The impact of climate change on small municipal water resource management
•
The case of Bredasdorp, South Africa

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Abstract

In response to the recent reports on climate change impacts, especially on the water supply sector, a methodology that incorporates climate change impacts in to water resource planning at small municipal level is proposed. The introduction of the term Climate Impact Factor helps to quantify the extend to which future drying will have on local water resources. The illustrative example reveals that a 30% reduction of available water by 2035 will be caused by a projected 8% reduction in precipitation. The reduction in available water resources due to climate change leads to in an increase of future supply cost of 3.5 times that under historical climate conditions. It is illustrated however, that this can to some extend be mitigated through demand side management strategies.

KEY WORDS:

climate impact factor, climate change, groundwater recharge, adaptation, water resource management

Acknowledgements

Publication

A copy of this paper was sent to the journal: "Water Research" for publication in May 2007. Still awaiting approval

Words: 8029

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1.   Introduction and background

When faced with actual or impending water shortages, water authorities throughout the world tend to estimate future requirements by extrapolating past trends in consumption, adjusted for expected increase in population and industrial growth. Water planning and management relies on the assumption that the future climate will be the same as the historical trends and hence all our water-supply systems are designed with this assumption in mind. Dams are sized using available information on existing flows in rivers and historical rainfall figures.

The most detailed and sophisticated planning methods in use in the urban water sector treat weather as an uncertain-but-stationary process. In other words, climate is assumed to be fixed. But climate does change – it has in the past and it will in the future. Many uncertainties remain about the timing, direction and extent of the climatic changes, as well as the implications. The most important effect of climate change for water supply systems is the increase in uncertainty, which greatly complicates rational water resource planning (Gleick 1998).

Long-term demand forecasts have generally used simplistic methods which ignore all influences on water use except population, and in most cases have overstated future water use. Water supply, while recognised as uncertain in the short term, has been assumed stationary in the long term. Future supply is expected to be the same on average as current supply. Supply works are designed for drought intervals of 50 years or more. There is considerable margin for error in the early years of a new facility. Overcapacity, often invisible to the public, has long been preferred to the possibility of undercapacity with its associated political risks. Least cost planning which is so familiar to electric utilities, is hardly heard of in the water industry. However in the latter half of the 20th century, difficulties in meeting planned supply targets were experienced due to diminishing numbers of untapped resources, competition with other users, or constraints imposed by environmental policy. As a result, sharp price increases lowered water use levels much below forecasts, which has led to a re-examination of forecasting practices (Boland 1998).

South Africa is an arid country and therefore water is a limiting resource for development and a change in available water supply could have major implications in 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 production and evaporation rates. Current modelling scenarios suggest that there will be significant climate change impacts in South Africa, even given a business-as-usual global emissions scenario. Climate change is expected to alter the present hydrological resources in southern Africa and increase the need for adaptation to climate variability of future water resources. It has been projected that by mid-century annual average river run-off and water availability will decrease by 10-30% in some dry regions at the mid-latitudes and dry tropics (IPCC 2007).

During the past 20 years, most of Africa has experienced extensive droughts, the recent ones being attributed to El Niño. If the occurrence of drought becomes more frequent, the impact on water resources would be significant. Based on these projections, the most severe impacts are likely to occur along the western part of South Africa. The South African Climate Change Response Strategy (DEAT 2004) states that South Africa's rainfall is already variable in spatial distribution and unpredictable, both within and between years. Much of the country is arid or semi-arid and subject to droughts and a reduction in the amount or reliability of rainfall would exacerbate the already serious lack of surface and groundwater. Therefore it is necessary that the management of water resources at local level needs to be closely integrated into the development plans of local governments.

Climate change models are not predictions of the future, but are rather projections of how the future global and local climates may evolve and how these scenarios could affect such things as local water resources. It is therefore important that planners, investors and decision-makers take into account the potential effects of climate change on the water resources and adopt strategies that ensure the long-term sustainability of the water supplies and the local resources.

In this paper we discuss both climate change and climate variability, so it is important to clarify the distinction between the two. Climate variability can be thought of as the way climatic variables (such as temperature and precipitation) depart from some average state, either above or below the average value. Although daily weather data depart from the climatic mean, the climate is considered to be stable if the long-term average does not significantly change. On the other hand, climate change can

be defined as a trend in one or more climatic variables characterized by a fairly smooth continuous increase or decrease of the average value during the period of record.[1]

There is little in the way of concrete examples of adaptation and more specifically the costs of adaptation in the municipal water sector. This paper firstly evaluates the climate impacts for a specific municipal area, Bredasdorp, with regard to its surface and groundwater resources. The additional water supply required to meet the projected future demand in 2035 is calculated and the related cost implications are discussed. This process outlines a methodology that can be followed by other municipal engineers and planners when planning future water management strategies.

2. Overview of current South African water sector

2.1 Water is a scarce resource

South Africa is a water-stressed country with an average annual rainfall of 500mm (60% of the world average). Only a narrow region along the south-eastern coastline receives good rainfall, while 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; 21% receives less than 200mm per year (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. This feature 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). Rainfall variability also has implications for water-related disasters such as floods and droughts.

Many urban and industrial developments, as well as some dense rural settlements, have been established in remote locations at a distance from adequate reliable water sources. As a result, the requirements for water already far exceed the natural availability of water in several river basins, and therefore large-scale transfers of water across catchments have been implemented, like the Lesotho Highlands Water Scheme. 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 (DWAF 1994).

The total average annual available water in South Africa is $49\ 200\text{x}10^6\text{m}^3$ (this includes the inflow from Lesotho and Swaziland). Of this, $13\ 911\text{x}10^6\text{m}^3$ can be economically harnessed as usable yield (this includes usable return flow).

Table 1: Available yield in year 2000

Source: DWAF (2002a)

Source	Million m^3/a
Surface water	10 928
Groundwater	1 042
Usable return flow	1 941
TOTAL	**13 911**

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[1] The IPCC defines climate variability as "variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability)". In contrast, climate change "refers to the statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use." (IPCC 2001).

The total amount of water required for 2000 was 13 280x10^{6}m^3, a figure close to availability limits (DWAF 2002a). Agriculture is by far the largest user of water, as shown in Figure 1, while urban and rural domestic requirements make up 25% and 4% respectively.
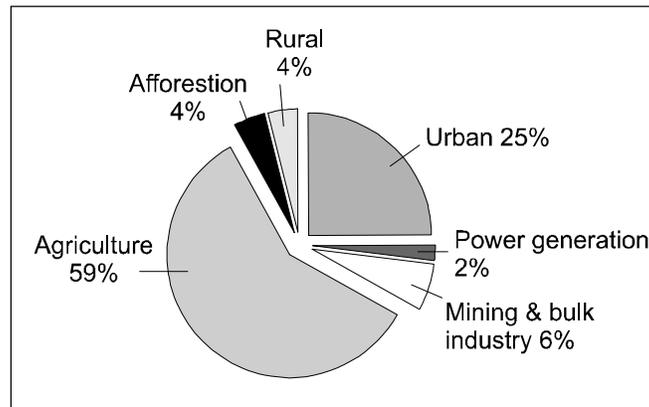
Figure 1: Water demand for 2000 per sector
Source: (DWAF 2002a)

2.2 Equitable access to water

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.

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'.

The amount paid for water is usually a very small fraction of the household's disposable income. However, social or political reasons may require that pricing of water for low consumers should be subsidized. A commonly observed approach in developing countries is to make use of a rising block tariff, where the first tier of 6-8 kl/person/month is subsidised or free and the following tiers have increasingly higher rates (Warford 1997). In South Africa, most municipalities offer this rising block tariff scheme to all consumers.

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 after a severe cholera epidemic in 2000 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.

Beyond scarcity and access, water security is also about risk and vulnerability[2]. 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.

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[2] 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).

3. Projected climate change scenarios for South Africa

According to the IPCC (IPCC 2001), global surface temperature is estimated to have increased by 0.6°C since the late nineteenth century, with the 1990s being the warmest decade on the instrumental record. Most of the 0.6°C increase occurred between 1910 and 1945 and since 1976. Mean daily surface minimum temperatures appear to be increasing at a faster rate than maximum temperatures (0.2°/decade versus 0.1°C/decade). Superimposed on these changes are seasonal, annual and inter-annual variabilities, producing a complex climate variability and change signal.

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 (Midgley et al. 2005):

a. *Natural variability*: 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.

b. *Future emissions*: Much of the projected change is dependent on how society responds to reducing emission of greenhouse gases.

c. *Uncertainty in the understanding of the climate system*: Current understanding of the regional understanding of the regional dynamics of the climate system of the African sub-continent is limited.

d. *Downscaling*: This is the development of regional scale projections of change from the global models, which introduce an uncertainty that limits the confidence in the magnitude of the project change, although the pattern of change can be interpreted with greater certainty.

Uncertainty associated with the global and downscaled regional circulation models (GCM and RCM) estimates of future changes in rainfall is much higher than with changes in temperature, since precipitation is dependent on a larger number of climatic variables.

The projected impact for southern Africa can best be summarised as follows (Hewitson & Crane 2006):

1. The downscaled rainfall scenarios project a general drying in most seasons in the SW parts of the Western Cape, particularly during MAM and JJA and in line with a shorter winter rainfall season. In summer, and autumn the northern and eastern regions of the country are likely to become wetter, especially over regions of steep topography around the escarpment and Drakensberg.

2. The projected changes in the intensity and frequency of precipitation events are less certain.

3. Temperature is likely to continue to increase across the country, with the greatest increases towards the interior, and strongest increase in the daily minimum. This is likely to further reduce soil moisture content in the dry regions.

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

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).

In a recent review of the current hydroclimatic "landscape" in southern Africa, Schulze motivates that there is a highly variable and highly sensitive natural hydrological system over southern Africa because of the following (Schulze 2005):

1. Even when considering average present climatic conditions, we already live in a high risk hydroclimatic environment in southern Africa
2. An already high inter-annual rainfall variability is amplified by the natural hydrological system
3. Intra-annual variabilities of hydrological responses are even higher than inter-annual ones
4. Different components of the hydrological system differ markedly in their responses to rainfall variability
5. Streamflow variability is high in individual external sub-catchments
6. Land use change by intensification or extensification of biomass often increases flow variability because it changes the partitioning of rainfall into stormflow and baseflow components
7. Degradation of the landscape can amplify further any hydrological responses, especially higher order responses.

The South African Country Study on Climate Change found that when running GCM and ACRU[3] models, runoff was found to be highly sensitive to changes in precipitation. Groundwater recharge was found to be even more sensitive (Kiker 2000). Therefore, changes in the climate system will affect hydrological systems and water resources.

Groundwater in South Africa usually occurs in secondary aquifers and normally soil cover is shallow. Recharge of the aquifer depends on its type. Some are more responsive to rainfall and recharge is closely linked to higher and persistent rains; others, such as deep aquifers, are slow to respond and require consistent rain over a period of time (Visser 2004). Studies by Kirchner (1991) have shown that before any recharge takes place, a rainfall and soil moisture threshold must be overcome. The bulk of the recharge takes place in the years in which the average annual precipitation is exceeded and during periods of high rainfall intensity. It stands to reason, then, that the areas that are dependent on groundwater will be most vulnerable to decreases in rainfall and/or variability. In addition, low storage aquifers are the most vulnerable to changes and variability in recharge. This is the situation in 90% of the country (Braune 1996).

5. Methodological approach to water planning for climate change impacts

In order to illustrate the effects of climate change impacts on water resource planning and management in small municipalities, a case study was developed for a small town in the Western Cape.

After interviewing practitioners in the water sector, it became evident that the issue of available historical records was key (Murray 2006; Groenewald 2007; Visser 2007; 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.

The approach advocated in this paper to plan for the climate impacts on local water resources for Bredasdorp includes establishing the following four key components:

1. Future water use and demand.
2. Future projected climate change.
3. Future climate impacts on water resources.
4. Future water resource management strategies.

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

5.1 Forecast of future water use and demand

Population growth introduces some uncertainty to the projection of future water use and demand. Researchers differ on their projections of future population growth in South Africa. More recent estimates are much lower than those done before 2000. Dorrington et al, for example, have included the consequences of HIV/AIDS in their projections, which results in a growth rate of less than 0.5% by 2015, whereas the those projections made by Roux in 1998, are in the region of 1% (Roux 1998; Dorrington et al. 2006).

Table 2: Project annual population growth

Source: Business Futures 1998 and Dorrington et al. 2006

Years	Projected annual population growth rates	
	Business Futures 1998 (Roux 1998)	**CAR (2006)** (Dorrington et al. 2006)
1999-2015	1.92 %	1.6-0.4 % (0.95 %)
2015-2030	1.06 %	0.4 %

Further, water use patterns differ markedly between urban and rural areas. Rates of water access are much higher in urban areas and urban population growth rates for earlier periods were substantially higher than rural areas. Urban population growth from 1946-1970 was 3.45% per year and 3.09% for 1970-1996 (SACN 2004). Overall, this gives a picture of a growing population, but growth slowing down to lower rates. Further, there have been some suggestions that rural populations have peaked and will stabilise or even decline due to rural-urban migration (Calitz 1996). This will put further pressure on urban centres due to migration.

Given this uncertainty associated with population growth, the current trend is to simply multiply the historic consumption per capita by the historic population to establish the estimated future demand for water. This is not ideal and also this method does not take into account the increased use of water as the population becomes more affluent and the level of poverty is reduced. The approach taken in this paper assumes that no inroads are made into the share of poorer households. Ideally the forecast should be spatially and sectorally disaggregated and be dependant on a realistic population and water demand growth figures.

5.2 Projected climate forecasts

Despite steady improvements in the various global and downscaled regional circulation models, the results from the various models give varying results. No one model is right or wrong, and all project a plausible time evolution of the climate. The models are in a high degree of consensus over the direction of change, and how the large-scale circulation features respond to greenhouse gas forcing, but ascribing probabilities to a magnitude of change is still problematic. Therefore, for planning and developing response strategies, it is best to consider the bounds of the envelope of possibilities, and consider the median[4] of this envelope. For this study, the median of seven GCMs for 2045-2064 was scaled linearly to 2035 to establish the percentage change in precipitation as compared with the model control period of 1980-1999 (Hewitson & Johnston 2006).

The projected percentage change in rainfall was then applied to the mean annual precipitation (MAP) to establish to potential monthly and annual rainfall in 2035.

5.3 Establish the climate impact on water resources

Both run-off and ground water recharge are affected by a change in rainfall. The extent to which this occurs has in this paper been called the *climate impact factor* (CIF). Therefore the expression that can be used to determine future water resources under a future climate change scenario is as follows:

$$FS = CS \, (1 + CIF) \qquad\qquad Eq \ 1$$

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[4] Median is used because sometimes a data point is an outlier, and would skew the results if using the arithmetic mean.

Where: FS = future supply (kl)

CS = current supply (kl)

CIF = climate impact factor (%)

If the CIF is positive, then we can expect an increase in future water supplies under future climate impacts due to an increase in rainfall, and visa versa. The CIF can be calculated for either groundwater or surface run-off. By using this factor, the future available water can be established.

The shortfall or surplus can established by comparing the available future water supplies with the expected future demand. Where the demand exceeds the projected available supply, additional sources should be sought and demand-side management (DSM) measures should be introduced. This is discussed further in the next section.

5.4 Water resource management strategies

Climate impacts are transforming the nature of global as well as local water security, firstly through climate variability and secondly in the future through projected climate change impacts. Callaway (2004) argues that there are more conceptual similarities than differences between the adjustments that are made to cope with climate variability and those made to adapt to climate change. The obvious similarity is that the aim of both types of actions is to avoid meteorologically induced damages when predicting them is subject to some error. Both actions have the potential to improve society, whilst making decisions under some risk, both involve reallocating scarce resources to make the adaptive adjustments. The major difference, according to Callaway, between variability and change is that historical records are more reliable for planning for variability than the reliability attached to climate prediction models. The variability in the existing climate is much easier to plan for than the variability associated with alternative climates.

As stated previously, global temperatures are rising, with some climatic models suggesting that this could cause a decrease in runoff in South Africa, spreading progressively from west to east during the next few decades. A key challenge will be the reconciliation of water demand and supply both for the medium and long terms. 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. By applying filtering tools which are both qualitative and quantitative (such as multi-criteria analysis, cost benefit analysis, cost effectiveness analysis) the responses to climate variability can be evaluated for their long-term suitability to ensuring resilience to future climate impacts, and thereby ensuring that the local development goals are achieved (as is illustrated in Figure 2).
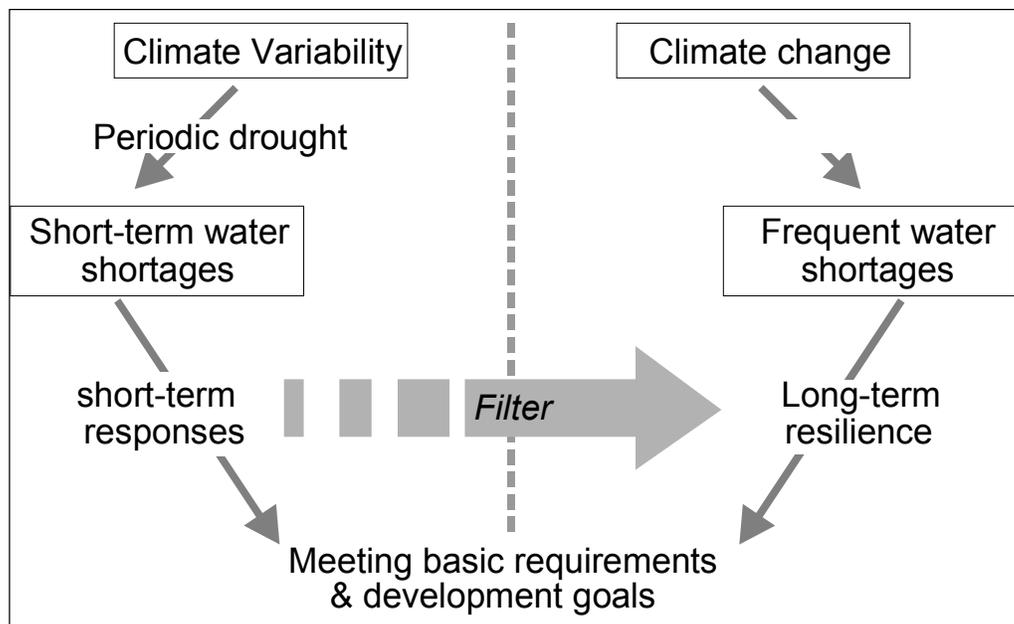

Figure 2: Diagrammatic view of the linkage between climate variability and climate change

Examples of qualitative filtering criteria are listed below (Mukheibir & Sparks 2006):

- potential for additional yield/savings;
- technology requirements;
- level of capital expenditure;
- impact of additional running costs;
- potential for local employment;
- availability of local capacity to implement;
- acceptability to users;
- impact on the local environment;
- potential for long-term applicability.

Quantitative assessments would include:

- capital and operational costs;
- volume of water saved or provided;
- unit costs R/kl.

It still remains standard practice, however, to project water use on the basis of population and other factors, but not as a function of climate. Detailed weather records are available for most parts of South Africa and the supply sources are designed to cope with drought events that have long return intervals. Large supply facilities therefore have excess capacity at nearly all times, but smaller systems do not usually have such large margins of safety built in, because of resource and financial limitations.

Boland (1998) provides some reasons for why conventional planning does not currently consider climate change:

- In the past, lengthy departures from "normal" weather conditions were viewed as random deviations around a stationary mean.
- Conventional planning practice leads to large infrequent capacity expansions. Any trend resulting from climate change would simply cause a change in the timing of the next capacity expansion, without a loss of reliability.
- Water supply planning based on a static climate assumption, have worked reasonably well in the past and hence there is no convincing evidence that they will not work in future.

Recently supply options have not been as prevalent and many more utilities are introducing DSM strategies. Reducing demand can increase excess in supply, thereby creating a greater margin of safety for future drought periods. 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).

Examples of current urban water supply management options is listed below (Mukheibir & Sparks 2006). These are, however, not being implemented in a structured and planned manner across all municipalities.

- Artificial groundwater recharge.
- Conjunctive use of surface and groundwater.
- Desalination.
- Dry sanitation systems.
- Dual flush toilets.
- Education programmes.
- Local water resource management and monitoring.
- Rainfall enhancement.
- Rainwater harvesting.
- Re use of grey water.
- Reduction of leaks programmes.
- Regional water resource planning.
- Saline water for toilets.
- Standby relief under critical conditions eg tankering of water.
- Tariff structures - i.e pricing.
- Water restrictions.

Drawing on the outputs of the case study by Mukheibir and Sparks, the obstacles and limitations to implementing these strategies successfully at a local municipal level were identified. Two key ones stand out:

1. *Local capacity:* The most notable issue affecting the viability of these strategies is the perceived lack of local capacity to implement the strategies. The former Director-General of DWAF, 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.

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

6. Water balance assessment for Bredasdorp

6.1 Present water resources

In 2002 Bredasdorp obtained its bulk water supply from the following surface and underground water resources:

Groundwater:
Five production boreholes (BD1-5) were developed 1985 with a safe yield of **480 000 kl/year.** The boreholes were located in the quartzitic sandstone of the Table Mountain Group to the south of the town. The maximum to be extracted over the summer peak period is 59 000kl/month (Toens et al. 1998). During the drought conditions in 2001 BD6 was developed and in 2002 testing pumping of BD7, BD8 & BD9 was done. The total annual available equipped yield for the groundwater in 2001 was 792 000 kl.

Table 3: Actual abstraction

Source: Afri-Coast (2003)

Year	BD1-BD6 (kl)	BD7-BD9 (kl)	Average rate (kl/d)	Available yield (kl)	% of available yield
1999	418 185	0	1 146	480 000	87.1 %
2000	216 965	0	595	480 000	45.2 %
2001	444 037	131 148	1 576	792 000	72.6 %

Surface water:
The Klein Sanddrift Dam, situated five kilometres to the west of the town, has a capacity of 455 000kl and was commissioned in 1997 to capture the "surplus" run-off from the catchment. The 98% yield of this source is 440 000 kl/year (1205 kl/day) (Ninham Shand 1998). In 2001 the water level dropped to below 33% of full capacity (Afri-Coast 2003).

Table 4: Water abstracted from Klein Sanddrift Dam

Source: Afri-Coast (2003)

Year	Bredasdorp	Farmers	Average total
1999	425 314	118 017	1 488
2000	388 447	159 581	1 501
2001	221 746	131 083	967

The Uitvlugt springs supplies water via a pipeline over 11km to the Vleikloof dam. The estimated sustainable yield is 160 000 kl/annum (438 kl/day). The Vleikloof dam has a capacity of 295 000 kl and is useful in meeting peak demands (Ninham Shand 1998).

Summary of water supply resources:
As can be seen in Table 5, the available potential equipment water annual supply is 1 257 Ml, of which 63% is dependent on groundwater.

Table 5: 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

6.2 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. The De Duine West option is much more expensive in terms of unit cost since it is located 22 km from Bredasdorp.

Table 6: 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

6.3 Water demand

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 4), we see that a shortfall can be expected around 2016 (see Figure 5).

6.4 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).

Table 7: In-line water losses

Source: Afri-Coast (2003)

Year	1999	2000	2001	2002
% losses	24.20%	20.40%	< 15%	~ 15%

7. Impact of climate change on water resource management

7.1 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 3, the mean annual precipitation (MAP) for Bredasdorp is recorded as 500mm (Ninham Shand 1998), but the average for the 25 year period (1980-2004) is 481 mm per annum (3.8% less), 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 summer will be characterised with drying in the west, with slight wetting in the north and east (Hewitson & Johnston 2006).

For the Bredasdorp catchment, the projected precipitation for 2035 decreases by 8% as compared with the mean annual precipitation (MAP; Hewitson & Johnston 2006; see Figure 3). Hydrological and engineering planning usually get done using the MAP. In future therefore, projects for Bredasdorp with a lifespan of 30 years should be planned for using 8% less precipitation than the MAP. The effect of climate change on rainfall amounts and patterns of rainfall, particularly on intensity and increased evaporative losses due to higher temperatures, may be more important in its impacts on run-off and groundwater recharge than the rising temperature alone.
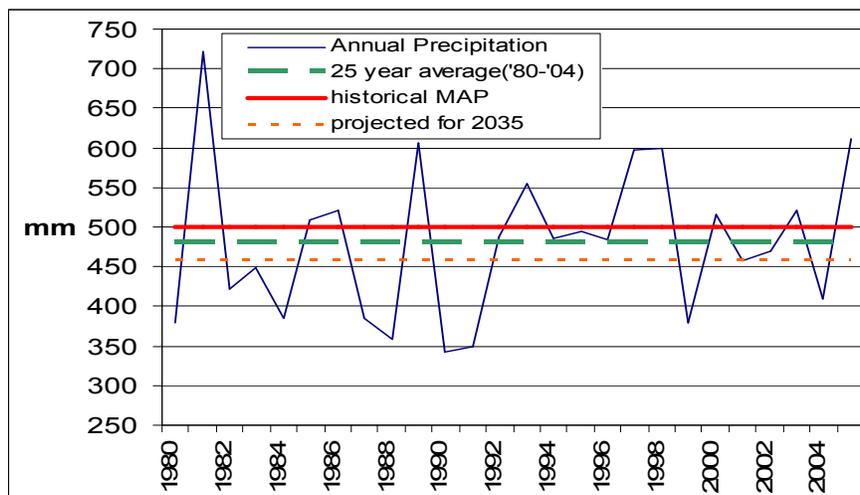

Figure 3: Annual precipitation for Bredasdorp

7.2 Run-off estimation

When considering the impact of reduced precipitation on run-off, work done by de Wit and Stankiewicz is of interest since it shows that for a hypothetical 10% reduction in rainfall in sub-Saharan Africa, regions with 1000 mm MAP would experience a 17% reduction in catchment run-off and for areas that have 500-600mm MAP would have 50-30% less run-off respectively (de Wit & Stankiewics 2006). While using an average precipitation reduction for the continent is a gross simplification and projections using climate models on a regional basis should be used, the related run-off reductions are of interest here.

Studies by Chapman (2007) on historical data reveal that the percentage reduction in run-off can be up to 2.5 times greater than the reduction in precipitation. He cautions that the use of simple trend-lines to arrive at these figures can be misleading, and that the absolute figures should not be used. However the clear trend that a percentage reduction in precipitation results in a greater percentage

reduction in runoff is important. A modelling study conducted by Bari et al of the impact of climate change on run-off in Western Australia revealed that for an 11% decrease in precipitation by 2050, a 31% reduction in annual catchment yield would likely be experienced (Bari et al. 2005). What these studies reveal is that the magnitude of the run-off reduction is two to four times greater than the reduction in the precipitation. However, historical data is required to establish the direct relationship for a site specific analysis.

Unfortunately, historical run-off data is not available for the Bredasdorp catchment. However, based on the above, we can assume that for a projected 8% reduction on a MAP of 500mm 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 would be -0.30.

Therefore, $FS_{runoff} = CS_{runoff} * (1 - 0.3)$

7.3 Recharge estimation

Groundwater recharge estimation is a key factor in determining the suitable management of groundwater resources. A wide range of techniques is used for estimating groundwater recharge as well as direct and indirect measuring methods with which recharge is calculated, inferred or simulated (Beekman & Xu 2003). Using long-term records of past climate-recharge interactions is difficult to apply in southern Africa, since there are very few locations where records of climate and groundwater have been kept in sufficient detail to allow for this analysis (Selaolo et al. 2003).

Various studies of Bredasdorp and the Table Mountain Group (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. This is supported by recharge calculation of 17.4% at neighbouring Struisbaai using cumulative rainfall collectors (Weaver & Talma 2005). Duah et al (2006) have estimated that recharge for TMG aquifer ranges from 0.28% to 12.6 % with an average of 30mm/year. For the purposes of this study, a recharge of 19.6% for MAP of 500mm is used as calculated by Toens et al.

Cave et al argue that short-term predictions of climate change are not necessarily more accurate than long-term ones. Human-induced climate change will occur against a backdrop of natural climate variability. Climate forcings in the short-term are weak in comparison to long-term ones and so the short-term signal is more difficult to separate from that of climate variability (Cave et al. 2003).

In general, decreasing precipitation will cause decreasing recharge and hence depletion of the groundwater resources. Changes in recharge will result from changes in rainfall as well as a change in the timing of the rainfall season. Rainfall-recharge relationships may therefore be used in a first-cut assessment of climate change impacts on the groundwater resources.

A comparison of studies conducted in many disparate locations using different methods revealed that in areas with annual precipitation less than 500mm/year, large differences exist between the recharge values found. Recharge becomes negligible for precipitation lower than about 400mm/year (Beekman et al. 1996). Beekman et al. developed the following equation:

$$y = 148 \ln(x) - 880 \qquad\qquad\qquad\text{Eq. 2}$$

Using this equation, changes in longer-term groundwater recharge due to predicted long-term changes in annual precipitation can be calculated. Applying this equation to a MAP of 500mm would result in a recharge of 39.8mm/year. If reduced by 8% to 460mm, recharge would be 27.4mm/year. This would equate to a 31% 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 recharge percentage MAP would change from 19.6% to 13.5%, a reduction of 31%, i.e the CIF would be -0.31.

Therefore, $FS_{recharge} = CS_{recharge} * (1 - 0.31)$

This would mean that groundwater abstraction would also need to be reduced by 31% so as not to dewater the aquifer.

7.4 Impact on water supply

To maintain the current levels of supply till 2035, an additional 430Ml/year (marked A in Figure 4) will be needed under projected climate change conditions, as compared with the supply under normal climate conditions. This equates to 31% of the current supply under normal conditions (i.e. A/Total Supply). In order to meet the projected demand for water in 2035, this climate-induced water supply decrease will need to accommodated. This climate-induced shortfall is also 54% of the unmet demand of 2035 under normal conditions (i.e. A/B). This means that by 2035, planners will need to plan for 54% more water than they would have under normal climate conditions.
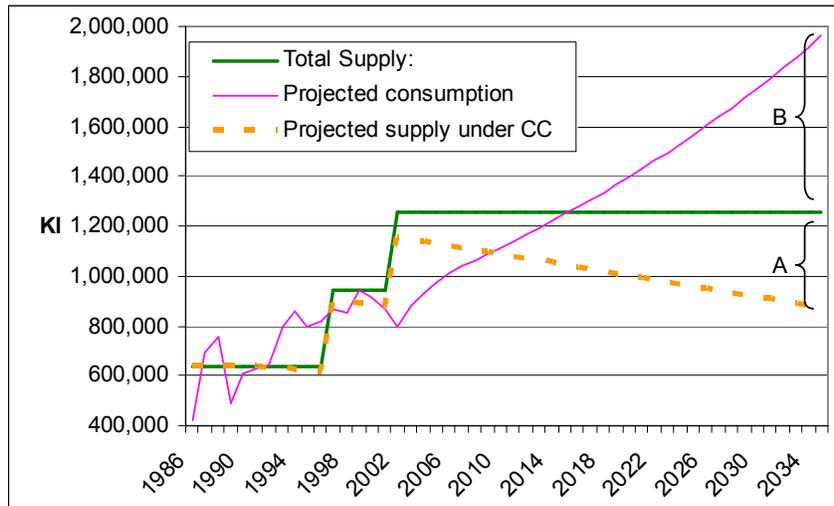

Figure 4: Water supply and demand graph under historical and climate change conditions for Bredasdorp

Further, under normal demand projections, the current water supply system experiences a shortfall by 2016. The projected climate change impacts (i.e. 8% reduction in MAP) will induce a shortfall by 2009, seven years earlier. This will have infrastructural and financial implications and is discussed later.
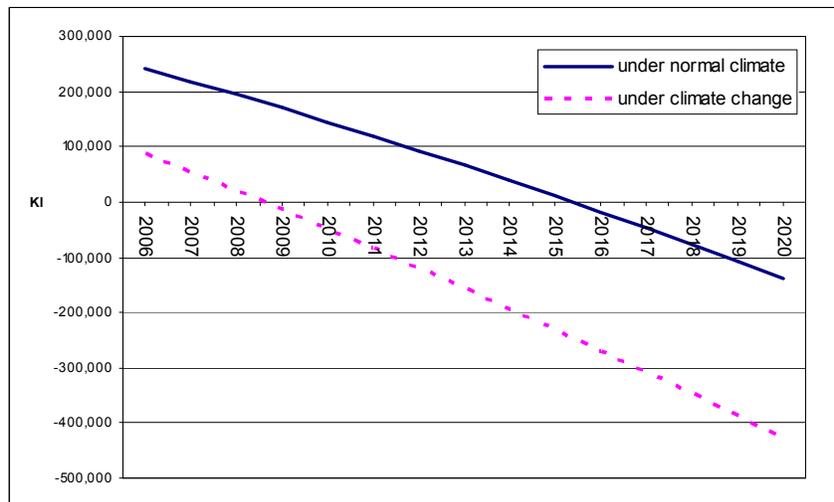

Figure 5: Timing of projected water supply shortfall for Bredasdorp

8.   Analysis of potential water resource management strategies under climate change impacts

A number of supply- and demand-side options are investigated to illustrate the impact of climate change on water resource management for the Bredasdorp case. These strategies have not been proposed or adopted by the planners of Bredasdorp.

8.1   Selected supply-side options

To meet the estimated demand by 2035, an additional 380Ml/year will be needed under projected climate change conditions, as compared with the supply under normal climate conditions. This is 54% more than under normal climate conditions. As can be seen in Figures 6 and 7, three additional sources of water supply will be needed under climate change conditions to ensure the demand is met in 2035.
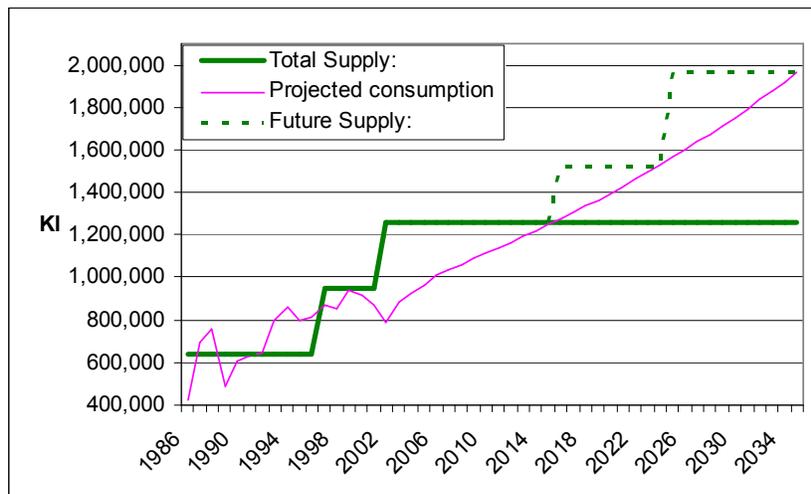
Figure 6: Projected water supply till 2035 under normal climate conditions
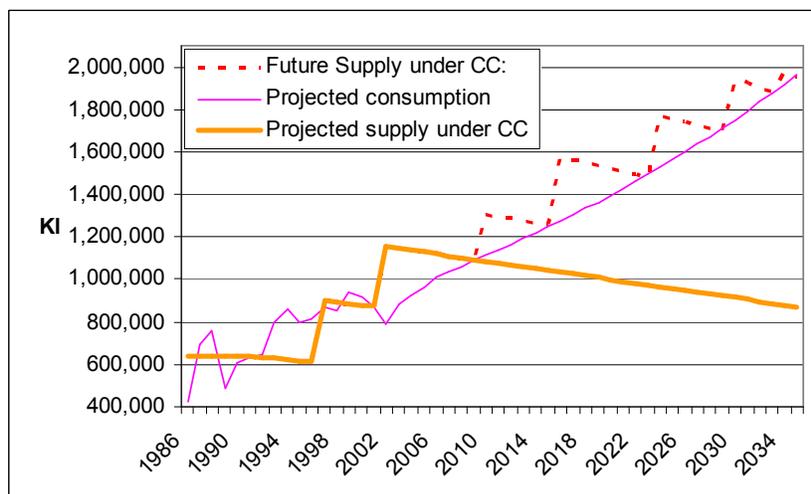
Figure 7: Projected water supply till 2035 under climate change conditions

There is a progressive reduction in available water supplies over the period ending in 2035, which results in a 31% and 30% reduction in recharge and run-off respectively. In other words, a potential resource in year 2000 of 400Ml would be reduced to 328Ml by 2016 and further reduced to 306Ml by 2024, due to the increasing impact of climate change (see Table 8).

Table 8: Future groundwater supply options commissioned (in kl/year)

Supply option	Normal climate (present estimated supply)			Climate change conditions (present estimated supply has been reduced by the annual CIF)					
	2016	2025	2035	2010	2016	2024	2030	2034	2035
Golf course compartment	260 000			224 178 (260000)					
Sanddrift/ Napier compartment		450 000			328355 (400 000)	306311 (400 000)			
De Duine West							260 800 (360 000)	111 502 (160 000)	
Cumulative	260 000	710 000	710 000	220 480	541787	811724	1028711	1 101 084	1 090 200

8.2 Selected demand-side strategies

A sample of possible DSM savings and related unit costs are provided in Table 9. To illustrate the effect of DSM measures on future water resource management and planning, outdoor water use restrictions and active leak detection programmes have been analyzed in this example.

Table 9: Examples of demand-side options

(after White & Fane 2002)

Measures	Saving (l/p/d)	Cost (2005 R/kl)
Shower head performance standard	8.6	0.01
Active leakage control	7.2	1.71
Clothes washer performance standards	3.5	0.23
Residential indoor audit and retrofitting - with discount	3.4	1.08
Industrial and commercial audits	2.9	2.40
Industrial reuse project 1	2.3	3.02
Price increase (R0.57/kl over 2 years)	1.9	0.01
Outdoor water use restriction	1.8	0.36
Industrial reuse project 2	1.8	3.71
Residential indoor audit and retrofitting - free for low-income	1.5	1.43
Hotel audits	1.3	2.40
Shower head rebate (R56.89)	0.7	0.80
Washing machine rebate (R853.28)	0.4	3.99
Outdoor irrigation system audits	0.3	3.82
Outdoor water use promotion	0.2	2.79

The introduction of the DSM measures results in a delay of 1-2 years for the implementation of the capital intensive supply options. Based on a projected population of 26150 by 2035, the volume of water saved for the year in 2035 is approximately 86Ml. The financial implications are discussed further in the next section.
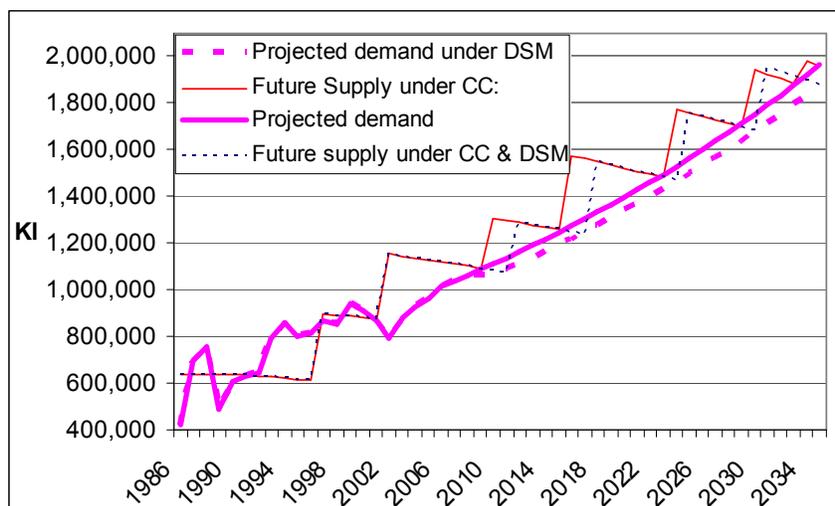
Figure 8: Projected water supply till 2035 under climate change and DSM conditions

9.   Financial assessment of strategy options

Financial cost indicators are ideal for qualitatively assessing the various supply and demand reducing options, since for local municipalities financial capital is one of the key resources at their disposal.

In order to assess the financial implications of meeting the projected demand for 2035 under climate change conditions, the real present day investment cost (assumed here to be as at 2005) of additional supply has been compared with that under normal climate conditions. The capital costs to secure the groundwater resources was obtained from relevant engineering reports (Toens et al. 1998). The influence of the change in revenue and running costs have been assumed to be negligible, since the projected demand is the same under both scenarios. Treatment costs will therefore remain constant, whilst pumping costs may be slightly higher due to low water tables and longer pumping times.

This analysis reveals that approximately an additional R30 000 000[5] will be required. This is approximately 3.5 times the capital expenditure under normal climate conditions. In other words, for this case study, a projected decrease of 8% MAP by 2035 will result in a 251% increase in cost.

Table 10: Capital cost comparison of ensuring water supplies under climate change conditions

	No CC	*Under CC*	*change*	
Impact by 2035				
Real 2005 costs of additional supply	11 902 128	41 728 505	251%	3.51times
Additional annual water supplied by 2035	710 000	1 090 200	54%	1.54 times
Real costs/additional water required by 2035 (R/kl)	16.76	38.28	128%	2.28 times
Impact by 2020				
Real 2005 costs of additional supply	4 869 999	11 120 780	128%	2.28 times
Additional annual water supplied in 2020	260 000	501 600	93%	1.93 times
Real costs/additional water required by 2020 (R/kl)	18.73	22.17	18%	1.18 times

Cost-effectiveness analysis is a specialised version of traditional cost-benefit analysis. All costs of a portfolio of strategies are assessed in relation to a policy goal that represents the benefits of the strategies, and all other impacts measured as positive or negative costs. The policy goal in this case is ensuring municipal water supply. The unit cost comparison has been calculated by dividing the

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5   Approximately US$ 4.25 million (using R:$ = 7:1)

real cost by the actual volume of additional annual water required in 2035, expressed in Rands per kilolitre. Therefore, under the normal climate scenario, the cost of meeting the 2035 demand is R16.5/kl as compared with R38/kl under climate change conditions. This is 2.5 times higher, as is graphically illustrated in Figure 9. This is less than the real cost ratio, since the additional volume of water required has increased by 54% (i.e. 1.54 * 2.28 = 3.51).

If we consider the climate impact by 2020, we note that the cost comparison for the year 2020 equates to an increase of 128% (2¼ times). This means that the cost increase due to climate change doubles from 2020 to 2035. This is due to the fact that over time the impacts of climate change on run-off and recharge become more pronounced, and hence water becomes more difficult and expensive to secure to meet the projected demand. This is further illustrated when considering the unit costs. The unit cost for water in 2020 was R22/kl – just more half that for 2035.
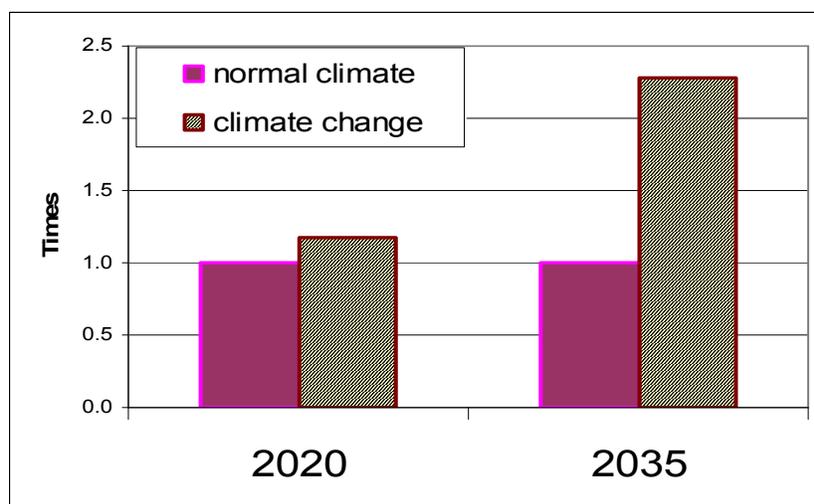

Figure 9: Magnitude of the increase in unit cost due to climate change over time

The impact of implementing DSM strategies is that the saved water results in a delay in the implementation of supply infrastructure, and hence saves capital investment costs. For example, there is a 7.6% increase in available water due to the two DSM options by 2035 i.e. 86 Ml. This results in a delay of the implementation of supply options by 1-2 years during the period of study, causing a net decrease in the investment cost of 7.8%, and a reduction of the unit cost by 8.1%. It is acknowledged that the reduction in demand may result in reduced revenues, but this will in all likelihood be offset by the reduced operational costs.

Table 11: Capital cost comparison of ensuring water supplies under climate change conditions and DSM

Impact by 2035:	Under CC	Under CC & DSM	Change	
Real 2005 costs of additional supply	41 728 505	38 477 070	-7.8%	0.92 times
Additional annual water supplied by 2035	1 090 200	1 007 400	-7.6%	0.92 times
Additional annual water saved through DSM by 2035	0	86 094	7.6%	
Total additional water secured by 2035	1 090 200	1 093 306	0%	1.00 times
Real costs/additional water required by 2035 (R/kl)	38.28	35.19	-8.1%	0.92 times

10. Conclusion

Based on this illustrative example, it is shown that as the projected climate change impact nears 8% reduction in rainfall by 2035 and the projected volumes of ground and surface water are reduced by the proportionate climate impact factor of 31% and 30% respectively. This results in the financial cost to meet the water demand in 2035 being over three times that which would have been required under normal climate conditions. Further, it becomes more expensive to secure new water resources since the groundwater resources are deeper and further away.

The introduction of DSM options eases the need for supply-side resources and in this example provides approximately 8% more available water for distribution.

These results are indicative of the potential impact of climate change on municipal water resources, but since aquifers and run-off regimes differ vastly from place to place, it is advisable that detailed monitoring of the variables be done to establish the relevant climate impact factor for the specific area under study.

Large uncertainties still plague quantitative assessments of climate change impacts and water resource management. What is known for certain is that the climate is changing, and 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 outlined in this paper will also assist municipal planners to evaluate these impacts and develop appropriate strategies that ensure long term water supplies.

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