Access to water - the impact of climate change in small municipalities

PIERRE MUKHEIBIR

Climate Change
Capacity Development

October 2007
ENERGY RESEARCH CENTRE
UNIVERSITY OF CAPE TOWN

Acknowledgements

This study was made possible with funding from the UNITAR C3D programme.

Author details:
Pierre Mukheibir is a Researcher at the Energy Research Centre at the University of Cape Town, working on adaptation to the impacts of climate variability and change, specifically in water resources management at municipal level.

Address: Energy Research Centre, University of Cape Town, Private Bag, Rondebosch 7700, South Africa; tel: +27 21 6502824; fax: +27 21 6502830; e-mail: Pierre.Mukheibir@uct.ac.za

Contents

List of figures

List of tables

1. Introduction

This case study has been undertaken to establish whether climate change is an economic issue and not primarily an environmental one. It is the argument of this paper that climate change directly impacts on sustainable development through physical and financial stresses. In small towns these resources are generally in short supply and a negative impact on either can adversely affect the achievement of and sustained delivery of services related to the local development goals, specifically the supply of clean safe water.

The key objective of this case study is to demonstrate the affect of projected climate change impacts on the local water supply of a small town and the related financial consequences in terms of water pricing and access. While the delivery of basic water services, free for the first 6kl per household per month, is driven by a national development goal, it is incumbent on local government to ensure this right. For this, the local municipality needs to ensure that water supplies meet the consumption demand, present and future. Technical and financial planning are therefore required to ensure that an undisrupted services is provided. The impact of climate change needs to be included in this planning.

Beyond scarcity and access, water security is also about risk and vulnerability[1]. One key such risk is that of projected climate change impacts. Climate change poses a threat to water security for many of the poorest countries and households. Of course, this threat is not limited to poor countries, wealthy countries will also experience the impact of changing climate and weather patterns. However, it is poor people and countries which lack the financial resources to reduce the risk through firstly preventative action, and secondly through adaptation to impacts or restoration if damage is inflected by extreme weather events.

In general, small towns do not have many high end users to fully subsidise the provision of a free basic supply to indigent and poor households. Whilst an unconditional external grant has been provided by the national government in South Africa in the form of the Equitable Share, it is not sufficient to fully cover this free service, usually due to fact that other priorities attract a larger portion of the budget allocation. It will be illustrated through this case study, that under future projected climate change conditions the need for additional funding to cover the incremental unit cost is evident, since the increased burden on the paying customers is not sustainable in the long term. This increase in unit supply cost is due mainly to the additional cost of securing water from sources that are further away and hence more costly, both in terms of investment and operating costs.

After interviewing practitioners in the water sector, it became evident that the issue of available historical records was key (Murray 2006; Groenewald 2007; Visser 2007a; Woodford 2007). Whilst there are small towns with chronic water problems, the author decided to use the small town of Bredasdorp (population of 13200 in 2005) as an illustrative example because of the availability of rainfall records, groundwater extraction records, consumption records, and climate projection information for the catchment area.

2. Ensuring access to water services in South Africa

2.1 Access and affordability

The urban and rural domestic requirements make up 25% and 4% of demand in South Africa respectively (DWAF 2002a). According to the 2001 census, 84% of South Africans have access to piped water, 32% directly into their homes (SSA 2003). A large percentage of those without access to clean water live in the historically disadvantaged rural areas, specifically in the previously demarcated 'homelands'.

[1] Vulnerability: "is 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 change and variation to which a system is exposed, its sensitivity and its adaptive capacity" (Falkenmark et al. 1989).

The issue of access to water is not always determined by scarcity. This is often cited as the reason, but poor access to water could also be due to political or economic policies. People who do not have access to water are mostly the marginalised – geographically, economically and socially.

While it may have been reported by the South African government that two million households had been provided with access to water via mostly communal standpipes between 1994 and 1999 (Kasrils 2003), inefficient cost recovery measures and institutional arrangements have made many such projects unsustainable and have resulted in small scale water systems becoming uneconomical and inoperative (RSS 1997). Wellman (1999) estimates that in 1999 at least 50% of the installed systems were no longer operational. This was mainly due to poor cost recovery and a lack of operation and maintenance capacity as was found in a study of the Eastern Cape (RSS 1997) and reconfirmed in the recent evaluation of the DWAF Masibambane II programme (Everatt et al. 2007), but Wellman also reports that vandalism of water meters was often cited by government officials as the cause for system failure.

Cost recovery is usually achieved by charging users the full short-run marginal cost of production plus a portion of the long-term operation and maintenance costs. This notion of "cost recovery" influenced levels set by Government for basic services. These service levels were based on "you get what you pay for" under Operation Masakhane. Communal standpipes were installed in villages and townships, with the understanding that collectively the costs would be covered by monthly household payments (Pape & McDonald 2002). Assessments of affordability were based on the communities agreement and "willingness to pay", rather than their "ability to pay" or affordability. This has resulted in systems failing and consumers, mainly the poor, being denied an equitable access to a basic service such as water.

2.2 Subsidising the poor

The amount paid for water is usually a very small fraction of the household's disposable income. Water services are generally accepted as affordable when the cost of the service is less than 5% of the household income – this is known as the "5% rule" (Eberhard 2001). However, Eberhardt calculated that a poor household using 66 litres/person/day would spend about 8% of its income on water, but a wealthier household using 350 litres/person/day would only spend about 1% of its income.

In a survey of case studies in South Africa, Loftus (2004) found that the central theme was the pressure being placed on households to restrict their demand since they have been unable to meet the payments. He found that water restrictions and flow controllers had been installed on individual households to "help" them manage their water bills. The flow restrictors consist of a simple disc with a narrow hole in the middle, which dramatically reduces the diameter of the pipe at the meter, thereby restricting the flow to daily level that approximates the free water allowance set by government. Such a method is notoriously unreliable since the flow is dependent on the pressure in the system, which varies depending on the other users in the system.

Another technical innovation was the introduction of prepaid meters in South Africa as an answer to the cost recovery difficulties. A prepaid meter is a device that not only measures the exact amount of water consumed, but also forces consumers to pay for the service in advance. They do not allow the consumer to go into default and therefore require no punitive measures. The pre-paid meters are installed at communal points and in some case at household connections. A survey of the Northern Cape by Deedat (2002), confirmed that the prepaid system is generally not accepted by consumers. In the past, they could settle their accounts with the municipality by arrangement. Under the pre-paid system however, they often went without water or used unsafe sources.

These two examples illustrate that poor people are typically deprived their right to access to clean safe water, whilst at the same time being the only people in the world who suffer from life threatening water scarcity. Schreiner and van Koppen (2002) identified two relevant key reasons for this. Firstly they lack the technical and financial assets to access sufficient clean water. Secondly, under growing competition for scarce water resources, high income users of high volumes of water have the socio-political power to assure their permanent access to water. Commercial agriculture is a case in point. The exclusion of the poor and subsistence farmers from water governance is reinforced by their general social exclusion from public governance due to their low levels of education, literacy and access to information. Institutional exclusion from decision making over water allocation further erodes poor peoples access to water and also further decreases their water demand.

To avoid this, the South African National Water Act (36 of 1998) (RSA 1998) shifted the locus of formal water control from riparian water title holders, consisting mainly of the white minority, to the national government as custodian of the nations water resources for all its citizens. Under the Act, compulsory licensing has resulted in the cancelling of past licensing and the reissuing of them on the basis of a new allocation schedule that redresses the inequities of the past. Under this legislative framework, an amount of water is reserved for human needs that is provided free to Water Services Authorities (WSA), as well as for ecological needs as determined by water management plans. Further, there are specific components of the National Water Act that contribute specifically to poverty eradication. The water reserve includes an ecological reserve and a basic human water need and is allocated before any other allocation is made. The South African "basic" level of water supply to promote a healthy standard of living is 25 l/p/d at a walking distance of less than 200m as specified in the RDP (DWAF 1994). This equates to 6 kilolitres per household per month for a household of 8 people and is regulated as part of the national strategy in terms of the Water Services Act (108 of 1997) (RSA 1997). However, the number, size and structures of households in South Africa have undergone dramatic changes during the past decade. The total number of households in South Africa has increased through government housing programmes and has resulted in the average household size declining from about 4.48 in 1996 to about 3.69 in 2005 (van Aardt 2007). The monthly volume therefore would equate to an average of just over 50 litres per person per day, which would be more in line with the WHO recommendation for on site water delivery (Howard & Bartram 2003).

Historically South Africa has had one of the most unequal distributions of income in the world, and by all accounts it is getting worse. South Africa's Gini[2] coefficient rose from 0.69 in 1996 to 0.77 in 2001 (HSRC 2004). To address the issue of affordability, the South African Government committed itself to providing a life-line tariff, implemented by local authorities, amounting to about 6 000 litres per household per month free. This was spurred on in 2000 after a severe cholera epidemic in several provinces and towns, including parts of Johannesburg. The outbreak was linked by some to the Government's policy of full cost recovery for water and the ensuing lack of access to water in sufficient quantity and quality by the poor (Budds & McGranahan 2003). This policy however does not cater for those individuals who are not connected to water systems such as people living in rural areas who still have to fetch water from springs and rivers. In addition, no additional finance was initially provided to local governments to implement this policy. The idea was to cover the cost through cross-subsidisation within the municipal area

In response to the concerns about access and equity, many countries (including South Africa) have introduced rising block tariffs in an effort to make the initial levels of consumption more affordable and, in some cases, free thereby addressing accessibility for the poor (Warford 1997; CCT 2007; Joburg 2007; Ravenscroft 2007; Visser 2007b). Increasingly higher tariffs are charged as consumption levels increase, effectively taxing the wealthy to curb their consumption and to make cross-subsidisation financially sustainable. The rising block tariff forces high end users to cross-subsidise even more. However, block tariffs provide an added complication due the arbitrary nature of their setting, as illustrated in Figure 1. In addition the capacity of local authorities to implement this policy is limited. Pape (2002) points out that for small rural towns and areas, there is little scope for mobilising funds through a block tariff, since most have relatively few industries or large scale users to subsidise the water costs to the poor. Further, few small urban centres have sufficient wealthy consumers to subsidise the poor. Those who cannot pay for their water are still cut-off since fees are still charged to cover the operational costs of providing the water service (Mehta & Ntshona 2004; Mosdell & Leatt 2005).

In the examples illustrated, the two small towns of Bredasdorp and Prince Albert charge an access fee across the board and then apply a block tariff to consumption. The larger metropolitan centres such as Cape Town and Johannesburg do not, but the cost for water for the higher end users is much higher than for the smaller centres. The large urban centres are able to provide a bigger subsidy to the lower end users than the smaller centres can offer, possibly due to there being fewer high end users in the small centres and cross-subsidation is more difficult to achieve.

[2] To measure inequality the Human Sciences Research Council in South Africa have used the Gini coefficient, which can vary from 0 in the case of a highly even distribution of income, to 1 in the case of a highly unequal distribution (HSRC 2004).

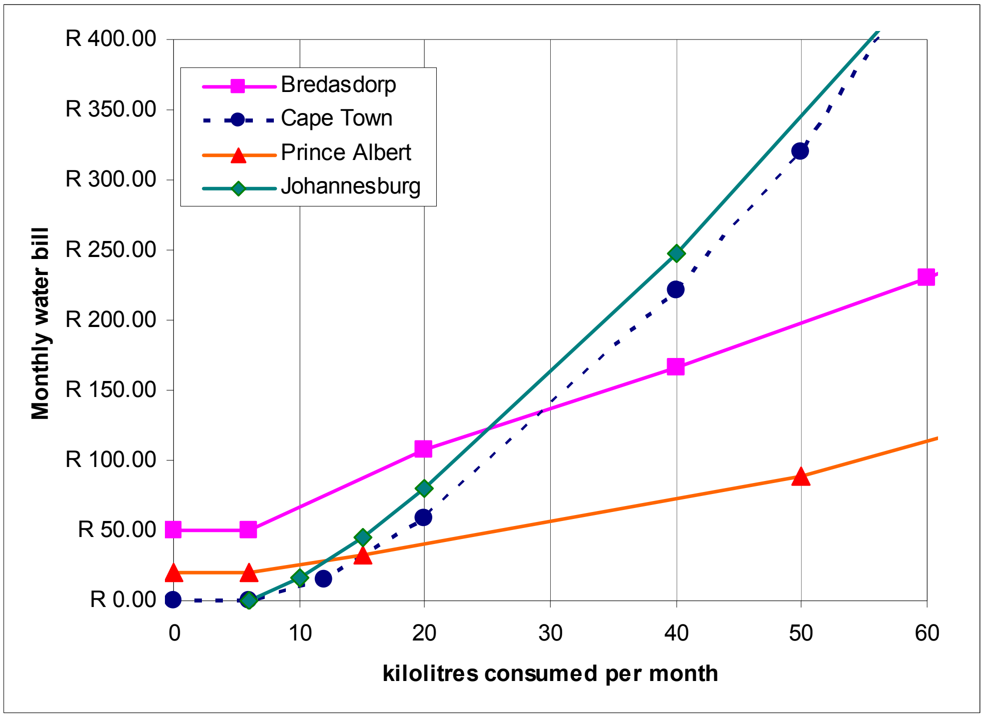

Figure 1: Block tariffs for 2006/07
Source (CCT 2007; Jo'burg 2007; Ravenscroft 2007; Visser 2007b)

Local governments have differing capacities to raise revenue within their boundaries as well as differing expenditure needs. These often do not correspond. Along with rates and user charges, transfers from national government make up the total revenue available to municipalities. Most countries internationally have some form of social assistance programme to ensure service delivery to the poor. In higher developed countries these programmes are generally in the form of a comprehensive social security system which is provided by central government while public service delivery assistance lies with local governments. This equalisation funding is aimed at addressing this mismatch (Parnell et al. 1998; PDG 2001). In South Africa, the Local Government Equitable Share[3] is one element in the system of financial transfers from national to local government (Whelan 2004). A severe cholera epidemic in 2000 in several provinces and towns, including parts of Johannesburg was linked by some to the Government's policy of full cost recovery for water and the ensuing lack of access to water in sufficient quantity and quality by the poor (Budds & McGranahan 2003). This together with the fact that in 2003 it was reported that only 57% of the population had access to free basic water services (Kasrils 2003), led to introduction of the Equitable Share policy

3. Projected climate change scenarios for South Africa

Over the past few decades, the global temperature has been increasing. Human activities release greenhouse gases (GHGs) into the atmosphere, which include carbon dioxide from energy production, methane and nitrous oxide from land use change and agriculture, and three trace gases. A combination of intensive agriculture, the burning of fossil fuels and industrial processes have raised the raised the levels of CO_2 resulting in an enhanced greenhouse effect. The concentration of these gases has increase by 34% from 1750 to 2005. This has resulted in the average linear warming trend over the last 50 years (0.13 °C per decade) being nearly twice that for the last 100 years (IPCC 2007). Superimposed on these changes are seasonal, annual and inter-annual variabilities, producing a complex climate variability and change signal.

[3] Equitable share: an external subsidy from national government for all local municipalities based on the number of indigent households in their geographical area. In South Africa this is known as the Equitable Share grant.

Despite this 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 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; Hewitson & Crane 2006).

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.

4. Vulnerability to climate variation and change in the water sector

South Africa is a water-stressed country with an average annual rainfall of 500mm (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 500m per year, which is usually regarded as the minimum for dryland farming (DWAF 1994). The natural availability of water across the country is variable, and rainfall displays strong seasonality. Stream flow in South African rivers is at a relatively low level for most of the year.

The variability in rainfall is pronounced over southern Africa. This makes planning for times of drought difficult, yet important, since with large interannual variabilities there are no rainfall guarantees. The impact of climate change on water resources, including groundwater, acts through a modification of the water balance, ranging from the micro to the macro-scale. This includes factors such as surface conditions, the soil column, aquifers and catchments (Braune 1996)

Hydrological responses are known to be sensitive to changes in rainfall. Runoff is highly sensitive to changes in precipitation and recharge is even more sensitive to changes in rainfall (Kiker 2000). In drier areas where annual rainfall is less than 500 mm, a 10% decrease in rainfall could translate into as much as a 40% decline in recharge (Cave et al. 2003). This has serious implications where rainfall is already low, and is predicted to decrease with projected future climate change and where groundwater is over-exploited at present.

The South African Country Study on Climate Change found that when running GCM and ACRU[4] models, runoff was found to be highly sensitive to changes in precipitation. Groundwater recharge was found to be even more sensitive (Kiker 2000; Schulze 2005). Therefore, changes in the climate system will affect hydrological systems and water resources.

5. Dealing with uncertainty

A key issue raised by planners when planning based on scenarios of future climate change is the uncertainty associated with projections of climate variables at specific geographical locations and spatial scales. This has been cited as a reason for the difficulty in using climate scenarios for adaptation planning beyond "no regrets" measures (Gagnon-Lebrun & Agrawala 2006). The water resources planning community has been dealing with variability in a formal sense for many decades which has facilitated the application of risk management methods such as conjunctive use of different resources, incremental construction, designing for extreme events and demand management measures. In considering the application of these techniques it is useful to distinguish between risk, where a probability distribution is known or can be assumed, and uncertainty, where no probability distribution can reasonably be assumed (Major 1998).

Introducing climate change into the water planning process involves a sequence of models and techniques that result in a cascade of further uncertainties. A number of commentators have

[4] ACRU - Agricultural Catchments Research Unit within the Department of Agricultural, Engineering of the University of Natal in Pietermaritzburg, South Africa

addressed the issue of uncertainty under climate change (Frederick 1998; Jones et al. 2007; Schelling 2007). Climate change studies inherently have to consider the significance of uncertainty. This does not mean that there is no confidence in the understanding, or that the understanding is not certain enough to allow for the development of appropriate adaptation strategies and policies for resource management. Rather, current research would suggest that the political and planning response is lagging the understanding of climate change. Four sources of uncertainty currently limit the detail of the regional projects, viz. natural variability, the understanding of the climate system, future emissions and the downscaling of the global circulation models (CGMs) (Midgley et al. 2005). Due to the finite historical records from which the range of natural variability at different scales of time and space has been defined, it is not possible to set the definitive limits of natural variability nor to establish how much of the change in variability is due to anthropogenic factors. In addition, the current understanding of the regional dynamics of the climate system of the African sub-continent is limited.

Given than much of the projected change is dependent on how society responds to reducing the emission of greenhouse gasses, these projections will need regular updating. The amount of CO_2 that will be emitted into the atmosphere if no or only partial global mitigation takes place is unknown. This will depend on population and economic growth, energy technology development and the level of commitment by national governments to meet Kyoto type targets (Schelling 2007). This will have an impact on the amount of average global warming which can be expected from specified increases in the concentration of CO_2 and other GHG's. The IPCC are preparing to update the emissions scenarios based on the data and trends of the past few years. The increase in warming will translate into changing climates around the world. The intensity and frequency of extreme climatic events will be affected - exactly how is not certain.

The modelling tools for projecting these trends is subject to a certain level of uncertainty which is driven by the structure of the GCMs and the parameters that have been used. No single tool for projecting future climate is perfect and the range of projections needs to be taken into account. It is important to note that the pattern of regional change is more robust than the absolute magnitude of the projected change (Tadross & Hewitson 2007). One needs to also consider the natural variability of the climate being studied, which add an additional uncertainty through unpredictable droughts and scarcity. Downscaling the GCM to a regional scale has its own inherent uncertainty.

There also exists an uncertainty attributed to the response measures. It is not a perfect science as to how these climatic impacts will affect livelihoods and productivity in sectors such as agriculture, fishing and forestry or how they will affect health in terms of vectors and pathogens. People, communities and large urban settlements will all adapt to these physical and resource impacts in different ways with differing levels of adaptive capacities.

The financial cost to firstly build resilience to adapt these impacts, and secondly the cost of damages and how this will affect the insurance industry is largely unknown. Specifically in the water sector, the elasticity of the high end users to pay higher prices per unit of water in order to cross subsidise the poor through a progressive block tariff is not easy to determine. The actual level of price elasticity is difficult to predict in the high end users (Martins & Fortunato 2007). The level of subsidisation varies from place to place and over time. Specifically in South Africa where a subsidy in the form of the Equitable Share is used to ensure access to a basic level of service of 6kl of water per household is provided, the issue of population growth and the increase in the number households is of concern.

While the uncertainties associated with the prospect of climate change may not provide sufficient basis for building new projects, they do provide added justification for developing water management institutions that are more flexible and responsive to change in supply and demand.

6. Methodology for urban water pricing under climate change

Typically water pricing would be based on the revenue objective of the institution and would be derived from an analysis of the capital and operating costs and the required surplus. There is no one correct approach to determining the overall *unit selling price* (P_U) (or tariff). However, one approach that is put forward by most scholars and practitioners is the marginal costing approach (Baumann et al. 1998; PDG 2000). This is a forward looking approach in which the unit selling price is based on estimates of future marginal costs rather than on historic costs. Whilst marginal costs are more difficult to collect and calculate, they do send the correct cost signal to the consumer. In the case of water supply, infrastructural investment often takes place in large increments and hence the marginal cost of supply varies considerably over time. According to Eberhard (2001), in addition to large infrastructural supply costs, there are three different types of marginal access costs:

- The incremental local distribution infrastructure costs
- The incremental cost of a new connection to the network
- The incremental cost of the administrative and management of a new consumer

In addition, there are two types of marginal consumption costs:

- The marginal capital costs of extending the capacity of the system
- The marginal operating costs to deliver another unit of water

These cost are likely to vary spatially and temporally. The cost may also differ per customer. Therefore in developing a pricing strategy, using the marginal cost approach, requires a sophisticated economic system and may discriminate against some consumers who live far away or may have joined at a different time. To address this problem of spatial and temporal differences urban water price policy makers advocate (in Eberhard 2001: 66) a long-run marginal cost[5] pricing approach based on the *discounted levelised cost* (DLC), which would include both current costs and future planned costs and where the costs and the available capacity are discounted to the base year. It is interesting to note that in a survey conducted by Eberhard (1999a), no instances were found of full marginal cost pricing in which the long-run marginal cost price had been applied to all units of water sold. His research showed unequivocally that political and economic factors mitigate against the implementation of full long-run marginal cost pricing, especially where these prices were significantly higher than the historical prices. Increases in the marginal price of water above the historic average have been resisted by the water service providers. The long-run marginal cost of supply is useful as a rough estimate of the magnitude of the tariff to be charged (Eberhard 1999b). In practice, the *average unit cost* (C_U) is calculated using the levelised cost (LC) formula, where the present value of the capital and operating costs are divided by total volume consumed or sold over the period. Therefore, without considering profit mark up, the C_U would represent the tariff (P_U) to be charged to consumers and would normally include all costs associated with providing the future service viz. operating and maintenance costs, refurbishment and capital costs for existing and planned new infrastructure. The tariff is therefore represented as:

$$P_U = C_U = \frac{\sum C_t / (1+r)^t}{\sum Y_t}$$ **Equation 1**

Where: C_U = average unit cost (R/kl)
P_U = unit selling price or tariff (R/kl)

P_U here would represent a simple flat tariff structure. In practice block or step tariffs have been used. Usually a simple two step block tariff is proposed, where the first block is set at the average unit cost and the second at the long-term marginal cost. The second block would be aimed at the luxury consumption consumers in order to send them a conservation signal.

Due to inconsistent application of the block tariff (as illustrated aove), the approach in this paper has been to simply balance the actual cost of supply with the net revenue received. A simple two tier system has been used i.e. free basic supply for 6kl per household per month and fixed rate for consumption in excess of the free volume based on the levelised cost (LC) approach. Under this cross-subsidy scheme the P_U would need accommodate both the C_U and the cost of the subsidised free water (V_F), as illustrated in Figure 2. The P_U of water is therefore calculated as follows:

[5] Long-run marginal cost – The cost of providing the next unit "in the long run", that is, when investments in supply capacity are not fixed.

$$P_U = \frac{C_U * V_T}{(V_T - V_F)}$$ **Equation 2**

Where: V_T = Total volume of water supplied
V_F = Volume of water provided for free

Based on this formula, it can be seen that for a large indigent population the total free water will increase resulting in an increase in the tariff (P_U) to be charged to non-indigent consumers. The converse is therefore also true.

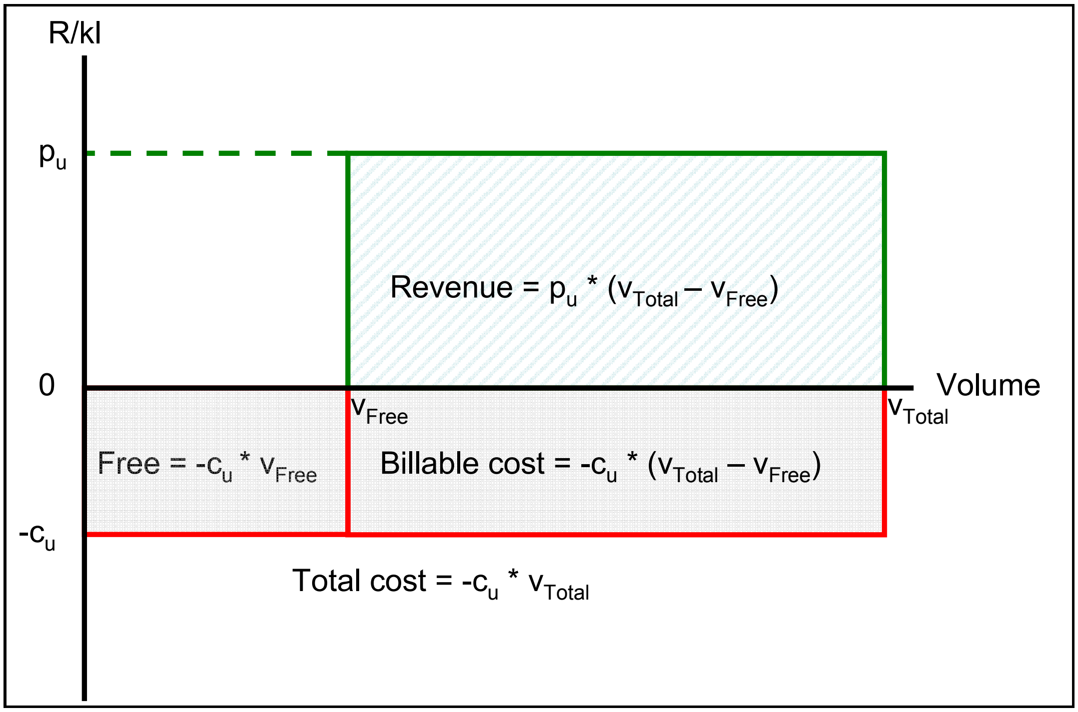

Figure 2: Schematic representation of simple cross-subsidisation

As discussed previously, some countries such as South Africa have introduced an external subsidy from national government for all local municipalities based on the number of indigent households in their geographical area. In South Africa this is known as the Equitable Share grant. This external subsidy has the function of reducing the burden of internally cross-subsidising the free basic water service. This is graphically illustrated in Figure 3. This has the overall effect of reducing the P_U.

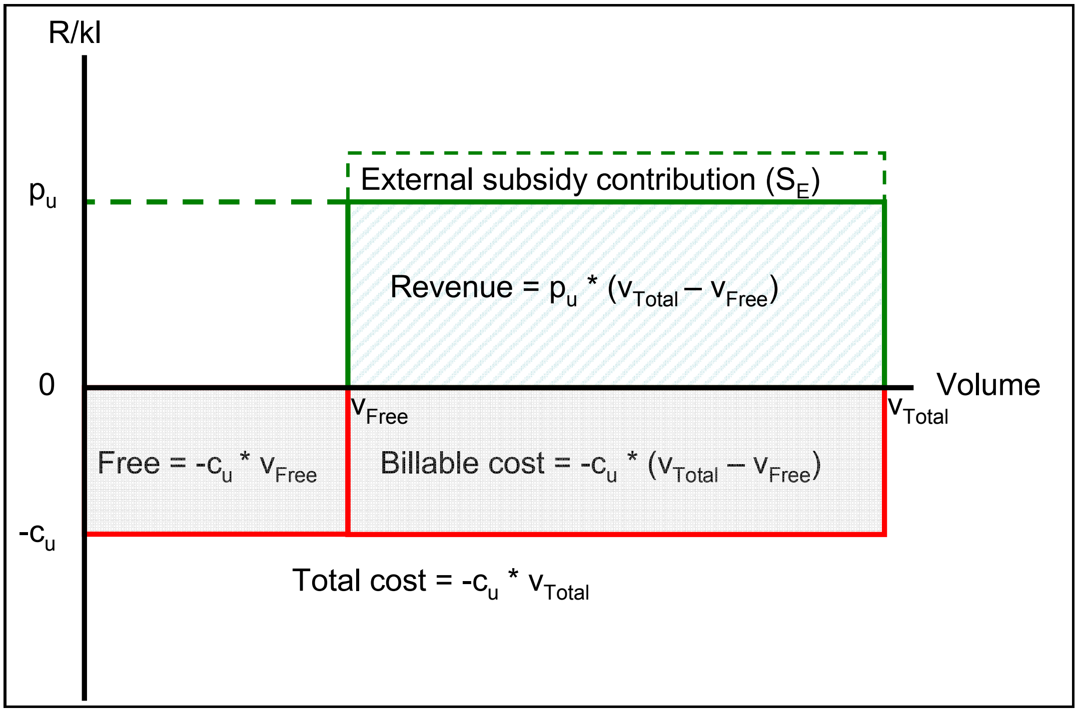

Figure 3: Schematic representation of cross-subsidisation with external subsidy

The Unit Price of water is therefore calculated as follows:

$$P_U = \frac{(C_U * V_T) - S_E}{(V_T - V_F)}$$ **Equation 3**

Where: S_E = External subsidy

Depending on whether an external subsidy is available or not, these two formulae can be used to calculate the additional cost to the paying consumer for the various strategic options being evaluated. The P_U for each one can be included in the multi-criteria decision analysis when assessing them against the quantitative criteria.

Financial sustainability of a water adaptation strategy will be dependent on the following:

- The cost of providing the water is less-than or equal-to the revenue received including any external subsidy i.e. $C_U * V_T \leq P_U * (V_T - V_F) + S_E$
- The internal subsidy (P_U-C_U) is acceptable to the paying customers
- the internal cross-subsidy and the external subsidy actually cover the free basic supply costs.
- The external subsidy (S_E) is actually paid to local government by the national government.
- Whether the subsidies will be sufficient under climate change to keep the P_U at an acceptable level for the paying customers.

In addition, the formulae are also appropriate for assessing the change in unit selling price for future climate impacts as compared with normal climate conditions. Increasing unit costs of water with time tends to be the rule, as sources close to urban areas become fully utilized and under climate change the sources will be needed sooner than originally planned. This will have the effect of increasing the unit selling price to paying customers. The ratio between these two prices can be termed the *climate impact factor for unit selling price*(CIF_{Pu}) and can expressed as:

$$CIF_{P_U} = \frac{CCP_U}{NCP_U}$$ **Equation 4**

Where: CIF_{Pu} = Climate Impact Factor for unit selling price
CCP_U = unit selling price under climate change conditions
NCP_U = unit selling price under normal climate conditions

7. Case Study: Bredasdorp

Bredasdorp is located approximately 200km south-east of Cape Town in the Overberg district. It falls in the Cape Agulhas municipal area and has an approximate population of around 13000(Afri-Coast 2003). Approximately 18% of the households have been classified as indigent i.e earning less than R 1,340 per household unit (Visser 2007b).

The specific location of Bredasdorp is 34°32′ S 20°02′ E and is located in the Western Cape province of South Africa, as illustrated by Figure 4.

Figure 4: Location map of Bredasdorp

The area experiences a Mediterranean climate with warm, dry summers and cool, wet winters. The average maximum temperature ranges from 17 to 28 ^{O}C in winter and summer respectively. Typically about sixty percent of the rain falls between April and August, as can be seen from the average monthly rainfall plot in Figure 5. The mean annual precipitation (MAP) is approximately 500mm (Visser 2002).

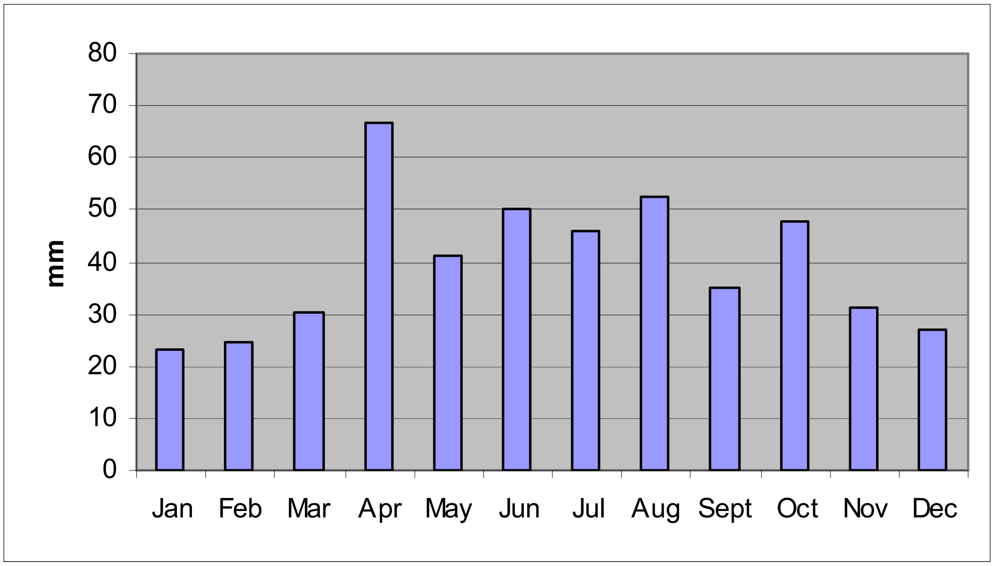

Figure 5: Average monthly rainfall for Bredasdorp (1980-2005)

Bredasdorp is located at the geological interface of the Bokkeveld Group (BG) and the Table Mountain Group (TMG). The faulted and fractured quartzites of the TMG host numerous perennial springs which feed into the wetland south of Bredasdorp. Both primary and secondary aquifers are present in the area. The secondary aquifers are more common are associated with fracture sets in the hard, consolidated sediments of the BG and TMG. Groundwater quality is usually determined by the host rock type and, in the case of Bredasdorp, the groundwater from the BG is brackish with an electric conductivity of between 150 to greater than 300 mS/m. For the TMG this value is less than 60 mS/m and hence not brackish (Visser 2002).

7.1 Data Collection

The data and information used in this study was extracted from both written reports and interviews and correspondence with practitioners with specialised knowledge of Bredasdorp and the Cape Agulhas Municipality. Specific reference is made to the following reports:

- Toens P, Visser D, Van Der Westhuizen C, Stadler W & Rasmussen J 1998. Overberg Coastal Water Resources (Volume II): A report to DWAF on the groundwater resources, current and future water requirements of the coastal strip and adjoining hinterland between the Potberg and Quoin Point. Toens & Partners. Feb 1998, T&P 980148 (Toens et al. 1998)
- Visser D 2002. Cape Agulhas Municipality: Bredasdorp - Report on the 1999-2002 groundwater investigation to augment the towns water supply. Toens & Partners. May 2002, T&P 2002278 (Visser 2002)
- Afri-Coast (Afri-Coast Engineers SA (Pty) Ltd) 2003. Water Services Development Plan 2003: Volume 1 Cape Agulhas Municipality. Overberg District Municipality. June 2003, P2402/1 (Afri-Coast 2003)

Personal communications were conducted with:

- South African Weather Service for historical weather records (SAWS 2007)
- Prof B Hewitson of CSAG for climate projections (Hewitson 2006)
- Mr S Visser - Financial manager for the Cape Agulhas Municipality (Visser 2007b)
- Mr P Groenewald – Municipal engineer for the Cape Agulhas Municipality (Groenewald 2007)
- Mr D Visser – Geohydrologist for Ninham Shands (formerly of Toens & Partners) (Visser 2007a)

7.2 Water resources

Summary of present water supply resources:
As can be seen in Table 1, the available potential equipment water annual supply is 1 257 Ml, of which 63% is dependent on groundwater.

Table 1: Summary of Bredasdorp water supply (in kl/year)

Source:(Afri-Coast 2003)

Year	*Dam*	*Spring*	*Groundwater*	*Total*
Potential	*305000*	*160000*	*792000*	*1257000*
1999	425314	148305	418185	991804
2000	388447	236354	216965	841766
2001	221746	233716	575185	1030647

Future supply options
No surface water is available for further exploitation, but three further underground aquifers were identified as potential supply options. This will increase the dependence of the town on groundwater.

Table 2: Future groundwater supply options

Source: (Toens et al. 1998):

Underground Supply option	*Estimated safe yield*	*Real cost in 2005*	*Unit cost (R/kl)*
Golf course compartment	260 000 kl/year	4 870 000	18.75
Sanddrift/Napier compartment	800 000 kl/year	12 500 000	15.65
De Duine West	720 000 kl/year	33 725 000	46.85
Total	1 780 000 kl/year	51 095 000	28.71

7.3 Water demand

The water demand growth rate until 2008 was estimated to be 2.3% based on the historical growth (Afri-Coast 2003). Based on this assumption, the annual demand in 2035 will be 1 963 ML. If we consider the demand for water against the existing supply (see Figure 9), we see that a shortfall can be expected around 2016.

7.4 Unaccounted for water – Losses

In 2002 water losses were in the order of 15% in Bredasdorp. In 1999 this was as high as 24.2%. This was reduced by implementing an improved water management programme (Afri-Coast 2003).

7.5 Water tariff structure

The tariff structure for the Cape Agulhas municipal areas is based on a rising block tariff. Table 3 shows how the tariff has been structured over the past six years. The tariffs have progressively increased over the years. The increases have been consistently applied across all blocks, ranging from 8% down to the more recent 3% increase.

Table 3: Cape Agulhas monthly water block tariff
Source (Visser 2002)

Volumetric Blocks (Kl)	Monthly Tariff (Rands per kilolitre)					
	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007	2007/2008
Basic fee per month	R 38.00	R 40.00	R 45.00	R 47.50	R 50.00	R 51.60
0 - 6	0.00	0.00	0.00	0.00	0.00	0.00
7 - 20	2.20	2.38	2.56	2.70	2.85	2.95
21 - 40	2.33	2.48	2.66	2.81	2.96	3.06
41 - 60	2.61	2.67	2.88	3.04	3.21	3.32
61 - 80	3.08	3.10	3.34	3.52	3.71	3.83
81 - 100	3.88	4.09	4.40	4.64	4.90	5.06
101 and more	5.28	6.47	6.96	7.34	7.74	7.98
Average increase		8%	8%	5%	5%	3%

It is interesting to note that the Cape Agulhas Municipality charges users a Basic Fee per month, which is in 2005/06 was R47.50. For poor and indigent households, this fee is waived and recovered from the Equitable Share funding. As can bee seen from Figure 6, 53% of all the water related revenue is received under the Basic Fee. Consumption charges make up less than half the billed revenue. The free 6kl/household per month is recovered through an internal cross-subsidy. All households, including the indigent, get charged for water used over the free 6kl per month. It is also interesting to note that two thirds of the water consumed is made up of volumes metered below 20kl per month, but this volume only yields 21% of the billed revenue.

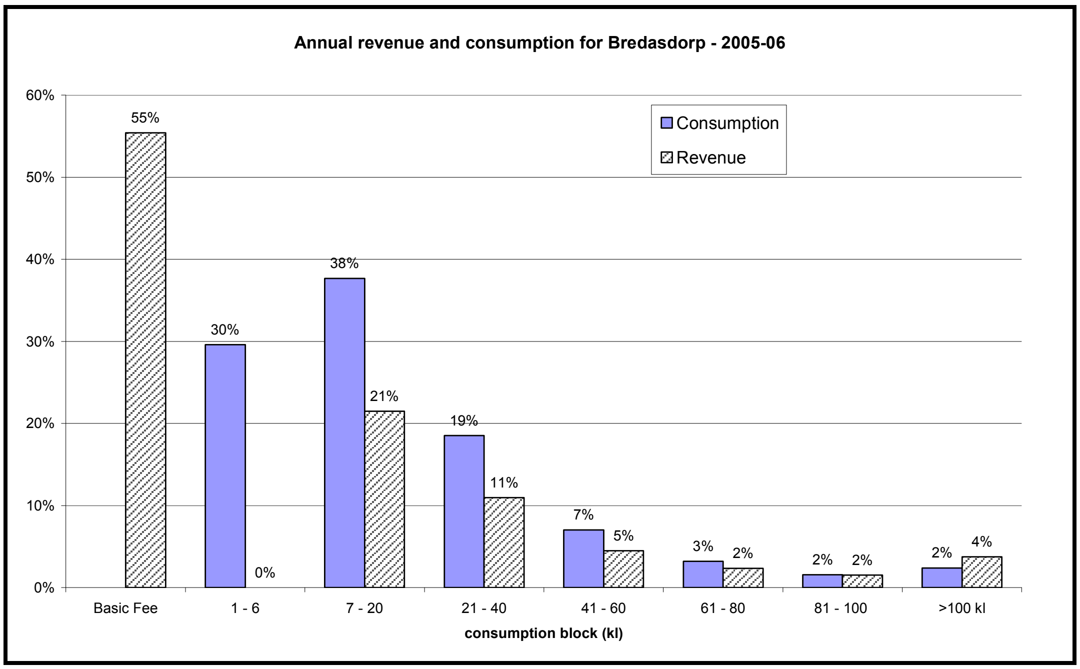

Figure 6: Annual revenue and consumption for Bredasdorp based on the consumption blocks
Source (Visser 2002; Groenewald 2007)

For the analysis of 2005 tariffs under a cross subsidising approach the consumption demand for that year has been used and not the installed capacity. The relevant consumption volumes and related financial information are provided in Table 4.

Table 4: Volumes and costs under normal climate conditions for the year 2005

Average annual volumes		Average present value finances	
Water losses at 17%	166,989 kl	Supply cost	R 4,171,638
Free basic water	206,208 kl	Unconditional external subsidy	-R 288,587
Billable supply volume	593,823 kl		
Total volume	967,020 kl	Total recovered Revenue	R 3,883,051
		2005 unit cost (C_U)	**R 4.31 /kl**
		2005 single block Tariff (P_U)	**R 6.54 /kl**

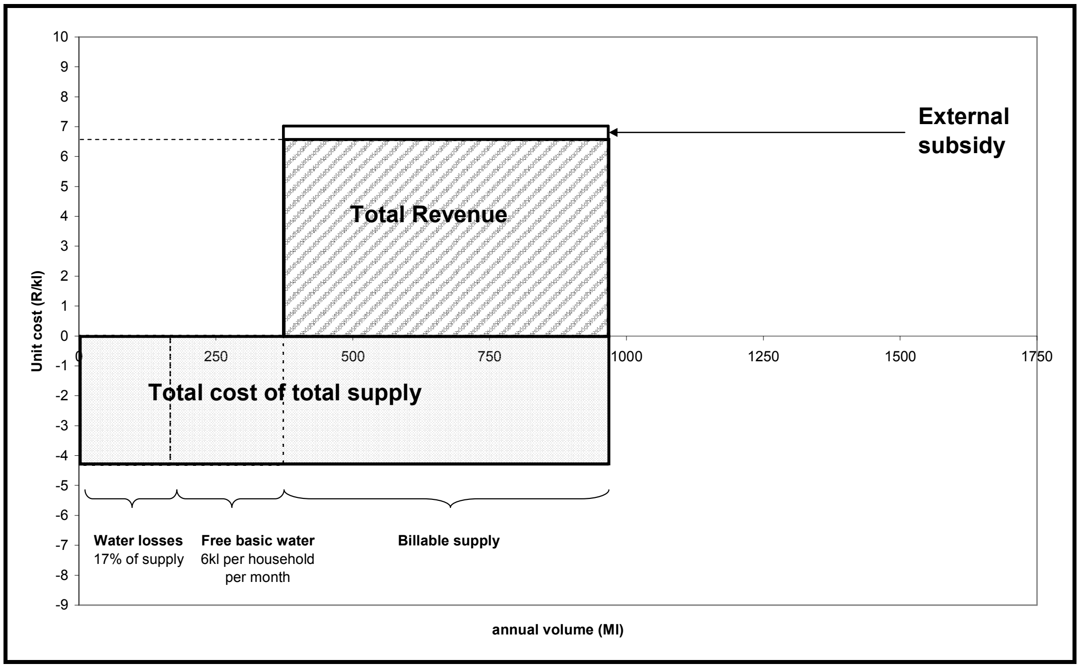

Figure 7: Cost and revenue balance for Bredasdorp under normal climate conditions for the year 2005

As can be seen from this example illustrated in the table and graph above, the single block unit tariff required to cover the free basic supply of 6kl per household (to all households) and the water losses is 52% more than the actual unit cost to supply the water. This is due mainly to the actual billable volume of water being 61% of that which is supplied. Also, the external unconditional grant effectively reduces the tariff required to cover the supply costs by 7.4%. It should be noted that in the case of Bredasdorp, the external subsidy (provided through the Equitable Share), does not precisely cover the free basic water provided to indigent households. This grant is unconditional and therefore its allocation to the various services is not consistently applied by all municipalities. In Bredasdorp, the grant is used to subsidise the monthly basic fee that is charged to each household as shown in Table 3. This subsidy is only applied to the indigent households. The balance of the cost to provide free basic water and to cover the water losses is effectively cross-subsidised through charging a unit tariff (P_U) of R6.54/kl, resulting in an increase of approximately 50% on the unit cost (C_U) of supplying the consumptive demand.

7.6 Projected annual precipitation for the Bredasdorp catchment

Most methods used to estimate future water supply resources assume that climate is stable and that mean precipitation does not change over time (Kirchner 2003). However, as can be seen by Figure 8, the long term historical mean annual precipitation ($MAP_{historical}$) for Bredasdorp is recorded as

500mm (Ninham Shand 1998), but the historic mean annual precipitation for the 20 year period 1980-1999 ($MAP_{1980-1999}$) is 476 mm per annum, which would indicate some drying already.

In the Western Cape region, precipitation is forced by large scale circulation but is significantly modulated by the topography. Future projections for winter are for continued winter drying in the west in both lowland and mountain regions. The winter season is likely to shorten, while for summer it will be characterised with drying in the west, with slight wetting in the north and east (Hewitson & Johnston 2006).

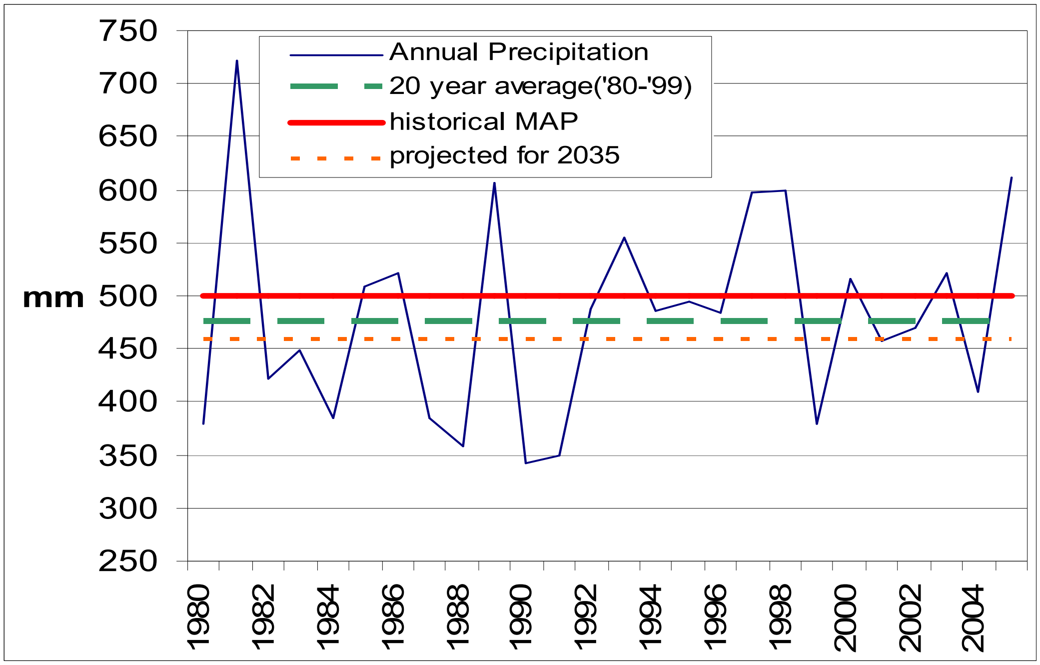

Figure 8: Annual precipitation for Bredasdorp

For the Bredasdorp catchment, the projected precipitation for 2035 decreases by 8% as compared with the $MAP_{1980-1999}$ (after Hewitson & Johnston 2006). Hydrological and engineering planning usually get done using the $MAP_{historical}$. In future therefore, projects for Bredasdorp with a lifespan of 30 years should be planned for using 8% less precipitation than the $MAP_{1980-1999}$.

7.7 Estimated future available water

Based on the climate induced reduction in rainfall of 8% from 1990 to 2035, the impact on available water resources is estimated. First the groundwater recharge is considered for the same period, followed by the impact on surface run-off into the dam. It should be noted that only the mean annual precipitation has been considered in these calculation. No assessment has been made which included the changes in rainfall intensity and its related impact on both run-off and recharge. A detailed historic data set of daily rainfall and daily run-off and recharge values would be needed for each abstraction site to establish the relationship. This information is not currently available.

Groundwater recharge:

Various studies of Bredasdorp and the Table Mountain Group[6] (TMG) aquifers provide varying information on the recharge of the aquifer. Toens et al (1998) obtained an average recharge of 19.6% from various reports citing other locations (See **Table 5**).

This is supported by the recharge calculation of 17.4% at neighbouring Struisbaai using cumulative rainfall collectors (Weaver & Talma 2005). However Duah et al. (2006) have estimated that recharge for TMG aquifer ranges from 0.28% to 12.6 % with an average recharge of 30mm/year.

[6] The Table Mountain Group (TMG) consists of predominately of quartzitic sandstones which, on the whole are highly fractured and jointed. (Toens et al. 1998)

Table 5: Average annual recharge estimates for sedimentary rock aquifers in mountainous catchments used for TMG areas
Source (Toens et al. 1998)

Location	MAP (mm/yr)	Recharge		Reference
		(mm/year)	(% of MAP)	
Pretoria/Rietondale	670	54-160	8-24	Bredenkamp et al., 1995
De Hoek	1852	20-290	1-16	Connelly et al., 1989
Rustenberg	749	114	15	Bredenkamp et al., 1995
Zachariashoek	1061	319	30	Bredenkamp et al., 1995
Olifant/Doring River Basin	365	102	28	Hay, 1997
Klein Karoo			10-30	Kotze, 1995
Average			19.6	Toens et al. 1998

In the absence of historical data sets of recharge for this catchment, the Beekman (1996) expression has been used to calculate the percentage change in recharge due to a change in MAP by 2035.

$$\text{Recharge} = 148 * \ln(\text{MAP}) - 880 \qquad \textbf{Equation 5}$$

Applying this equation to the $MAP_{1980\text{-}1999}$ of 476mm results in a recharge of 32.5mm/year. If reduced by 8% to 440mm, recharge would be 20.8mm/year. This would equate to a 36% reduction in groundwater recharge. Therefore recharge is reduced by a greater percentage than the reduction in rainfall and the groundwater storage would be thus accordingly affected.

The *Climate Impact Factor* (CIF) for the period 1990-2035 would therefore be -0.36.

i.e., $FS_{recharge} = CS_{recharge} * (1 - 0.36)$

This would mean that groundwater abstraction would also need to be reduced by 36% so as not to dewater the aquifer.

Surface run-off:

Unfortunately, historical run-off data is not available for the Bredasdorp catchment. However, we can assume that for a projected 8% reduction on a $MAP_{1980\text{-}1999}$ of 476mm by 2035 a reduction in run-off would be in order of 50-30%. Therefore, for the purposes of this study we have chosen a conservative reduction of 30%, i.e the CIF for the period 1990-2035 would be -0.30.

Therefore, $FS_{runoff} = CS_{runoff} * (1 - 0.30)$

In order to accurately calculate the run-off for future water resources studies for Bredasdorp, a monitoring programme should be put in place to collect this data in order to calculate the historical run-off trends.

7.8 Impact on water supply

Given that the available water resources are likely to be reduced by 30-36% by 2035, the loss water from available sources needs to be factored into the water balance. In order to maintain the current levels of available supply (1257 Ml/annum) till 2035, an additional 434Ml/year (marked A in Figure 9) will be needed under projected climate change conditions, as compared with the supply under normal climate conditions. This equates to 35% of the current available supply under normal conditions (i.e. A/total available supply).

In order to meet the projected water consumption (1964 Ml/annum) in 2035, this climate induced water supply decrease will need to accommodated. This climate induced shortfall is also 61% of the unmet demand (707 Ml/annum) for 2035 under normal conditions (i.e. A/B). This means that by 2035, planners will need to plan for 61% more water than they would have under normal climate conditions.

Table 6: Supply and demand under climate change

Details	Volume (kl/annum)
Projected water demand for 2035	1,963,678
Current available supply	1,257,000
Shortfall by 2035 under normal climate conditions (B)	706,678
Future available supply under climate change	609,280
Reduction in supply due to climate change (A)	434,220
Total shortfall against 2035 demand under climate change (A+B)	1,140,898

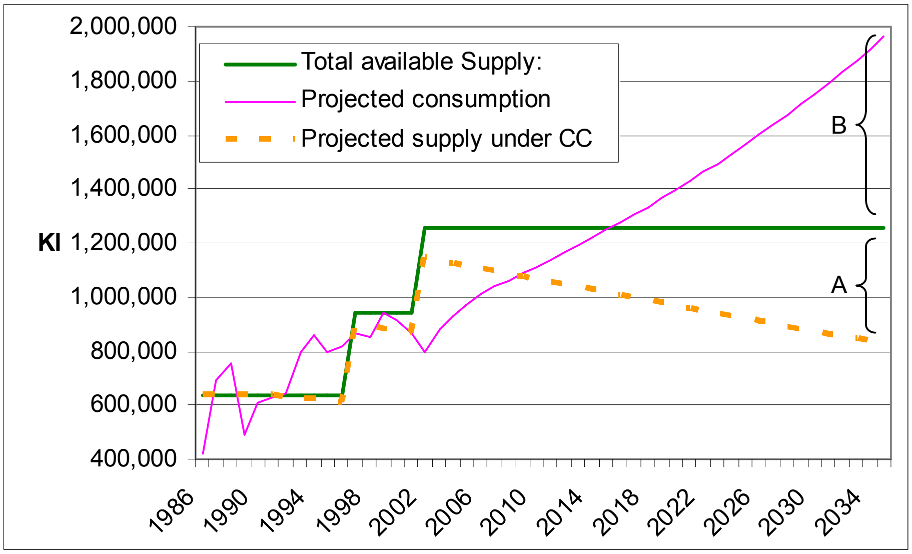

Figure 9: Water supply and demand graph under historical and climate change conditions for Bredasdorp

Further, under normal climate conditions, the current water supply system experiences a shortfall in meeting the projected demand by 2016. The projected climate change impacts will induce this shortfall before 2009, almost eight years earlier. This will have infrastructural and financial implications and is discussed later.

In order to meet the project water demand and the reduction in available supplies due to climate change, the investment costs are in the order of approximately **4¼ times** the capital expenditure under normal climate conditions. In other words for this case study, a projected decrease of 8% MAP from 1990 to 2035 will result in a 329% increase in present value investment cost (Mukheibir 2007).

7.9 Impact of climate change on equitable access and affordability

In order to compare the base year (2005) tariffs with those of the future, the average volumes and costs for the period 2006-2035 were calculated. For this analysis, the levelised cost equation has been used to calculate the average unit cost (C_U) for the period 2006-2035. In this case the consumption demand has been used and not the installed capacity. The relevant consumption volumes and related financial information are provided in Table 7. The demand was estimated to grow at 2.3% per annum over this period.

Table 7: Average annual volumes and present value (2005) costs for normal climate conditions for the period 2006-2035

Average annual volumes		**Average present value finances**	
Water losses at 17%	244,738 kl	Supply cost	R 6,210,466
Free basic water	299,059 kl	Unconditional external subsidy	-R 418,532
Billable supply volume	895,840 kl		
Total volume	1,439,637 kl	Total recovered Revenue	R 5,791,934
		Average unit cost (C_U)	**R 4.31 /kl**
		Average Tariff (P_U)	**R 6.47 /kl**

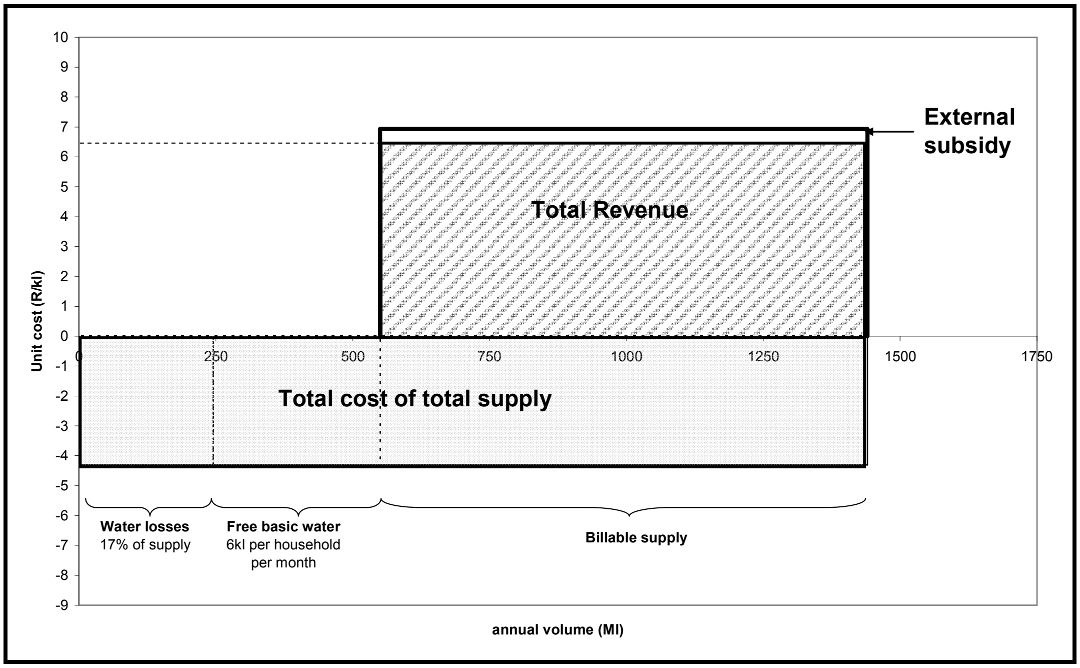

Figure 10: Average cost and revenue balance for Bredasdorp under normal climate conditions for the period 2006 – 2035

When considering the impact of climate change on the system for the same period, it can be seen from Table 8 that the water demand has remained the same. Only the cost of supply has increased due to the increase in the cost of securing further water sources which are further away from the town. This has the effect of increasing the average unit cost of supply (C_U) from R 4.31/kl to R5.34/kl – an increase of 24%. This in turn results in an increase of the tariff (P_U) by 25%.

Table 8: Average annual volumes and present value (2005) costs for Climate Change conditions for the period 2006-2035

Average annual volumes		**Average present value finances**	
Water losses at 17%	244,738 kl	Supply cost	R 7,684,097
Free basic water	299,059 kl	Unconditional external subsidy	-R 418,559
Billable supply volume	895,840 kl		
Total volume	1,439,637 kl	Total recovered Revenue	R 7,265,538
		Average unit cost (C_U)	**R 5.34 /kl**
		Average Tariff (P_U)	**R 8.11 /kl**

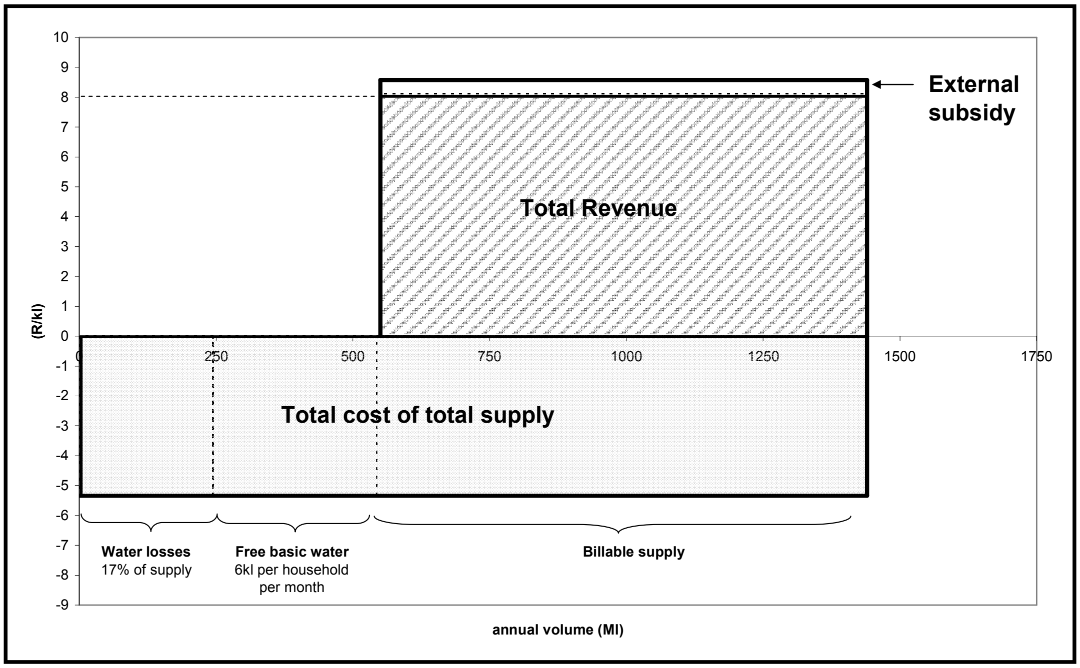

Figure 11: Average cost and revenue balance for Bredasdorp under climate change conditions for the period 2006 – 2035

Therefore the unit selling price will need to increase by an average of 25% over the period 2006 to 2035 in order to accommodate the climate induced water scarcity by 2035. If this price increase was implemented in a linear fashion over the period, it would equate to a price increase on the normal climate scenario of 50% in 2035, as illustrated in Figure 12.

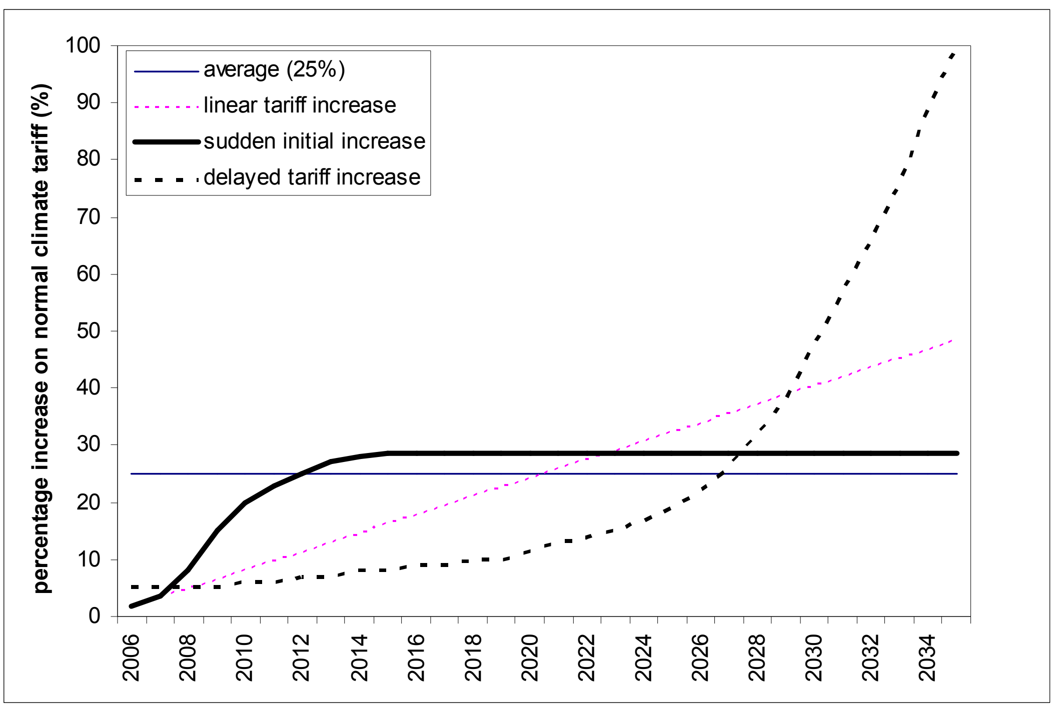

Figure 12: Possible climate induced tariff increases against normal climate tariff

Another option would be to apply a sudden initial increase and then stabilise the percentage increase for the rest of the period. This would have the same impact as reducing consumption through tariff mechanisms and may result in reduced demand thereby effectively delaying the capital investment and reducing the tariff. A delayed price increase could also be an option if the impact of climate change is uncertain, and political buy-in is not possible. However the steep tariff increases towards the end of the period would make the financial sustainability of the system unworkable with an 100% increase in the tariff by 2035 relative to the normal climate case.

Therefore for comparative purposes the *average* CIF_{Pu} ratio for the period 2006-2035 is +0.2 and is derived using the following formula:

$$\text{Average CIF}_{P_U(2006-2035)} = \frac{CCP_{U(average)}}{NCP_{U(average)}} = +0.25$$ **Equation 6**

By using the linear increase approach, where the tariff increase by 2035 would be 50% above the normal climate price increase, it could said that the Climate Impact Factor (CIF) for the tariff (P_U) is 0.5. The linear decrease in rainfall for this 30 year period (2005-2035) is 5.33%[7]. Therefore the CIF_{Pu} for the change in price over this period can be expressed as:

$$CIF_{P_U(2005-2035)} = \frac{CCP_{U(2035)}}{NCP_{U(2035)}} = +0.5$$ Equation 7

[7] The projected decrease in rainfall for 1990 to 2035 was estimated as 8%, therefore for 2005 to 2035 is would be 5.33%, using a linear extrapolation.

8. Conclusion

Using the economic principle that as the scarcity of a resource increases, price adjustments will alter the demand to be balanced with supply. This is not necessarily the case with water. As discussed, water demand is an inelastic commodity for the lower end user and also the correction of prices does not always address the issue of equity and access. The price may be increased to cover increased costs of supply due to both increased demand through population growth and climate induced shortages.

There is no one correct method for calculating the unit tariff for water supply system, but in this paper the discounted levelised cost (DLC) is proposed and has been used. Using this method, the future tariff under normal climate conditions can be compared with that for under climate change conditions.

In order to ensure a basic level of water access the poor, most countries have adopted some form of free water or subsidised delivery to the poor. This is mostly accommodated through a cross-subsidy system within the municipal water tariff structure, using the rising block tariff method. In some instances an external subsidy is also provided by the national government to cover this social benefit. In order to accommodate this as simple equation has been proposed where the unit tariff takes these amounts into consideration.

The impact of project climate change on the future unit tariff can be expressed using the Climate Impact Factor ratio, where the tariff under climate change conditions is divided by the tariff established under normal climate conditions for specific period. This is useful for comparison purposes or when deciding which water supply system is potentially financial unsustainable.

This case study reinforces the hypothesis that climate change is an economic issue and not primarily an environmental one. It is clear from the results of this analysis that an average tariff increase of approximately 25% due to an 8% reduction in projected rainfall by 2035 is a likely scenario. The introduction of such a tariff increase would not be sustainable over the longer term. Considering that for the past 5 years, the tariff increases have been in the region of 3-8%, such a large average tariff increase over the period would likely be met with political resistance.

The price increase would be on top of any inflationary increases. This would seem an unrealistic burden for consumers in a small town to be able to absorb. The number of high end users in small towns are not as prevalent as in larger urban centres. Therefore an average increase such as 25% over the period would need to borne by the middle and low end users, since they make up the majority of the users (66%), this would unduly burden them. Since water is basic need, other sacrifices would need to be made in the household budget (Cairncross & Kinnear 1992).

A policy intervention is required if these small water systems are to remain financially viable and at the same time meet their social obligations of providing a basic water service for free. Further allocation through the external subsidy from National government could be motivated for on the basis of projected climate impacts. International adaptation funding is not yet sophisticated enough to accommodate numerous requests from small towns around the world, but at a national level programmatic adaptation funding could be leveraged for this purpose.

It is true that large uncertainties still plague quantitative assessments of climate change impacts and water resource management, yet what is known for certain is that the climate is changing, that this will have an effect on water resources. Therefore increased efforts will be needed to plan and manage water supplies in future, through increased monitoring and understanding of the interrelationships between climate change and water availability. The methodology illustrated in this paper will also assist municipal planners to evaluate these financial impacts due to climate change and develop appropriate strategies to ensure the sustainability and affordability of long term water supplies.

References

Afri-Coast (Afri-Coast Engineers SA (Pty) Ltd) 2003. Water Services Development Plan 2003: Volume 1 Cape Agulhas Municipality. Overberg District Municipality. June 2003, P2402/1

Baumann, D, Boland, J & Hanemann, W M 1998. *Urban water demand management and planning*. New York, McGraw-Hill Inc,

Beekman, H, Gieske, A S M & Selaolo, E T 1996. GRES: Groundwater recharge studies in Botswana 1987-1996. *Journal of Earth Science.* III 1-17.

Braune, E 1996. Chapter 6.5 Groundwater resources. L Y Shackleton, S J Lennon and G R Tosen (Eds). *Global Climate Change and South Africa*. Johannesburg, Environmental Scientific Association**:** 152pp.

Budds, J & McGranahan, G 2003. Are the debates on water privatization missing the point? Experiences from Africa, Asia and Latin America. *Environment & Urbanisation.* 15 (2), 87-113. October 2003.

Cairncross, S & Kinnear, J 1992. Elasticity of demand for water in Khartoum, Sudan. *Social Science and Medicine.* 34 (2), 183-189.

Cave, L, Beekman, H & Weaver, J 2003. Impact of Climate Change on Groundwater Recharge Estimation. Y Xu and H Beekman (Eds). *Groundwater Recharge Estimation in Southern Africa*. Paris, UNESCO ISBN 92-9220-000-3.

CCT (City of Cape Town) 2007. Water tariffs. 12/09/07, http://www.capetown.gov.za/tariffs/

Deedat, H 2002. Viva prepaids, viva! Assessing new technology for cost recovery in the rural Northern Cape. D McDonald and J Pape (Eds). *Cost recovery and the crisis of service delivery in South Africa*. Cape Town, Human Sciences Research Council**:** 143 -156.

Duah, A, Xu, Y & Wu, Y 2006. Spatial recharge of the Table Mountain Group aquifer in South Africa, the case of the Kammanassie mountain region - Paper 194-4. *The Spatial and Temporal Variability of Ground Water Recharge*. Philadelphia, Geological Society of America. 38**:** 469.

DWAF (Department of Water Affairs and Forestry) 1994. Water supply and sanitation policy - White Paper. Water - an indivisible national asset. Cape Town. November 1994,

Eberhard, R 1999a. Supply pricing of urban water in South Africa: Volume 1. WRC Report No 678/1/99. Pretoria, Water Research Commission.

Eberhard, R 1999b. Supply pricing of urban water in South Africa: Volume 2. WRC Report No 678/2/99. Pretoria, Water Research Commission.

Eberhard, R 2001. Urban water pricing: a critical-realist approach. PhD thesis. School for Oriental and African Studies. London, University of London**:** 275.

Everatt, D, Ravenscroft, P, Still, D, Smith, M, Dube, N, McLeod, N, Gibson, J, Illing, C, Hazelton, D, Khanyi, J, Mbanjwa, P & Jennings, R 2007. Summative evaluation of Masibambane II: Project Evaluation Report. DWAF. July 2007,

Falkenmark, M, Lundquist, J & Widstrand, C 1989. Macro-scale water scarcity requirement scale approaches: Aspects of vulnerability in semi-arid development. *Natural Resources.* 13 (4), 258-267.

Frederick, K 1998. Principles and concepts for water resources planning under climate change uncertainty. *Water Resources Update.* (112: Global change and water resource management), 41-46. Summer 1998.

Gagnon-Lebrun, F & Agrawala, S 2006. Progress on adaptation to climate change in developed countries: An analysis of broad trends. ENV/EPOC/GSP(2006)1/Final. Paris, OECD. May 2006,

Groenewald, P 2007. Personal communication. Cape Agulhas Municipality. 1 March 2007.

Hewitson, B 2006. Personal communication. Climate Systems Analysis Group, University of Cape Town. 12/11/2006.

Hewitson, B & Crane, R 2006. Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. *International Journal of Climatology.* 26 (10), 1315-1337.

Hewitson, B & Johnston, P 2006. Climate change projections 2035. *CCRAS 2006.*

Hewitson, B, Tadross, M & Jack, C 2005. Scenarios from the University of Cape Town. R E Schulze (Ed). *Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation*. Pretoria, South Africa, Water Research Commission. WRC Report No. 1430/1/05.**:** 39 -56.

Howard, G & Bartram, J 2003. Domestic water quality, service level and health. WHO/SDE/WSH/03.02. Geneva, World Health Organisation.

HSRC (Human Sciences Research Council) 2004. Poverty in South Africa. 26 July 2004, Fact sheet No. 1

IPCC (Intergovernmental Panel on Climate Change) 2007. Summary for policymakers: Climate Change 2007: The Physical Science Basis. IPCC WG1 Fourth Assessment Report. Geneva, Intergovernmental Panel on Climate Change. 1 Feb 2007, http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_SPM.pdf (Accessed in Feb 2007).

Jo'burg (City of Johannesburg) 2007. Water tariffs - 2007. 12/09/07, http://www.joburg-archive.co.za/2007/pdfs/tariffs_2007.pdf

Joburg (City of Johannesburg) 2007. Water tariffs - 2007. 12/09/07, http://www.joburg-archive.co.za/2007/pdfs/tariffs_2007.pdf

Jones, R, Kay, A & Bell, V 2007. Towards an end to end uncertainty analysis, UK MetOffice**:** Presentation at EGS Seminar series.

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. www.sanbi.org/countrystudy/main.htm (Accessed in Dec 2004).

Kirchner, J 2003. Changing Rainfall - Changing Recharge? Y Xu and H Beekman (Eds). *Groundwater Recharge Estimation in Southern Africa*. Paris, UNESCO

Loftus, A 2004. "Free Water" as commodity: the paradoxes of Durban's water service transformations. D McDonald and G Reuters (Eds). *The age of commodity: water privatization in South Africa*. London, Earthscan

Major, D 1998. Climate change and water resources: the role of risk managment methods. *Water Resources Update*. 112 47-50.

Martins, R & Fortunato, A 2007. Residential water demand under block rates - a Portuguese case study. *Water Policy*. 9 (2), 217-230.

Mehta, L & Ntshona, Z 2004. Dancing to two tunes? Rights and market-based approaches in South Africa's water domain. Brighton, Institute of Development Studies.

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. Stellenbosch, CSIR. www.erc.uct.ac.za/publications/wcape_climate_change_impacts_11.pdf (Accessed in Nov 2005). Report No. ENV-S-C 2005-073

Mosdell, T & Leatt, A 2005. On Tap: A review of the Free Basic Water Policy. A Leatt and S Rosa (Eds). *Towards a Means to Live: Targeting poverty alleviation to make children's rights real*. Cape Town, Children's Institute, University of Cape Town ISBN 0-7992-9997-6.

Mukheibir, P 2007. The impact of climate change on small municipal water resource management: The case of Bredasdorp, South Africa. Energy Research Centre, University of Cape Town. May 2007,

Murray, R 2006. Personal communication. Groundwater Africa. 6 November 2006.

Ninham Shand (Ninham Shand Consulting Engineers) 1998. Eastern Overberg Coastal Water Resources (Volume III): A report for DWAF on the surface water supply options. Department of Water Affairs and Forestry. April 1998,

Pape, J 2002. Looking for alternatives to cost recovery. D McDonald and J Pape (Eds). *Cost recovery and the crisis of service delivery in South Africa*. Cape Town, Human Sciences Research Council**:** 183-193.

Pape, J & McDonald, D 2002. Introduction. D McDonald and J Pape (Eds). *Cost recovery and the crisis of service delivery in South Africa*. Cape Town, Human Sciences Research Council**:** 1-16.

Parnell, S, Midwinter, A & Zollner, E 1998. Providing affordable basic services: Tariff modelling and targetting subsidies - Towards an indigent policy for local government. Pretoria, DCD and DFID.

PDG (Palmer Development Group) 2000. Guidelines for setting water tariffs. WRC Report 992/1/00. Water Research Commission.

PDG (Palmer Development Group) 2001. Free Basic Water: Implementation Strategy. DWAF. May 2001, Version 1

Ravenscroft, P 2007. Personal communication. Water Tariffs for Prince Albert Municipality. 23/0/02007.

RSA (Republic of South Africa) 1997. Water Services Act (Act 108 of 1997). Department of Water Affairs and Forestry.

RSA (Republic of South Africa) 1998. The National Water Act (Act 36 of 1998). Pretoria, Department of Water Affairs and Forestry.

Rural Support Services, Maluti Water & Community Engineering Services & MATTCOMM 1997. Evaluation of the Community Water Supply Services Programme in the Eastern Cape. DWAF. November 1997, SAWS (South African Weather Service) 2007. Personal communication. Historical weather data for station [0003020 4] - Cape Agulhas. 22/03/07.

Schelling, T 2007. Climate change: the uncertainties, the certainties, and what they imply about action. *Economists' Voice.* July 2007.

Schreiner, B & van Koppen, B 2002. Catchment Management Agencies for poverty eradication in South Africa. *Physics and Chemistry of the Earth.* 27 969-976.

Schulze, R E 2005. Setting the Scene: The Current Hydroclimatic "Landscape" in Southern Africa. R E Schulze (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 6, pp 83 - 94.

Tadross, M & Hewitson, B 2007. Chapter 5: Future climate change scenarios for southern Africa. *in Midgley GF, Chapman RA, Mukheibir P, Tadross M, Hewitson B, Wand S, Schulze RE, Lumsden T, Horan M, Warburton M, Kgope B, Mantlana B, Knowles A, Abayomi A, Ziervogel G, Cullis R and Theron A Assessing impacts, vulnerability and adaptation in key South African sectors: A background study for the Long Term Mitigation Scenarios process*, Energy Research Centre

Toens, P D, Visser, D, Van Der Westhuizen, C R, Stadler, W & Rasmussen, J M 1998. Overberg Coastal Water Resources (Volume II): A report to DWAF on the groundwater resources, current and future water requirements of the coastal strip and adjoining hinterland between the Potberg and Quoin Point. Toens & Partners. Feb 1998, T&P 980148

van Aardt, C 2007. Population and household projections for South Africa by province and by population group: 2001-2021. Research Report No. 364. UNISA.

Visser, D 2002. Cape Agulhas Municipality: Bredasdorp - Report on the 1999-2002 groundwater investigation to augment the towns water supply. Toens & Partners. May 2002, T&P 2002278

Visser, D 2007a. Personal communication. SRK Consulting.

Visser, S 2007b. Personal communication. Financial manager - Cape Agulhas Municipality. 27/07/2007.

Warford, J 1997. Marginal Opportunity Cost Pricing for Municipal Water Supply. *Special Papers*. Ottawa, International Development Research Centre

Weaver, J & Talma, A 2005. Cumulative rainfall collectors - A tool for assessing groundwater recharge. *WaterSA*. 31 (3), 283-290. July 2005.

Wellman, P 1999. Sustainability of South Africa's 'water miracle' questioned. *African News Service*. 9 May 1999. http://www.africanwater.org/SAWSProblems.html

Whelan, P 2004. The local government equitable share. Occasional Papers. Cape Town, IDASA. February 2004,

Woodford, A 2007. Personal communication. Department of Water Affairs and Forestry. 8 February 2007.