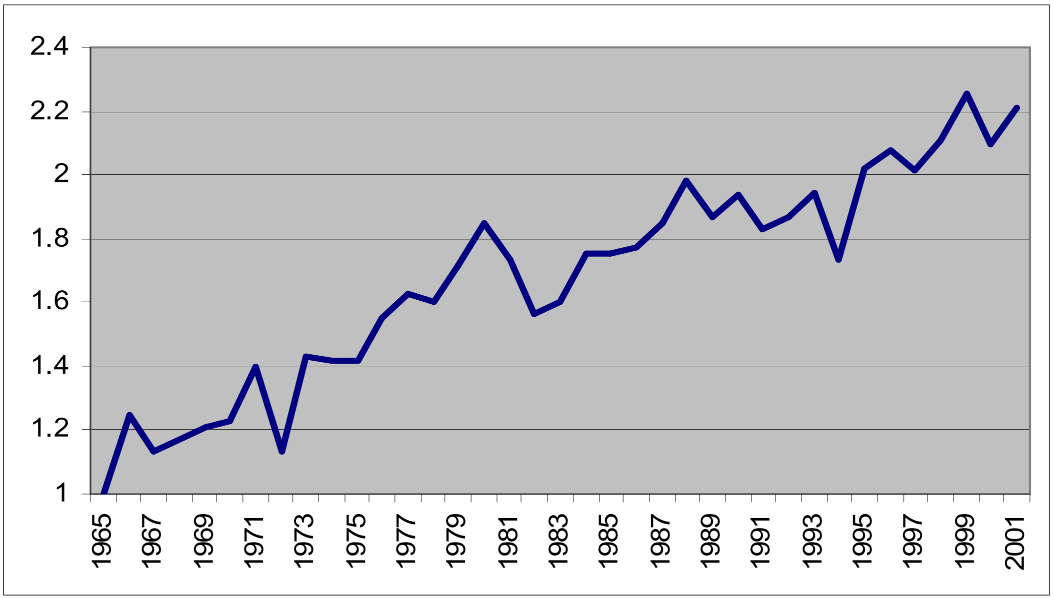

Figure 2. Indices of the volume of agricultural production measured against 1965 **(NDA 2002)**

Crop yield modelling predicts that, under future climate scenarios, maize production will decrease by up to 20%, mostly in the drier western regions. Speciality crops may also may also be at risk, since both rainfall and temperature effects may cause significant changes in areas uniquely suited for such specialised production (DEAT 2004).

Research conducted by Abraha et al (2006) showed that under increased carbon dioxide concentration regimes, maize yields are much more likely to be affected by changes in mean air temperature than by precipitation (Abraha & Savage 2006).

Whilst climate change and variability are high on the list of stresses that farmer face, both small and large scale farmers have identified social, economic, political and environmental issues at all scales that expose their vulnerability to periods of climate stress. It important that these issues are included when assessing the vulnerability of farmers and when implementing plans for assistance and development, especially if such events increase in frequency and magnitude (Reid et al. 2005).

4.4 Water management drivers

4.4.1 Demand - overview

The National Water Resource Strategy document of DWAF states that overall water demand is expected to increase by approximately 9% over the period 2000-2025 (DWAF 2004a), the total demand for water rising to 14 814 x $10^6 m^3$. The reliable local yield is set to increase to 14 940 x 10^6 m^3 over this same period, mainly due to growing wastewater return flows.

Factors such as climate, nature of the economy and standards of living influence water requirements, with population and economic growth being are the primary factors with the respect to future water requirements. Urbanisation and the negative impacts of HIV/AIDS are also key considerations when making future projections on water requirements. In the NWRS document, DWAF states that this estimate of future requirements is based on a scenario of high population growth and high standard of services together with a strong increase in the economic requirements for water so as serve as a conservative indicator.

Access to basic water services:

Access to piped clean water in 2001 was 84% (SSA 2003). DWAF has projected that the remainder will all have access to water infrastructure by 2008 (Kasrils 2003). To address the issue of affordability, the government has committed itself to providing a 25 litres per day free of charge (life-line tariff), implemented by local authorities, amounting to about 6 000 litres per household per month, based on eight people per household. This provision should result in an increase in the use of water and should be considered when projecting future water use requirements. Currently 57% of the population have access to free basic water services – 73% of those with access to water infrastructure (Kasrils 2003).

4.4.2 Supply – water security

In the long term the total water demand will likely exceed the availability of water within the country's borders after 2025 (DWAF 2004a), and there will be a need to both reduce consumption and increase supply to maintain water security and allow for sustainable development. Specific drivers to reduce consumption would include demand-side management through pricing mechanisms and other non-economic mechanisms to achieve the goals of sustainable use, demand reduction, efficient allocation and equitable allocation.

International experience has shown that countries with renewable freshwater resources below 1000 m^3 per capita per year are prone to experience severe water scarcity that will impede development and be harmful to human health (WRI 1996). By 2010 the population is estimated to be approximately 53 million and the per capita water resources will dip below the 1000 m^3 benchmark, based on a growth rate of 2% per annum and an available average runoff is estimated at 53 500 million m^3 (DEAT 1999).

There is still 5500 million m^3 of potential yield from current freshwater resources to meet the projected future demands over the next 25 years. By 2025 the local yield will be increased by 936 million m^3 at a cost of R6 029 million (approximately US$800 million) (DWAF 2004a).

In recognising that climate change impacts are a potential threat to the water related development goals of the country, substantial investments are required for water infrastructure and other water management strategies to be put in place.

5 Strategies for future sustainable water supplies

5.1 Policy vision

The challenge for the future is to balance the demand for water with the available supply. Since it is not possible to increase the amount of water, except to extract more from the available resources, the opportunity exists to satisfy both urban and rural needs using appropriate management mechanisms.

Currently, climate change does not feature prominently as a real threat to the reduction of the existing available water resources, so that strategies have not been developed to adapt to the projected impacts. Current water management mechanisms and policies have been developed to ensure that the existing supply of water meets the growing demand. Some of the mechanisms may be appropriate to deal with the future shortage that will be brought about by climate variation, but robust long-term strategies are required to ensure the demand for water matches supply, even in times of reduced availability. In addressing future projected climate change impacts, some of the measures may need to be introduced sooner than originally planned.

5.2 The linkage between climate variability and climate change

Climate variability affects water resources through periodic droughts resulting in short term water shortages at local municipal level. In order to address these shortages, short term strategies are employed to meet basic domestic requirements (see Figure 7). On the other hand, climate change is projected to increase the frequency of droughts which will in turn have the impact of more frequent water shortages. The implementation of long term strategies is required to reduce the vulnerability to future frequent droughts. By evaluating and screening the short term strategies, a suite of long term strategies can be identified and relevant policies developed to ensure that resilience to current and future climate impacts is ensured.

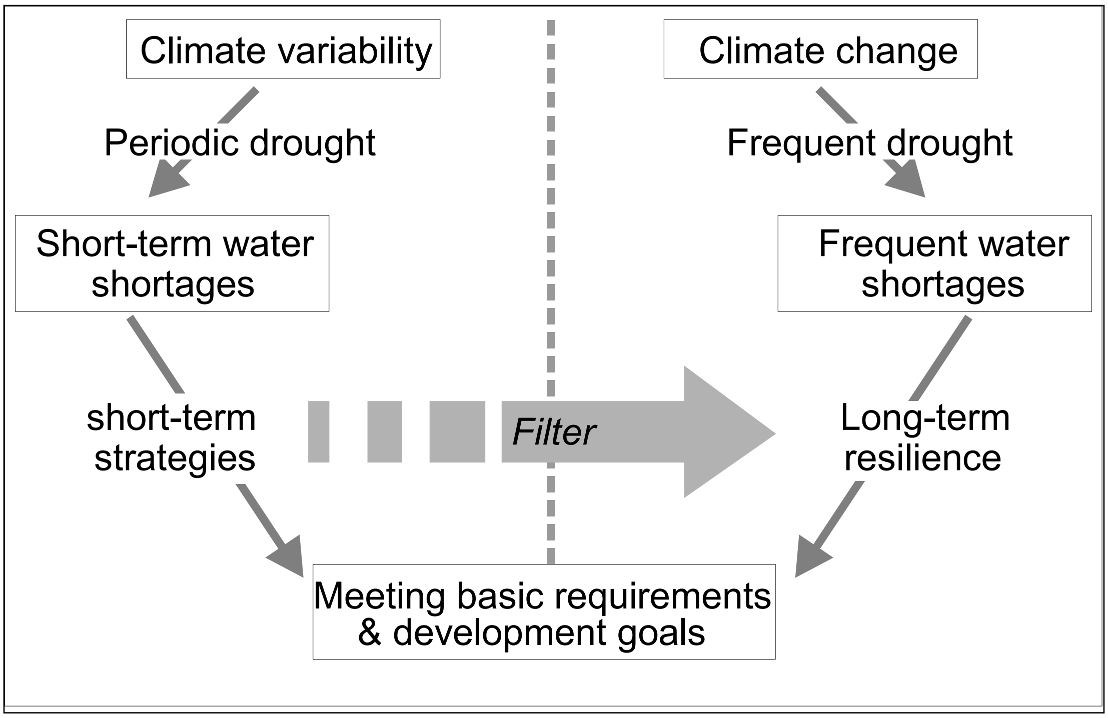

Figure 7: Diagrammatic view of the linkage between climate variability and climate change

Short term responses might be seen as coping strategies, whereas longer term actions that help to deal with future variability could be collectively called adaptation strategies. There are two basic areas of adaptation strategies for water resources are proposed, viz supply side and demand side. Examples of these are discussed in the following sections. These strategies are later analysed to assess whether they are suitable for long term applicability as well as meeting the development criteria of the country.

5.3 Supply side management strategies

5.3.1 Planning and management

5.3.1.1 Overall water resource planning and management

At a national level, DWAF has developed a National Water Resource Strategy (NWRS) (DWAF 2004b) to address the management of the water resources to meet the development goals of the country. It will be reviewed at least every five years (Kasrils 2002). One of the key objectives of the NWRS is to identify areas of the country where water resources are limited and constrain development as well as development opportunities where water resources are available. In addition, industrial users are be required to develop and submit a water management plan if they draw their water directly from a water source (DWAF 2004b).

DWAF have further stated that they will assist municipalities to anticipate drought cycle conditions and prepare contingency plans for their specific areas through the Water Services Development Plan support (DWAF Northern Cape 2005). During these periods, DWAF state that they will assist municipalities to identify and initiate actions to mitigate the impacts of drought affected areas. Whilst this support is not monetary, DWAF state that they are able to provide technical and planning expertise to the province.

5.3.1.2 Groundwater resource planning and management

Groundwater is likely to be most severely affected, with the groundwater table dropping due to reduced recharge in particularly the western parts of the country. Strict groundwater management systems should be put in place with early warning mechanisms to report depleted groundwater reserves. The long term goal of DWAF is that local authorities manage their own water supply and demand. This can only be attained if they are informed of the possible supply resources, monthly abstraction volumes and water quality and aquifer levels (van Dyk et al. 2005).

At a local level, Murray and Ravenscroft identified key legal obligations for groundwater management, as listed in the following table.

Table 2: Legal obligations for groundwater management
(Murray & Ravenscroft 2004)

Responsibility	Catchment Management Agencies	Water Services Authorities	Water Services Providers
Ensuring groundwater monitoring meets the requirements as stipulated in the license agreement	x		
Setting up the groundwater management system	x		
For managing and maintaining the monitoring system		x	
Data collection			X
Sampling at the point of use (standpipes and hand pumps)- could be delegated to the WSP by the WSA.		x	X
Analysing groundwater monitoring data and ensuring that operational changes are made		x	

5.3.1.3 Assurance of supply

As part of the planning and management of water resources, it has been suggested that each local authority be in a position to guarantee an assurance of water supply to its users under existing climatic conditions (van Dyk et al. 2005). As is illustrated in Figure 8 for example, approximately 25% of the towns in the Northern Cape were using more than 80% of their available groundwater resources in 2000. It is proposed that the peak demand should be 80% of the available yield of the resource. The would allow for a buffer against drought and climate variability. It would also allow the aquifer time to for recharge (van Dyk 2004).

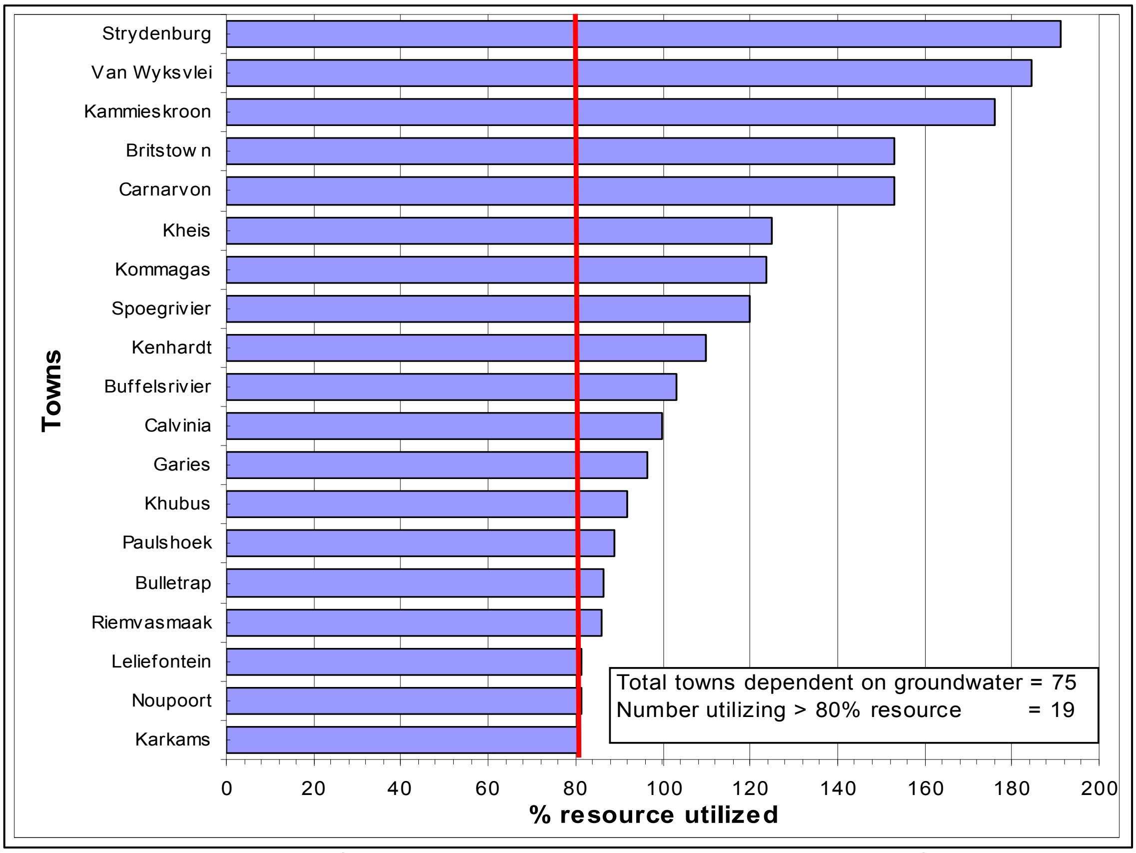

Figure 8: Example of groundwater resource utilization in 2000 in the N-Cape
(van Dyk et al. 2005)

5.3.1.4 Conjunctive use of surface and groundwater

To avoid the dependence on one source or type of source, some local authorities have made use of more than one type of water source, for example using both groundwater and surface water. This is most common where groundwater is found to be too saline for domestic use. One way to increase the available supply is to dilute the saline water with fresh water to acceptable concentrations. Alternatively, the saline water can also be used for flush toilets, whilst the treated water can be used for drinking and cooking. This type of system requires dual water supply and dedicated plumbing for each source, and hence could be costly to install. If identified at an early stage, the infrastructure can be installed in new developments to reduce the reticulation costs.

5.3.1.5 Artificial groundwater recharge

This is the process of transferring surface water into an aquifer, and could be in the form of rainfall run off, treated wastewater and urban storm runoff. The surplus run-off is often lost due to evaporation from dams and rivers. The main reasons for artificial recharge include the following (Murray 2004):

- to provide security during drought and dry seasons and reverse the negative dewatering trend;
- to provide storage of local or imported surplus surface water;
- to manage the operation of surface and groundwater reservoirs;
- to improve the quality of the groundwater, specifically the salinity by replenishing the aquifer when river runoff is available:

Examples of this practice by municipalities in South Africa include the following:

- Atlantis (> 20 years in operation);
- Polokwane (> 10 years of operation);
- Karkams (> 5 years operation);
- Calvinia (>2 years in operation).

They have demonstrated that this strategy is effective and applicable to both large scale schemes as well as small scale operations. It does require basic maintenance to ensure that the injection rate is optimised. Also, the quality of the water being injected needs to be of a high quality.

5.3.2 Drought relief

5.3.2.6 Standby relief under critical conditions

Standby relief usually takes the form of tankered water and drought relief funding for basic water infrastructure. This forms part of the National Disaster Management plan, which is co-ordinated by provincial local government. The Disaster Management Act 57 states that each province is charged with the responsibility of preparing a disaster management plan for the province as a whole, coordinating and aligning the implementation of its plans with those of other organizations of state and multinational role-players and regularly reviewing and updating its plan (Republic of South Africa 2003). Likewise, each metropolitan and each district municipality is responsible to establish and implement a framework for disaster management in their municipalities aimed at ensuring an integrated and uniform approach to disaster management in their respective areas. These relief measures should, however, be seen as the exception and not be implemented on an ongoing basis.

5.3.2.7 Water tankering

Water tankers are used to bring freshwater from other resources during times of drought and breakdown in critical domestic water supply. As stated above, this forms an essential part of standby relief. In some cases, however, water tankering has become a regular form of municipal water supply.

5.3.2.8 Drought relief funding and aid schemes

In most cases, the drought relief funding has been used to expedite the delivery of basic services and provide co-funding for bulk infrastructure to remote areas.

5.3.3 Rainwater harvesting

Whilst acknowledging the agricultural benefits of surface water harvesting, there are also benefit of improving the recharge of underground water, either by natural infiltration of the soil or by artificial recharge methods. The effectiveness of this does, however, depend on the aquifer type. In the southern tributary catchments of the Lower Orange water management area, the unique use of soil embankments has been employed as a means of rainwater harvesting (DWAF 2004b). This practice enables additional recharging of the aquifer and reduces the runoff. Appropriate measures are required to manage the impacts of these “soomwalle” on downstream users (BKS (Pty) Ltd 2003).

At a domestic level, rainwater harvesting from roofs is an effective way of augmenting drinking water, watering gardens and filling up swimming pools.

5.3.4 Desalination

Desalination offers an opportunity for coastal municipalities to convert seawater into freshwater. Presently this technology is both a capital- and energy-intensive source of freshwater that would make the cost of water out of the reach of most local municipalities – in some case 3-4 times the cost of conventional sources (Eglal R et al. 2000). However, in places such as the Middle East, where there is no alternative this technology provides a solution. In Dubai, for example, 95% of the drinkable water comes from the sea (Makin 2005).

There are specific locations within South Africa where small-scale desalination has proven to be more cost-effective than transporting fresh water over long distances. In these instances, groundwater with a high saline content is desalinated using small plants, especially at schools and clinics.

5.3.5 Reduction of leaks

In South Africa, the level of unaccounted for water in urban distribution systems is between 15 and 20%, which is viewed as high by international standards (Goldblatt et al. 2002). Unaccounted for water not only amounts to losses in usable water, but also in potential revenue due to additional treatment and distribution costs. These losses are often passed onto the consumer, who are required pay higher tariffs to offset these losses. Conveyance losses in the agricultural sector due the age of some schemes is also a major source of leakage losses.

With the stress on available water supplies, consumers cannot be expected to increase the available water resource through a reduction in demand alone. Losses in the system need to be addressed as part of supply management. Service providers should see this as one of their main target areas for "creating" more available water. Just as any viable business would aim to reduce their commodity losses in order to maintain their competitiveness, so too should Water Service Providers aim to run an efficient operation. It has been estimated that a saving of up to 15% of demand can be achieved by implementing effective distribution management measures (DWAF 2004c). The following measures have been suggested to water service institutions to reduce distribution leaks:

- leak detection;
- repair of visible and reported leaks;
- pressure management;
- effective zoning of the distribution system;
- pipe replacement programme;
- cathodic protection of pipelines against corrosion.

The implementation of leak detection and repair programmes have been implemented by some municipalities. A wider roll-out of this programme would reduce the water losses from reticulation systems in the province. In addition, the introduction of pressure management systems where water lost from undetected leaks is reduced by reducing the off peak water pressure in the pipes. This would also reduces the water lost through leaks within the piping on private property.

5.3.6 Control of invasive alien vegetation

DWAF have initiated the 'Working for Water' programme to remove invasive alien tree species (wattles, pine etc) from catchments in South Africa as part of local catchment management strategies. Through the modification of the vegetation in various catchments, where water-thirsty vegetation with high transpiration rates has reduced the stream flow, the available water supply can be increased. Invading alien plants have covered some 10 million hectares, about 8%, of South Africa. They cause the loss of some 7% of the annual flow in South Africa's rivers each year – about 33 million m^3 of water (This excludes the severe impact upon groundwater reserves). Through the Working for Water Programme it is estimated that approximately 750 000 hectares will need to be cleared each year over a 20-year period (Kasrils 2000).

5.3.7 Rainfall enhancement

Research has shown that only 10% of moisture in atmospheric systems passing over South Africa falls as rain (Shippey K et al. 2004). By using cloud seeding, i.e. the artificial introduction of additional particles into clouds around which raindrops can form, the ability of the clouds to produce rainfall is enhanced. Rainfall enhancement can only stimulate raindrop formation where clouds already exist and meet particular physical criteria.

However, these areas are limited to the Eastern and North Eastern parts of South Africa. Furthermore, the cost implications may make this practice prohibitive for small municipalities (Otieno FAO & Ochieng GMM 2004).

5.3.8 Control of water pollution / water quality

Polluted water that is unfit for drinking or other uses can have a similar effect as reduced water supply. Reducing water pollution effectively increases the supply of water, which in turn increases the safety margin for maintaining water supplies during droughts (Schulze & Perks 2000). The protection of water quality presents a major challenge to water policy in South Africa.

5.3.9 Contingency planning for drought

Much research has been conducted into the adaptation to climate variability (droughts and floods) and specifically measures that could be taken to prevent or minimise the disruption and damage caused by such occurrences. In the past, most of this research has been conducted in agricultural sector; more recently research has been focused on the impacts of drought and floods on people and their livelihoods. The lessons from this research, and resilience strategies of vulnerable communities, need to be taken into consideration when developing strategies to deal with the impacts of future long-term climate change. If the development goals of the country are to be achieved despite the impacts of climate change, then the appropriate lessons need to be incorporated into national and local water management policy. The cost of developing contingency plans to adapt to water shortages and mitigate droughts is relatively small compared with the potential benefits (Schulze & Perks 2000).

5.3.10 Improved monitoring and forecasting systems for floods and drought

It is possible that climate change will affect the frequency of floods and droughts. Monitoring systems will help in coping with these changes, even without the impact of climate change (Schulze & Perks 2000). Planning for the most vulnerable water supply areas should be such that proper monitoring can provide early warning of problems including global change impacts.

Seasonal forecasts have been shown to be useful as an adaptive strategy to respond to climate variability, especially in determining the planting and harvesting times. The forecast information is currently available on an annual time step. However, there is still a need for improved support of seasonal forecast information at the national and district level (Ziervogel & Bharwani 2005).

5.3.11 Inter-basin transfers

Transfers of water between basins may result in more efficient water use under the current and future changed climate. Inter-basin transfers are considered an effective short-term measure for addressing drought and water supply on a regional scale. This, however, is an expensive option (Schulze & Perks 2000).

5.3.12 Marginal changes in construction of infrastructure

Marginal increases in the size of dams or marginal changes in the construction of canals, pipelines, pumping plants and storm drainage should be considered (Schulze & Perks 2000).

5.3.13 Maintain options for new sites

Potential sites for new dams should be kept open till they are required, since there are a limited number of sites that can be used efficiently as reservoirs and removing structures once an area has been developed may be very costly or politically difficult (Schulze & Perks 2000).

5.4 Demand side management strategies

There a number of ways to reduce the water demand by consumers. The first is to influence their consumption behaviour. This could be done through education as well as through persuasive means eg restrictions and tariff structures. The second would be to provide incentives or assistance projects. The implementation of urban water demand management will not make any significant impact on the availability of water on a catchment-wide scale. However, it is a crucial intervention that must be implemented by all local authorities, so as to prolong the life of existing urban sources of supply. To encourage this at local level, DWAF have stated that they will not consider the licensing new water resource developments for any local supply schemes unless water demand management has been implemented (Ninham Shand et al. 2004).

It is calculated that the total opportunity in reducing water demand in the water services sector is approximately 39% of the total existing demand. (DWAF 2000)

5.4.1 Water restrictions

In a some towns and cities water restrictions have been implemented as means of curbing water demand (Department of Housing and Local Government 2005). This has been done either through rising block tariffs or the restriction of certain water uses, such as the watering of domestic gardens. In severe cases, users are restricted to a certain volume of water per day. Those exceeding this are fined.

Instituting water restrictions requires additional personnel capacity to police the interventions and to prosecute those who are offenders. The implementation of an education campaign to both inform users of the new measures and to make them aware of water saving practices also requires capacity and funding..

5.4.2 Tariff structures

Most policy papers dealing with natural resource management in South Africa recognise the need for economic instruments and market mechanisms for efficient utilisation and allocation of natural resources and environmental resources. The provision of water at prices below the true economic value is considered the main reason for inefficient use of water and allocation in South Africa. Further, in the context of water scarcity, an argument can be made for the introduction of economic incentives in water-stressed catchments to encourage the conservation of water and its shift from low to higher value use. This can be done administratively or by using market-related mechanisms. Issues to be considered when reviewing the pricing of water are (Hassan et al. 1996):

- Marginal cost pricing is more appropriate than average cost pricing since it sends the right signal to efficient water users.
- Variable tariff rates, as apposed to flat rates, to provide for periods of scarcity and peak demands.
- Opportunity cost of water, especially when water is scarce.
- Pricing undelivered water i.e rainfall runoff that is absorbed by crops vs natural vegetation.
- Property rights and tradable permit systems in water.
- Lifeline tariffs and equity.
- Rewarding quality return flows from waste streams.

The Department of Water Affairs and Forestry has implemented a water pricing strategy which includes abstraction, storage of water for recreational purposes and stream flow reduction for the purposes of afforestation. Water use charges are divided into four sections viz. (DWAF 2004b)

- Municipal
- Industrial, mining and energy
- Agriculture
- Stream flow reduction activities

Unit charges per kilolitre for each sector will be determined for each user sector and water management area. The charges are based on recovering costs of managing the total volume of water that may be allocated for use in each water management area.

One of the most effective ways being used by local authorities to encourage consumers to use water more efficiently is through tariff mechanisms. Market-based allocations are able to respond more rapidly to changing conditions of supply and also tend to lower the water demand, conserve water and consequently increase both the robustness and resilience of the water supply system (Schulze & Perks 2000). In most cases a rising block tariff has been used to curb excessive use of water. This mechanism is designed along the principle of “the more you use the more you pay”, as illustrated below. This mechanism does not usually require additional staffing or resources, but an adjustment to the billing system. An education campaign is also advisable in this instance to make people aware of the new billing systems and also to make them aware of water saving practices. As can be seen from the example for Cape Town (Table 3), the local authority increased the water tariffs substantially in an attempt to curb excessive water use. This measure was implemented as a result of the very low water levels in the dams due the prevailing drought conditions during 2003 and 2004.

Table 3: Example of domestic consumption rising block tariff
(City of Cape Town 2005)

Consumption in kl	*Tariff per kl*		
	2004/5	*2005/6*	*increase*
0 – 6	R0.00	R0.00	R0.00
7 – 12	R2.32	R2.46	6%
13 – 20	R6.15	R6.52	6%
21 – 40	R10.41	R11.04	6%
41 – 60	R13.34	R25.00	87%
61 +	R17.20	R50.00	191%

5.4.3 Changes in agricultural management practices

Adaptation strategies in the agricultural sector can be categorized into two levels: grower level responses and government level responses (Kiker 2000).

Grower level responses would include, changes in planting dates, row spacing, planting density and cultivar choices could be implemented to counter the effects of limited water. Practices such as conservation tilling, furrow dyking, terracing, contouring and planting vegetation as windbreaks, protect fields from water and wind erosion and assist in retaining moisture by reducing evaporation and increases infiltration (DEAT 2004). Early planting dates could serve as a means of mitigating impacts of climate change (Abraha & Savage 2006).

Irrigation, which is widely used, will most likely become more expensive and this may need be phased out in favour of dry land farming. Currently losses through irrigation range between 30-40% of the demand, and is indicative of the potential for water demand management in the agricultural sector (DWAF 2004d).

To mitigate against crop losses, more drought resistant crop such as sorghum or millet should be planted. Crop land could in future be turned into grazing land (DEAT 2004).

Government level responses would most likely be limited to financial resources and should be focused to aid both commercial and subsistence farmers in activities such as crop substitution where the financial input is substantial.

5.4.4 Sanitation systems

1.1.1.1 Dry sanitation systems, low-flow systems

In areas where there is a lack of water to allow conventional flush toilets, dry sanitation, pour flush and low flow systems should be considered. In areas that are dependent on groundwater, care must be taken to avoid contamination of groundwater source when installing VIP latrines. Composting latrines or lined chambers should be considered if there is a potential for contamination. However, sometimes it is difficult to get buy-in from consumers in South Africa who have developmental aspirations for flush toilets.

5.4.4.9 Dual flush toilets

This strategy reduces the demand for water for the provision of waterborne sanitation. Studies have shown that toilets account for approximately 30% of total residential indoor water use. Some models of dual flush toilets use six litres of water to flush solid waste but only three litres of water to flush liquid waste. These toilets save an average of 26% more water over the single-flush six litre toilets. In places such as Australia and Singapore, this technology is mandatory (Soroczan & Baynes 2003).

5.4.4.10 Saline water for toilets

As discussed under conjunctive use of surface and groundwater, saline water can be used for flush toilets. A dual system can be adopted where the salt water is used for the sewage system and the fresh water is used for drinking. This type of system requires a dual water supply and dedicated plumbing for each source. If identified at an early stage, the infrastructure can be installed in new developments to reduce the reticulation costs, which can be costly if implemented at a later stage.

5.4.5 Water education

Public information and school education programs are key to highlighting the need and benefits of initiating water demand strategies. These programmes could include brochures, advertising, newsletters or magazine and newspaper inserts, exhibits and informative billing.

5.4.6 Re-use of grey water

Grey water utilisation at a domestic level can be beneficial for irrigating small gardens, and to lesser extent assisting in the recharge of groundwater resources. This practice not only reduces the water demand, but also relieves the volume on the waste water treatment works. Municipal byelaws are required to regulate this practice to avoid the contamination of the groundwater and to ensure that pooling of grey water does not take place, which could lead to the spread of diseases. The use of properly constructed French drains should be regulated.

5.4.7 Leak reduction

The average water wastage due to plumbing leaks in the household is estimated at 20% of the total indoor household water use (DWAF 2004c). Consumers should be encouraged to maintain their internal reticulation systems. Whilst no revenue may be lost due these leaks by the service provider, unused water is being wasted through leaking taps, pipes and faulty toilet systems. Together with the education programme and pressure control systems, these internal leaks can be reduced.

5.4.8 Assistance projects

These are interventions of best management practice, which could be funded or partially funded by the WSA. Examples of this would include projects to repair leaks, to retrofit dual-flush toilets, installation of dual water supply and distribution systems (using saline groundwater for flushing and using treated potable water for drinking and cooking) and replace exotic gardens with waterwise gardens. By providing incentives, more efficient use can be made of recycled water, such as grey water for gardens.

6 Strategy analysis – A case study of municipal water supply

A simplified multi criteria analysis (MCA) was developed for the assessment of municipal water resources for the Northern Cape province and is described below (Mukheibir & Sparks 2005) .

6.1 Criteria for strategy analysis

In order to rank the appropriate strategies and interventions discussed in the previous section, a set of criteria were developed in consultation with relevant stakeholders to be used for the comparative analysis of the inputs and the impacts of the strategies as suggested in table 4.

Table 4: List of criteria for multi-criteria analysis
(Mukheibir & Sparks 2005)

1. Additional Yield / saving	*How will the intervention impact on water supply through additional yield and/or savings?*
2. Technology required	*Is the technology for the intervention readily available?*
3. Additional Capital Expenditure	*Will the intervention require additional capital expenditure?*
4. Additional Running costs	*Will the intervention incur additional running costs?*
5. Local Employment	*To what extent will the intervention impact on job creation?*
6. Local Capacity to implement	*What level is the institutional capacity currently at with respect to the intervention?*
7. Acceptability to local community	*What is the consumer acceptability of this intervention in terms of additional cost to them and convenience?*
8. Impact on local water Resources	*What impact will the intervention have on the water resources and the environment in the area?*
9. Long term applicability	*What is the period of impact of the intervention? (short - long term)*

For the most part these criteria are subjective and should be used as a first cut. The following could be used to obtain objective and quantifiable criteria for a more detailed analysis:

- Access to clean drinking water:
  - short-term 20-30 litres per person per day (percentage of people with access);
  - medium to long-term 50-60 litres per person per day (percentage of people with access).
- Subsidy of 25 litres per person per day free of charge (percentage of people receiving subsidy);
- Share of people without improved water access/population not using improved water resources (as percentage of total population).
- Urban households with access to onsite water (percentage of households with onsite water)
- Water quantities used by different sectors (in percentages).
- Additional yield per day
- Volume of available freshwater per capita per annum (percentage of people receiving less than 1000 kl).
- Water costs as a share of income (percentage of income). Water costs as share of production costs (percentage of production costs).
- Investment costs in Rands
- Number of jobs related to the intervention.

It is important to weight the criteria since some will carry more significance than others. However, this exercise is also rather subjective as can be seen in Figure 9 where different stakeholders[1] placed lesser or greater importance on the different criteria, most notable is "local employment", where the local government officials and those from the Department of Agriculture placed a higher priority on this weight compared to the officials from the national Department of Water Affairs and Forestry. 'Acceptability to the local community' and 'capital expenditure' followed a similar trend.

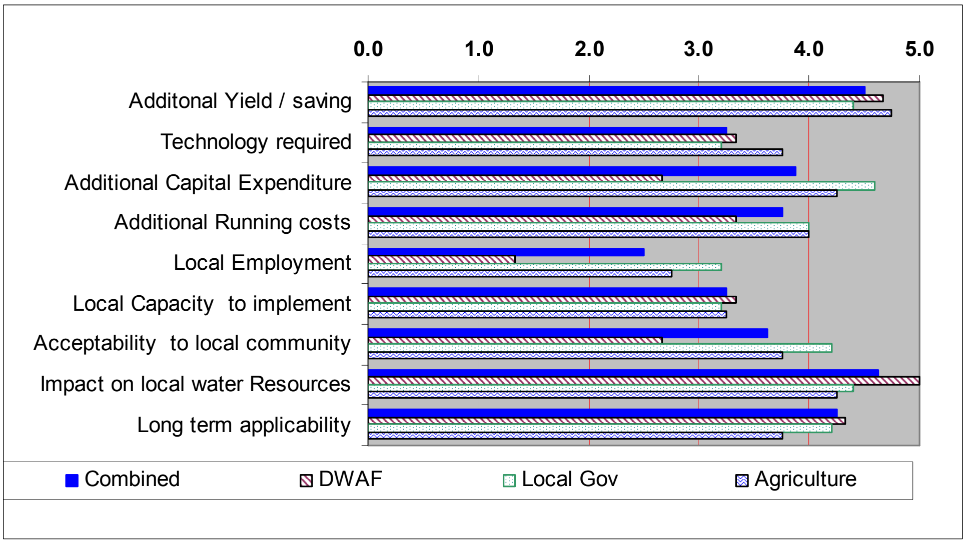

Figure 9: Weighting of criteria by various stakeholders
(Mukheibir & Sparks 2005).

6.2 Multi-criteria strategy analysis

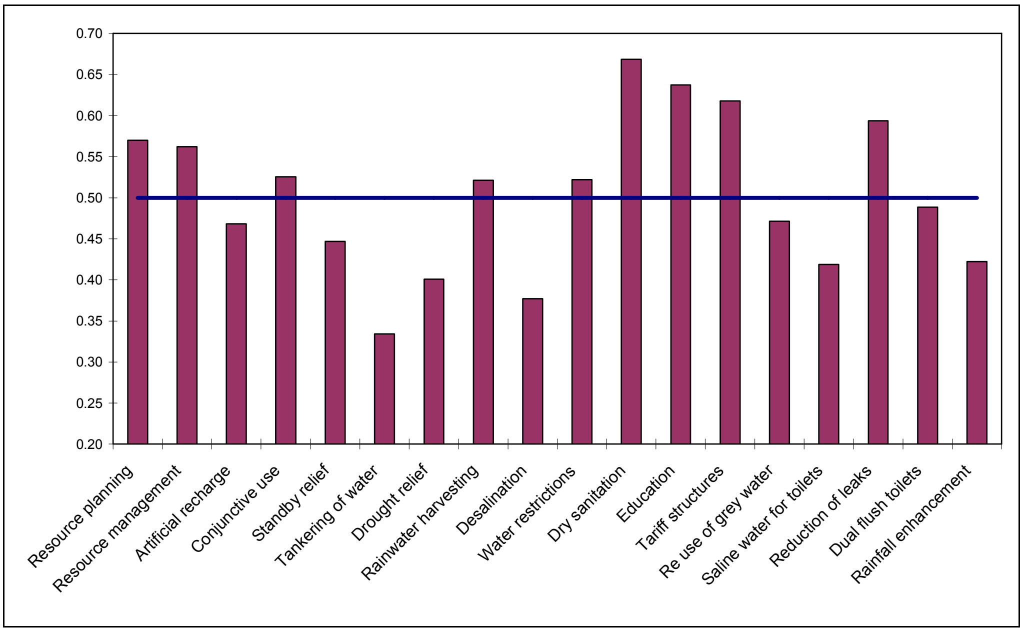

Figure 10: Strategies analysed against combined criteria
(Mukheibir & Sparks 2005).

This case study revealed a number of viable strategies. By using the multi-criteria analysis methodology the strategies most likely to be appropriate for municipal water resource management

[1] Stakeholders drawn from the Northern Cape Drought Relief Forum, which is co-ordinated by the Department of Housing and Local Government, were requested to rank the list of strategies according to these criteria.

were identified. This was done in consultation with representatives of the various Local Municipalities and the Department of Water Affairs and Forestry.

As can be seen from the graphical representation, the following strategies were seen as priorities (scoring above 50%) :

- Regional water resource planning
- Local water resource management and monitoring
- Conjunctive use of resources
- Dry sanitation systems
- Education programmes
- Tariff structures
- Reduction of leaks programmes
- Rainwater harvesting
- Water restrictions

Only “ water restrictions” can be viewed as typically a short term strategy. Which points to the fact that in order to address climate change, long term strategies need to be adopted and implemented. Almost all the strategies listed above would be viewed as having a greater than 20 year design life.

7 Barriers to implementing adaptation

7.1 Agricultural sector

Common barriers to implementing water conservation and water demand management in the agricultural sector include the following (DWAF 2004d):

1. *Financial:* Water conservation and demand management measures require investment in appropriate new irrigation schemes.
2. *Planning:* Resources planning is usually only focused on the supply side and often only infrastructure options are considered.
3. *Institutional and technical capacity*: Due to the transition from former Irrigation Boards to Water User Associations, there has been inadequate clarity on institutional arrangements, roles and responsibilities. The is also a general lack of technically qualified people to plan and implement WDM measures.
4. *Social:* Demand management is not perceived as an every day activity and is only enforced during drought periods.

Reid et al (2005) argue that “macro” activities should be included that are strongly coupled to development activities including improved institutional structures to heighten resilience to climate stresses. Case by case institutional and local response interventions should be developed to enhance adaptation to climate variability in the short term and climate change in the longer term (Reid et al. 2005).

7.2 Municipal water sector

Drawing on the outputs of the case study the obstacles and limitations to implementing these strategies at a local municipal level have been identified. Two key ones stand out:

1. *Local Capacity:* The most notable affecting the viability of these strategies is the perceived lack of local capacity to implement the strategies. The former Director-General of DWAF, Mr Mike Muller has stated that there is a severe shortage of qualified water managers in small to medium-sized municipalities which has resulted in 63% of municipalities not complying with the drinking-water quality standards. There is an urgent need for formal training in this sector (Venter 2005).
2. *Financial:* This is further exacerbated by the low financial resource base to cover the capital and running costs of most of the strategies. Local government competes for nationally allocated funds for capital expenditure. Running costs are mostly covered from local revenues, which for the smaller and remote local municipalities, are insufficient to ensure water security at this level.

Political buy-in for some of the strategies such as water restrictions and dry sanitation will need to be obtained through education programmes, but these also require human and financial resources.

In order to address the impacts of climate change, policies and resources need to be focused on addressing the building of both financial and human resources at local government level. Adaptation to climate impacts for the most can only be addressed at the local level as part of an integrated development plan.

8 Conclusions

Climate change does not feature prominently as a real threat to the reduction of the existing available water resources, so much so that strategies have not been developed to adapt to the projected impacts. Current water management mechanisms and policies have been developed to ensure that the existing supply of water meets the growing demand. Some of the mechanisms may be appropriate to deal with the future shortage that will be brought about by climate variation, but robust long-term strategies are required to ensure the demand for water matches supply, even in times of reduced availability. In addressing future projected climate change impacts, some of the measures may need to be introduced sooner than originally planned.

Water resource planners and officials of local and provincial government would be well advised to undertake a similar exercise as the one illustrated above, to identify specific local strategies that are appropriate for their specific situations. Long term strategies should be adopted that meet the local developmental needs and the address the water resource management concerns.

It is also clear from the responses from different sectors, that some trade-offs will be necessary when choosing appropriate water management strategies. In some cases some unpopular interventions may be required to ensure the long term sustainability of a specific water resource. Education programmes would be required in these circumstances.

The strategies can be grouped into demand-side management and supply-side management. Each group would require different resources viz. financial and human, and the political support for the initiative. Local and national government should look at policies and programmes that would address the low levels of financial and human resources. Adaptation to climate change will cost money, and therefore should be mainstreamed into development programmes. The integration and institutionalisation of adaptation with development activities, in the advent of climate change, should seriously considered by planners in South Africa.

It is necessary for decision makers to see the urgency in addressing climate variability now with robust strategies so that long term climate impacts are addressed at the same time. This will ensure that local governments have in place the necessary adaptive resilience to ensure that the communities they serve are assured adequate clean water to meet their developmental needs, despite the uncertainty of future climate projections.

References

Abraha, M G & Savage, M J 2006. Potential impacts of climate change on grain yield of maize for the midlands of KwaZulu-Natal, South Africa. *Agriculture, Ecosystems and Environment*. pending.

BKS (Pty) Ltd 2003. Lower Orange Water Management Area. Overview of the water resources availability and utilisation, DWAF.

City of Cape Town 2005. Development and Infrastructure (Tariff funded) - Water Services - 20% restriction tariff. http://www.capetown.gov.za/tariffs/.

DEAT 1999. National State of the Environment Report - South Africa, DEAT.

DEAT 2004. A national climate change response strategy for South Africa. Pretoria. September 2004.

Department of Housing and Local Government 2005. Provincial Drought Task Team Meeting minutes 13/01/2005. Kimberley.

DWAF 1994. Water Supply and Sanitation Policy - White Paper. *Water - an indivisible national asset*. Cape Town.

DWAF 1996. The Working for Water Programme annual report 1995/96. Pretoria, DWAF.

DWAF 1997. White paper on a National Water Policy for South Africa, DWAF.

DWAF 1998. The National Water Act.

DWAF 2000. DRAFT Water conservation and demand management strategy for the water services sector.

DWAF 2004a. National Water Resource Strategy. July 2004.

DWAF 2004b. National Water Resource Strategy. First Edition. September 2004.

DWAF 2004c. Water conservation and demand management strategy for the water services sector.

DWAF 2004d. Water conservation and water demand management strategy for the agriculural sector.

DWAF Northern Cape 2005. Contingency Plan guideline. DWAF. 13 January 2005.

Eglal R, Rathgeber E & Brookes DB 2000. *Water management in Africa and the Middle East: Challenges and opportunities*, IDRC.

Fischer, G, van Velthuisen, H, Shah, M & Nachtergaele, F 2002. Global agro-ecological assessment for agriculture in the 21st century. Austria, International Institute for Applied Systems Analysis.

Goldblatt, M, Gelb, S & Davies, G 2002. Macroeconomics and sustainable development in Southern Africa. Development Bank of Southern Africa.

Hassan, R, Breen, C & Mirrilees, R 1996. Management of Water Resources and Emerging Water Policy Challenges in South Africa. The Economics, Policy & Natural Resource Management Southern Africa Workshop, Pretoria, 1996. IUCN.

Hewitson, B, Tadross, M & Jack, C 2005. Scenarios from the University of Cape Town. *In*:Schulze, R.E. (Ed) *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*. Pretoria, Water Research Commission. WRC Report 1430/1/05.**:** Chapter 3, P 39 - 56.

IPCC 2001. Climate change 2001: Synthesis report. *A contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernment Panel on Climate Change*. [Watson RT and the Core Writing Team (eds)]. Cambridge, Cambridge University Press**:** 398.

Kasrils, R 2000. A water perspective on invasive species. The best management practices symposium, Kirstenbosch.

Kasrils, R 2002. Parliamentary Media Briefing, DWAF.

Kasrils, R 2003. Parliamentary Media Briefing, DWAF.

Kiker, G A 2000. Synthesis report for the vulnerability and adaptation assessment section: South African Country Study on Climate Change. Pretoria, Department of Environmental Affairs and Tourism.

Majola, B 2002. Highs and lows of state's delivery. *Mail & Guardian*. February 8-14**:** 10.

Makin, A 2005. Desalination in focus. *News Drop* February 2005. Vol 22 Issue 1.

Midgley, G F, Chapman, R A, Hewitson, B, Johnston, P, De Wit, M, Ziervogel, G, Mukheibir, P, Van Niekerk, L, Tadross, M, Van Wilgen, B W, Kgope, B, Morant, P, Theron, A, Scholes, R J & Forsyth, G G 2005. A Status Quo, Vulnerability and Adaptation Assessment of the Physical and Socio-Economic Effects of Climate Change in the Western Cape, Report to the Western Cape Government, Cape Town, South Africa. Report No. ENV-S-C 2005-073. Stellenbosch, CSIR.

Mukheibir, P & Sparks, D 2005. Climate variability, climate change and water resource strategies for small municipalities. WRC K5/1500. Pretoria, Water Research Commission. September 2005.

Murray, E C 2004. Wise water management for towns and cities - Artificial groundwater recharge. Report No TT219/03. Pretoria, Water Research Commission. January 2004.

Murray, E C & Ravenscroft, P 2004. A framework for groundwater management of community water supplies. CSIR Environmentek. Forthcoming.

NDA 2002. Abstract of agricultural statistics. Pretoria.

Ninham Shand, Asch Consulting Engineers & Jackoet & Associates 2004. Clanwilliam Dam Raising Study Specialist Screening Workshop. *Workshop starter document*.

Otieno FAO & Ochieng GMM 2004. Water management tools as a means of averting a possible water scarcity in South Africa by the year 2025. *Water SA* 30 (5): 668 - 672.

Reid, P, Massay, R & Vogel, C 2005. Climate and development: Experiences of farmers in Kwa-Zulu-Natal, South Africa *In*: Schulze, R.E. (Ed) *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*. Pretoria, Water Research Commission**:** Chapter 25, pp 395 - 414.

Republic of South Africa 2003. Disaster Management Act 57 of 2002. *Government Gazette 24252 of 15 January 2003*.

SADC 2001. Key Priorities for SADC. SADC Sub Regional consultations in preparation for the WSSD, Mauritius.

Schulze, R & Perks, L 2000. Assessment of the Impact of Climate Change on Hydrology and Water Resources in South Africa. ACRUcons report 33. Pietermaritzburg, School of Bioresources Engineering and Environmental Hydrology, University of Natal. January 2000.

Shippey K, Gorgens A, Terblanche D & Luger M 2004. Environmental challenges to operationalisation of south African rainfall enhancement. *Water SA* 30 (5): 636 - 640.

Soroczan, C & Baynes, S 2003. Dual-flush Toilet Testing. Canadian Mortgage Housing Corporation.

SSA (Statistics South Africa) 2003. Key results: Census 2001. Pretoria. www.statssa.gov.za/SpecialProjects/Census2001/KeyResults/Key%20results.htm.

van Dyk, G 2004. Personal communication. Geohydrology, DWAF Northern Cape. 03/06/04.

van Dyk, G, Peters, R & Fourie, S 2005. Water provision from Groundwater in the Northern Cape: Balancing demand and supply. Biennial Groundwater Conference, March 2005. pp. 381 -391.

Venter, I 2005. Back to basics. *Engineering News* October 21-27 2005.

WRI (World Resources Institute) 1996. World Resources 1996-97. Washington D C, World Resources Institute.

Ziervogel, G & Bharwani, S 2005. Adapting to climate variability: Pumpkins, people and pumps. *IHDP Meeting*. Bonn. Part A.