A planning tool for mainstreaming climate change adaptation in the water and sanitation sectors in South Africa

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Abstract
South Africa is a water-stressed country, and predicted climate changes are expected to have an additional and possibly dramatic impact on the ability of local and national authorities to abide by national policy and deliver, free, a basic minimum of water and sanitation services to all households. The efficient and cost-effective provision of water and sanitation services is a critical challenge faced by all local authorities. Consequently, a clear understanding of the costs and benefits of alternative options for service provision is essential. Local governments therefore need decision-support tools that consider long time horizons, and which are simple to apply and not data intensive, in order to mainstream long-term planning for climate change adaptation. In this study an economic model was developed and used as a planning tool to evaluate the cost-effectiveness of a range of service-provision options over a period of 50 years; where the cost of water was allowed to increase as a non-linear function of time. The development options evaluated included baseline scenarios and adaptation options for 'Urban Housing' (where water-supply and sanitation infrastructure already exist) and remote 'Rural Housing' (where fully waterborne sewage is impractical and unaffordable, water is supplied by tank, and ventilated-improved-pit toilets are used for sanitation). In the Urban Housing case two adaptation options were considered: the use of greywater and rainwater harvesting. In the Rural Housing case, the 'urine diversion toilet' was the only adaptation option investigated. The model results show that all adaptation options are more cost effective than the baseline choices and provided additional environmental co-benefits. The model was evaluated by potential users and was found to be an effective decision-support and education tool. Finally, possible barriers to the widespread implementation of adaptation options are identified and discussed and ways of overcoming these are suggested.

Keywords: climate change adaptation, mainstreaming adaptation, economic evaluation, cost analysis, water supply and sanitation, municipal planning, South Africa, eThekwini

1 INTRODUCTION

Substantial climate change is already inevitable over the next 30 years (Stern, 2006). In the southern African region, climate change is expected to lead to: an increase in the number of days with temperatures greater than 30˚C; a change in rainfall distribution, with longer periods of no rainfall and shorter periods of intense rainfall; and a wetter escarpment in the east and drying in the far west (Shultze, 2005). Attempts to understand and quantify the biophysical, social and economic consequences of these climatic changes have been undertaken by Turpie *et al*. (2002), Scholes and Biggs (2004) and Midgley *et al.* (2005). These studies predict impacts to be dramatic for many regions and communities. In particular, the vulnerability of many large communities in southern Africa to even small fluctuations in climatic variables (due to their direct dependence upon the natural resource base and their low income which is insufficient to mediate these impacts) is highlighted and the need for prompt, large scale development and implementation of adaptation strategies within the region is emphasised.

Water resources are inextricably linked with climate, so the prospect of climate change has serious implications for water resources and regional development. A reduction in precipitation projected by some General Circulation Models (GCMs) for southern Africa, if accompanied by high inter-annual variability, could be detrimental to the hydrological balance of the region and disrupt various water-dependent socio-economic activities (Shultze, 2005). South Africa (SA) is classified by the International Water Management Institute (IWMI) as approaching a situation of *absolute water scarcity* (Claasen *et al*., 2004). Many river basins are approaching a point of closure where all of the available resource has been allocated at a high assurance of supply, and in some cases even over-allocated (Turton & Ashton, in press). Efforts to meet the demand need to consider the vulnerabilities of communities to climate change and incorporate adaptation strategies into water-resource planning and development. Since the provision of domestic water and sanitation services in SA is the responsibility of local authorities (i.e. municipalities) (Water Services Act – 1997, No. 108 of 1997), research and development efforts must focus on building their capacity to do this.

The objectives of this study are therefore threefold. The first involves the evaluation of the economic and water-use implications of various water supply and sanitation options in peri-urban and rural housing developments. The second involves evaluating the sensitivity of the various options to changes in water costs (which reflect increasing water scarcity) and the impact of the costs of water supply and sanitation on affordability for low-income groups. The final objective is to develop a decision-support tool for resource-limited local authorities in data-scarce environments to assist in their implementation of policies/programmes/projects to provide water and sanitation services to peri-urban and rural dwellers while taking into account the possible economic consequences of climate change.

Widespread application of this tool will support the mainstreaming of climate change adaptation into planning processes and the consequent reduction in vulnerability in the water supply and sanitation sector. These objectives are investigated within a cost-effectiveness framework using the eThekwini municipality as a case study.

2 CASE STUDY – ETHEKWINI MUNICIPALITY

2.1 Case study selection

The eThekwini Metropolitan Municipality is located in KwaZulu-Natal province and was created in 2000. It includes the city of Durban (the second most populous city in South Africa) and surrounding towns. The eThekwini municipality is located along SA's east coast, stretching approximately 40km north, 52 km south and 40km west of Durban bay (Figure 1).

This project builds on the Hounsome and Iyer (2006) study for the eThekwini municipality, which identified the water sector as one of the sectors most vulnerable to climate change. The main drivers of this vulnerability were determined to be the continuously increasing demands for water (as a result of continued economic growth and urbanisation of the South African population) in an environment of ever decreasing water supplies (due to increases in water pollution and the impacts of climate change on rainfall frequency and variability). As a consequence, the eThekwini municipality has a critical role to effectively and efficiently provide safe and reliable water and sanitation services to the growing peri-urban and rural low-income communities to improve livelihoods and reduce their vulnerability to climate change. This critical role is recognised as being especially challenging because of their limited financial and human-resource capacities; a situation characteristic of many local authorities (Agyemang, 2002; Koch *et al.,* 2007).

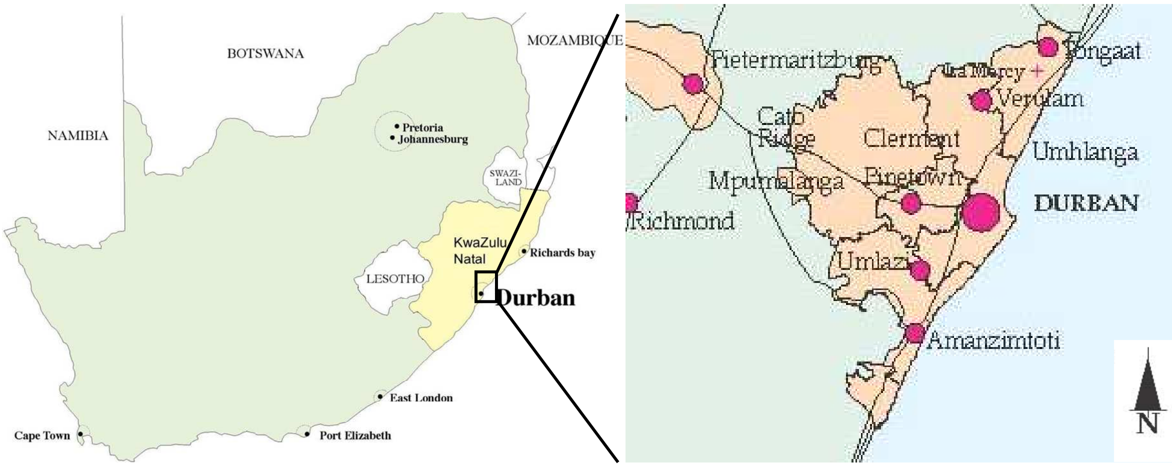

Figure 1: Map of eThekwini municipal area (Pietermaritzburg excluded) and its location within South Africa

The data and information for all options were collected from numerous stakeholders including eThekwini officials, government departments (the Department of Science and Technology and the Department of Water Affairs and Forestry) and private consultants. These primary data were supplemented with data from the comprehensive report by Walker *et al*. (2006), which evaluated the financial sustainability of the provision of basic sanitation services. All the calculations are made per household as most of the information used in the water sector is available in this format and it makes comparison between options easier.

2.2 Development options and adaptation scenarios

Two options were considered in this analysis, which closely represent actual demands for housing and associated services and which currently do not incorporate climate change adaptation into their planning: 1) 'Urban Housing' projects in the urban fringe and 2) 'Rural Housing' projects. The Urban Housing development option involves meeting increased demands for water-supply and sanitation in areas where water-supply and sanitation infrastructure already exists. In other words, the Urban Housing baseline option assumes that 100% of the households receive municipal water supply services and utilize sanitation treatment works. The Rural Housing option involves the provision of water-supply and sanitation services to remote areas where fully waterborne sewage is impractical and unaffordable. These areas are currently receiving water from municipalities by means of tanks and sewerage provision in the form of Ventilated Improved Pit (VIP) toilets.

The adaptation scenarios considered in this study focus on minimising households' use of, and reliance on, municipal water as well as identifying the most appropriate sanitation option. In this context, 'appropriate' means that the adaptation options available depend on the characteristics of the existing water-supply and sanitation infrastructure and the location of the development. Two adaptation scenarios were investigated for the Urban Housing option: 1) the introduction of greywater reuse technologies; and 2) the introduction of rain-water tanks. Only one adaptation scenario was investigated for the Rural Housing development option and involved the introduction of Urine Diversion Toilets (UDT) (i.e. ecological or dry sanitation). Each of these technologies is mature and well known and widely described in literature. Therefore only a brief list of advantages and disadvantages of each is presented in the table below.

Table 1: Advantages and disadvantages of modelled options

Option	Advantages	Disadvantages
Urban baseline	The water supply and waterborne sanitation option is preferred by consumers and is suitable for centralised systems.	The cost of infrastructure development and maintenance is a heavy burden on municipalities and vandalism, unaccounted for water and culture of non-payments in low income areas exacerbates this burden.
Urban – greywater	The greywater option allows for the reuse of approximately 40% of consumed water for other purposes, especially landscape irrigation. If applied to soils, greywater is purified to a high degree in the upper, most biologically active region of the soil. This protects the quality of both the surface water and groundwater. In addition to water savings, it reduces the volume of sewerage, resulting in less energy and chemical use in sewerage treatment. It increases groundwater recharge and enhances plant growth. The latter is particularly important for subsistence small-scale farmers and therefore is suitable for low-income developments.	*"The negative impact on health of greywater irrigation of vegetables for private household use may be potentially significant if irrigation is not carefully controlled, where hygiene standards relating to irrigation management, vegetable harvesting and food preparation are not upheld. If improperly managed, greywater irrigation areas can become sources of public nuisance, with the development of nuisance conditions such as insect breeding, odours, unsightly discolouration, etc" Murphy, 2006*
Urban – rainwater tanks	This option requires a small capital investment and minimal maintenance. Good quality water suitable for any use is collected. In urban environments it also reduces storm water drainage loads and flooding, which are important issues in the eThekwini area.	This option is more effective for larger systems, but even simple roof-collection systems can provide significant water savings if applied on a large scale, which requires substantial capital investment.
Rural – VIP (baseline)	When correctly designed, operated and maintained, the VIP has proved to be an acceptable, cost-effective, hygienic and environmentally friendly sanitation system.	The biggest problem occurs when the pit has to be emptied. The use of conventional suction tankers requires additional water to liquidise the pit contents before suction and is expensive. The most simple, cost-effective method of emptying pit toilets is by hand. This practice is culturally not acceptable and the maintenance of VIPs is therefore a problem in South Africa. In addition, during periods of heavy rainfall and runoff, pits often fill up faster. which reduces the maintenance intervals and leads to overflowing of the pits or leaks from poorly maintained VIPs. This is a significant source of disease.
Rural- UDT	This technology is more environmentally friendly and economical than that of the VIP. The re-cycling of urine is simple and can be used as an effective fertiliser. The urine separation and use of double chambers simplifies removal of dry matter which is rendered disease free and safe to handle over time and therefore reduces the potential impact of pollution.	As with the VIP, there is a need for correct maintenance, hygiene and the education of users. Historically, this form of sanitation has not been looked upon favourably, but improvements in technology and education of users has slowly increased its acceptance in both developed and developing countries.

2.2.1 Urban-housing development

The Urban Housing development baseline option represents the current situation whereby water and waterborne sanitation is provided in the peri-urban low-income area. Fully water-borne sanitation is often seen as the most desirable form of sanitation from a user perspective. In South Africa it is considered as the standard system of sewage disposal in high density urban areas.

The sewage-collection-network and treatment-infrastructure costs include capital and recurrent costs. The cost of building the infrastructure and recurrent costs of maintenance and operation of the collection network and of sewage treatment works vary widely, depending on many technical and local factors. The eThekwini municipality uses a model to evaluate the cost of building infrastructure (roads, water supply, waste water, etc.) and the output of this model shows that the further away from the sea and from the city centre, the higher is the cost of water and wastewater services. Beyond the city edge, costs could be as high as 16 600$ for each new site developed (Breetzke, 2005).

Sewage charges paid by households to cover sewerage collection and treatment costs, are the proxy for the recurrent costs. As with water tariffs, no information could be obtained on under-recovery and subsidies and therefore this cost is probably underestimated.

The capital cost for constructing sanitation structures for each household includes the costs of materials, labour, administration and other expenses such as training. The recurrent costs are the costs of maintaining the structure, which the municipality assumes to be negligible.

The baseline assumes standard water supply and waterborne sanitation services by municipality. Estimates of all costs are summarised in Table 2.

Table 2: The establishment and recurrent costs (US$) associated with the baseline and adaptation options available for Urban-household developments

Urban Households	Fully waterborne water & sewage		
	Baseline	Greywater	Rainwater
Establishment cost	1 785	1 993	2 146
Infrastructure replacement costs (every 20yrs)	304	512	665
Recurrent cost - excl water	274	230	290
Water charge - year 1	84	36	48

Greywater is particularly promoted for decentralized or semi-centralized solutions and for flexibility of planning and therefore addresses the need to adapt to climate change uncertainty (McCann, 2007).

The cost of the greywater option includes the costs listed for the baseline plus the additional capital cost of setting up the greywater technology. These capital costs include: house drain pipes, construction materials, a storage tank and labour for construction.

The costs of harvesting rainwater include all the costs of the baseline option with additional capital costs such as connecting pipes, the storage tank, labour for construction, a conveyance system and gutters. The estimates of all costs for this option are summarised in Table 2.

2.2.2 Rural-housing development

One of the objectives for the eThekwini municipality is to provide a basic sanitation service to all rural people. Many provinces have strategies for the provision of sanitation services (DWAF, 2006), but fully waterborne sewage is unsustainable, impractical and unaffordable in many rural areas. The cost of basic sanitation services is fully subsidised and Walker et al. (2006) evaluated the financial sustainability of the provision of basic sanitation.

The Ventilated Improved Pit toilet (VIP) is the prevailing and dominant type of sanitation for rural areas and therefore forms the baseline for this development option. About 500 000 people in Kwa-Zulu Natal currently use VIPs and an additional 500 000 use pit latrines, but without ventilation (Milstein, 2006).

The capital cost of constructing a VIP structure for each household includes the cost of material, labour, administration and other miscellaneous costs such as education. Recurrent costs include chemicals, maintenance and pit emptying. The estimates of all costs are listed in Table 3.

The UDT option is particularly attractive in KwaZulu Natal, where inadequate sanitation was one of the risk factors that led to a number of cholera outbreaks. For example, of the 81 265 cases recorded in South Africa between August 2000 and April 2001, 80387 occurred in KwaZulu Natal (Mugero and Hoque, 2001).

The capital costs of the UDT are similar to those of the VIP. The capital cost incurred in the construction of the UDT structure for each household includes the cost of all materials, labour, administration and training (if required). From an economic perspective the main advantage of the UDT is that there is practically no maintenance (recurrent) cost, however a minimal cost is assumed. Estimates of all costs for this option are listed in Table 3.

Table 3: The establishment and recurrent costs (US$) associated with the baseline and adaptation options available for Rural household developments

Rural Households	VIP	UDT
Establishment cost	492	508
Recurrent cost	82	6

Although the above listed figures were used for model calculations, in reality these costs can vary significantly. For example the establishment cost of VIPs, varies between 150$ to more than 650$. The value chosen for the model was selected to represent the recent value listed in Walker *at el.* (2006).

The re-current cost for the VIP used in the model is the lowest possible cost representing manual pit emptying, as suggested by Walker *et al*, 2006. However according to the study done in this area in 2004, the price was much higher and ranged between 154$ and 221$ (Walker *et al*, 2006).

3 ANALYTICAL FRAMEWORK

One of the objectives of this study is to determine the most appropriate allocation of water, labour and financial capital to ensure that the well-being of society is improved. Therefore an environmental-economics evaluation framework was adopted. Environmental economics provides a suite of tools to value and evaluate resource use and assist decision- and policy-makers to allocate scarce resources efficiently between competing demands. The three main economic decision-support tools available that are particularly suited to assessing the benefits and/or costs of alternative resource-use options within a partial-equilibrium framework are: Cost-Benefit Analysis (CBA), Multi-criteria Decision Analysis (MCDA), and Cost-Effectiveness Analysis (CEA). These tools have been widely used for evaluating climate change mitigation options (Stern, 2006) and recently have been increasingly applied to climate change adaptation. When many options and permutations require evaluation, a trade off has to be made between undertaking a thorough CBA (which requires the collection of a massive amount of data) or undertaking a CEA. A CEA has the advantage of not requiring data on the benefits of alternatives – provided each alternative is likely to achieve the same or similar level of benefit. Blignaut and de Wit (2004), however, highlight the limitation of a CEA in that this approach does not tell us whether the benefits realised justify the cost incurred.

In this study a decision-support tool for budget-constrained local governments is developed. This tool is suitable for economically evaluating and prioritising alternative adaptation options based on their cost-effectiveness at achieving a certain environmental or physical outcome (benefit). The adaptation options evaluated are the various technologies that can readily be incorporated in development planning and implementation. The urban development options would decrease both an individual's and the community's demand for and use of water (i.e. decrease their dependence/reliance on water and consequently their vulnerability to climate change), while rural development options would reduce water pollution. Three cost criteria were used to prioritise the alternatives: 1) the present value of total costs, 2) levelised costs and 3) the adaptation benefit based on a quantitative biophysical criterion such as the 'total quantity of water saved'. These criteria and the process followed are described in the next section.

4 THE ECONOMIC MODEL

The model was developed iteratively over a 12-month period under continual discussion with the eThekwini municipality (K Breetzke, B Pfaff and S Sathnarayan), national government (M Milstein from Department of Water Affair and Forestry and R Holden from Department of Science and Technology) and technical experts, who contributed to the Walker *et al*. 2006 study (D Still and R Hazelton). It is used to estimate the present value of total costs and the total water used over a 50-year period for all available options. The present value of total costs is then divided by the total amount of water used by household to get the total cost per unit of water used (volumetric cost). The model includes the capital cost of establishing each of the options, the recurrent costs, the cost of water as an increasing function of time and the amount of water used (as described below).

The model structure and the criteria used are in line with the recommendations for the evaluation of climate change mitigation options (Clark and Spalding-Fecher, 1999).

The economic model is represented algebraically as:

$$PVC_j = \sum_{t=0}^{T} (vc_{jt} + ec_{jt}) \cdot \delta^{-t} \tag{1}$$

Where, PVC_{jt} represents the present value of the costs of each option *j* over *T* years, where *T* is assumed to be 50; vc_{jt} represents the recurrent costs of each option *j* for all years *t* and includes operation and maintenance costs; ec_{jt} is the establishment cost of each option *j* that is incurred periodically and includes all capital costs and once-off payments such as connection fees; and $\delta^{-t} = (1+r)^{-t}$ is the discount factor for the discount rate *r*. Note that the first year of the project is represented using a zero in the model to ensure that the capital costs incurred at the start of the project are not discounted.

The recurrent costs are represented as:

$$vc_{jt} = \sum_{k=1}^{K} p_{kjt} \cdot \alpha_{wt} \cdot q_{kjt} \tag{2}$$

where, p_{kjt} and q_{kjt} are the prices and quantities respectively of all the annual inputs, *k*, into each of the options, *j,* for each year of the project, *t;* and α_{wt} is a factor that represents the exponential increase in the price of water (i.e. where *k* = *w*) over time in response to decreasing supply and increasing demand, and takes the form:

$$\alpha_t = \exp^{t \cdot f} \tag{3}$$

where, *f* is a parameter defining the rate at which α_t increases; $\alpha_0 = 1$; and *t* is as defined above. The values for *f* that have been used in this study range between 0.02 and 0.06. The lower value in this range means that the water tariff will have doubled within 35 years and the upper value in the range means it will have doubled within 12 years. These assumptions are supported by real-world observations over the last decade or so, where water prices have increased almost all over the world. In Australia, for example, the price reached US$0.75 per cubic meter in December 2006, having increased 20-fold in a year, primarily due to the prolonged drought. In India, water scarcity has made water prices escalate, to the point where it is now more profitable for some farmers to sell their water instead of farming (Clark, 2007).

The levelised cost (*LC*) for each option was calculated to provide another criterion by which the various alternatives can be compared. *The* levelised cost is recommended as a standard for comparison of investments that involve a flow of payments (and receipts) that occur at different points in time. In other words, the levelised cost represents a stream of equal cash flows whose present value is equal to that of a given stream of variable cash flows. This is important when comparing costs with water savings.

$$LC_j = PVC_j \cdot \left(\frac{r}{1-(1+r)^{-T}} \right) \qquad (4)$$

where, PVC_j is as defined above and estimated using equation (1); r is the discount rate; and T is the time horizon.

Different approaches to the calculation of the levelised cost are described in Fane *et al*., 2006, but a decision was taken to adopt the methodology which has been applied in South Africa (Clark and Spalding-Fetcher, 1999).

Finally, the adaptation benefit is calculated for the urban housing options. It is calculated as the ratio of the difference in the present value of the total cost for the adaptation option and the baseline and the difference in water used in the adaptation and the baseline options. It quantifies the benefit to society (in a form of R/kl of water saved) as a result of the introduction of either of the adaptation options. This value is similar to the marginal mitigation cost used widely in climate change studies, which represents cost or benefit of each mitigated unit in the form of R/ton CO_2.

5 MODELLING ASSUMPTIONS

5.1 Assumptions on the costs

The costs of all the options considered in the model, consist of establishment costs and recurrent costs. The establishment component includes expenses on infrastructure.

The recurrent costs are categorised into two groups: subsidies from government (municipalities) and costs attributed to the household. The water tariff imposed by municipalities to supply water to each household does not cover the real cost of water supply and therefore is partially subsidised. Hence, the estimates in this study are underestimates of the costs of water provision. However no information could be obtained on under-recovery and subsidies paid by the government and therefore the subsidies component could not be included in the model. This limitation applies to all the options modelled.

The costs of basic sanitation provision are fully subsidised. Unfortunately, no current data on these subsidies could be obtained and therefore they were not included in the model.

Economic theory predicts price to be an important factor influencing demand (Varian, 1999). The price charged for water is largely driven by three factors: the cost of treating and transporting water from its source to the user; total demand for the water; and government subsidies. Consumers around the world, however, are rarely required to pay the true cost of water (i.e. the minimum amount that covers all expenses of its provision). In fact, many governments practically give water away. A recent survey of 14 countries, for example, found that average municipal water prices range from US$0.66 (United States) to US$2.25 (Denmark and Germany) per cubic meter in developed countries (Clark, 2007) and can reach as much as US$3.54 in developing countries (e.g., the price paid to a vendor in the slums of Guatemala City).

In SA, a step function is used when setting retail water tariffs. The first 6 kilolitres per month is the minimum quantity of water specified within the constitution that has to be provided to people free of charge (DWAF, 2002).The price is then increased as the quantity of water consumed increases. The retail water tariff and sanitation charge applicable at household level are affected by the different charges and tariffs which are described in the figure 2 below, but these are not included in the model.

The eThekwini municipality uses block tariffs and when household consumption exceeds 30 kilolitres per month the charge is almost tripled
(Online http://www.durban.gov.za/durban/government/munadmin/treasury/tariffs).

Table 4: Water tariffs (US$ per kilolitre) charged by the eThekwini municipality between 2005/6 and 2006/7 financial years.

Tariff (incl. VAT)	2005/6	2006/7
From 0 to 6 kilolitres	0	0
Higher than 6 kilolitres and lower than 30 kilolitres	0.50	0.62
Above 30 kilolitres	1.51	1.85

In addition to the consumptive tariff, there is a fixed monthly charge applied for properties with a value above 5200$. Since this case study considers a low income community, the fixed charge is excluded from the calculations.

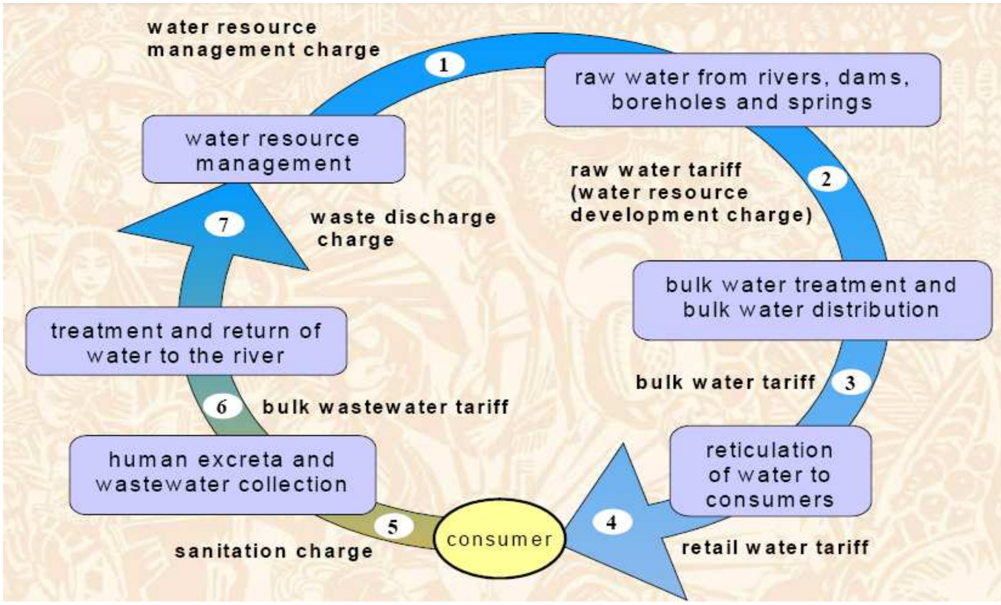

Figure 2: Water charges and tariffs in South Africa
(source: http://www.dwaf.gov.za/Masibambane/documents/structures/wsslg/nov06/wsslg.pdf)

5.2 Assumptions on the amount of water used

For the Rural Housing option the quantity of water used is the minimum amount provided free by the municipality. Based on the eThekwini tariff structure this is 6 kilolitres per month (72 kilolitres per year). In the case of Urban Housing developments, where water-borne sanitation is the baseline, it is assumed that an average household uses 240 kilolitres per year. This assumption was tested in a sensitivity analysis (see section 7 below).

It was further assumed that the implementation of greywater can reduce this municipal usage by 40%. The amount of greywater produced (i.e. water used for dish washing, showering, and laundry) by urban households, varies from 35% to 80% for poor and rich households, respectively.

Since the roof area available for rainwater collection is relatively small for the type of housing development considered and because there are a few dry months in the year, it was assumed that only 30% of municipal water usage could be saved by installing rainwater-collection tanks. The water used for each of the baseline and adaptation options for both the Rural and Urban Housing developments are summarised in Table 5.

Table 5: Annual water consumption (kilolitres) for all options

Urban Households	Kilolitres yr^{-1}
Total water used (Fully WB)	240
Total water used (Greywater)	144
Total water used (Fully WB + Rainwater)	168
Rural Households	
Total water used (UDT)	72
Total water used (VIP)	72

5.3 Miscellaneous assumptions

Additional assumptions made include:

1. The Rural Housing sanitation facility is in a separate structure away from the house, whereas the Urban Housing sanitation facility is inside the house.
2. Regardless of whether national government, the municipality or the household is responsible for a cost (whether capital or recurrent), the total costs are included in the model. The model does not, however, include the cost of providing water to rural households, as this is fully subsidised by municipalities and varies greatly for different areas. However, since the adaptation scenario considered for rural housing does not include water savings and the

water costs will continue to be subsidised, this cost was not required in the model as it does not impact on the affordability of the sanitation service.

3. The refurbishment/replacement/upgrade of household structures is assumed to occur every 20 years.

6 RESULTS

6.1 Urban-household developments

The results of the model, using base-case values for all parameters, indicate that the introduction of greywater technology into all households is the most cost-effective option based on the total-cost criterion (column 2, Table 6). Over the 50-year time horizon investigated, a saving of approximately 28% in total costs relative to the baseline is achieved through the use of greywater technology. Associated with this cost-saving is an additional saving of approximately 6 000 kilolitre of water over the 50-year period (Table 5). In addition, a benefit of 0.82 $/kl per household is achieved. The rainwater option is also more cost effective than the baseline, but the benefits are lower than for the greywater option.

6.2 Rural-household developments

Evaluation of the Rural Housing options indicates that the use of UDT instead of VIP in all households leads to large savings in terms of the costs of providing sanitation services (Table 6), but that no savings in water can be achieved in this way (as neither the UDT nor the VIP use water). The benefit, in terms of climate change adaptation, is the cost saving that will be achieved if UDT technology is adopted (in place of VIP technology). Therefore the UDT may now be effectively introduced as an alternative measure to decrease the economic vulnerability of rural communities to climate change. The co-benefits of the UDT compared to the VIP were described in the section 2 above.

Table 6: The estimated present value of total costs (US$) over 50 years for a range of options available to the eThekwini municipality for providing water and sanitation services to Urban- and Rural-households

Option	*PV of costs over 50 years*	*Adaptation benefit ($/ kilolitre of water)*	*Levelised Cost (R / year)*
Urban-housing development			
Baseline: Fully waterborne sewerage	$15,033	-	$584
Adaptation 1: Greywater	$11,014	0.82	$428
Adaptation 2: Rainwater harvesting	$14,001	0.28	$544
Rural-housing development			
Baseline: Ventilated Improved Pit	$4,513	-	$136
Adaptation 1: Urine Diversion Toilet	$1,517	-	$46

Finally, it is significant that the present value of the total cost of providing the VIP and the UDT sanitation services to rural households is between 5 and 15 times lower than providing urban households with waterborne sewerage, respectively. This provides a strong argument for the introduction of such a technology into new urban developments. Education is needed, however, as urban dwellers do not look favourably upon this type of sanitation.

It must be re-emphasised that no alternative water-supply options were investigated for Rural Housing as none is considered more practical than the existing method (where water is provided in subsidised tanks).

6.3 Comparison of rural and urban household developments

The criterion of levelised costs is useful for comparison of all the options that have been considered. Since household income is usually reported in terms of annual or monthly values, the evaluation of long term affordability could be achieved by comparing levelised values with annual income. Based on estimated values for levelised costs (Table 6) a cost saving of almost 30% can be achieved by selecting the greywater option instead of the baseline (fully waterborne) option which could bring significant relief to Urban Households. It is also clear that the costs of the baseline option (VIP) over a 50-year horizon become high for those living in rural households.

The levelised cost of fully waterborne is almost 20 fold higher than the UDT option (this also includes the cost difference in water supply) and this could provide justification for the wider implementation of

UDT, even in peri-urban areas. The levelised annual cost for the UDT option is only 46$/a, which is affordable even for the low income population group. However, this value is based on a rough estimate of the cost of maintenance and further investigation is required to determine this value more accurately.

The costs could also be compared with the latest income data (StatsSa, 2006), which showed that almost 50% of households earn less that 100$/month. This shows that services affordability is an issue for a large portion of population.

7 SENSITIVITY ANALYSIS

The sensitivity of the results to changes was tested in four economic-parameter values: discount rate, establishment cost, recurrent cost and the exponential rate of increase in the water price. Sensitivity to water consumption under the baseline scenario was also analysed.

A range of discount rates between 1 and 5% was tested, which is a little lower than the 8% discount rate recommended by the Reserve Bank of SA, but is justified in situations where long-term (50 years and more) environmental impacts are being assessed (Stern, 2006). The outputs from this sensitivity analysis are not presented here as the relative cost-effectiveness of each option does not change in response to changes in the discount rate – even though, as expected, the total cost estimates decrease with increases in discount rate.

Using a lower rate of water consumption for the baseline scenario reduces the absolute values of savings and benefits slightly, but the relative cost-effectiveness of each option does not change.

Finally, the parameter f in equation (3) was varied in the sensitivity analysis from 0.02 to 0.06 to investigate how sensitive the optimal solutions are to changes in the rate at which water tariffs increase over time – to reflect increasing water scarcity. As with discount rates, the optimal solutions do not change in response to changes in f. However, the results have been included for discussion (Table 7) because they clearly show the sensitivity of the magnitude of the adaptation benefits to the change in water tariffs. If water tariffs are increased substantially the benefits from saving additional kilolitres of water in the greywater option almost double and increase almost 3 times for rainwater harvesting compared to the baseline. The benefits for the greywater option are high compared to the cost of water provision and it demonstrates again how attractive this option is.

Table 7: The sensitivity of the present value of total costs (US$) and the adaptation benefit ($/kilolitre) to changes in the rate at which water tariffs increase over time

Option	***Water tariff inflation rate***		
	Low (f=0.02)	***Average (f=0.04)***	***High (f=0.06)***
PV of costs over 50 years			
Urban-housing baseline: Fully waterborne sewerage	$12,801	$15,033	$19,547
Urban-housing adaptation 1: Greywater	$10,057	$11,014	$12,948
Urban-housing adaptation 2: Rainwater harvesting	$12,726	$14,001	$16,581
Adaptation benefits per unit of water saved			
Urban-housing baseline: Fully waterborne sewerage	-	-	-
Urban-housing adaptation 1: Greywater	0.56	0.82	1.35
Urban-housing adaptation 2: Rainwater harvesting	0.02	0.28	0.81

8 CONCLUSIONS

South Africa is already faced with the problem of meeting increasing demands for water and sanitation services in an environment of increasing water scarcity and variability. As a consequence, all development planning and implementation needs to incorporate strategies that increase the cost-effectiveness and efficiency of the allocation and use of available resources (financial, social and natural capital). In this study we investigated alternative approaches to the provision of water and sanitation services to both urban and rural households in terms of their water-saving and cost-saving abilities.

In general, it was found that the options involving water-demand management were particularly effective at saving water, and these should be promoted in water-stressed countries as appropriate climate change adaptation options. Also, in a similar way to energy-efficiency options, water-demand management has co-benefits in the form of significant cost savings, in terms of the opportunity cost (i.e. its value in its next best alternative use) of the water saved.

Furthermore the promotion of ecological sanitation (Urine Diversion Toilets - UDT), both from economic and environmental perspectives, offers a more effective solution for rural, and in some cases, urban areas than do Ventilated Improved Pits or waterborne sewage. And, since the South African Government acknowledges the need to 'green' its budget and expenditure (Davie, 2007), refocusing its existing sanitation subsidies towards UDT could contribute to the government meeting this objective at both local and national levels.

The model developed in this study has clearly demonstrated the importance of evaluating costs over a longer time horizon than is currently the practice in local government. Consideration of long term impacts, such as those of climate change, helps to mainstream adaptation into planning processes. Since planning processes involve wide stakeholder participation, this model could be a useful tool to demonstrate to decision makers, service providers and consumers the benefits of the suggested technologies. The model is also sufficiently simple to allow for it to be applied within data and resource-scarce environments and yet provide reliable, consistent results.

9 RECOMMENDATIONS

The proposed model is a simplistic one and does not account for indirect health (avoided sickness) and livelihood benefits that come from providing additional water more effectively and efficiently (at a lower cost) to larger numbers of people and over wider areas. Similarly the damage caused by the negative impacts of VIPs on water pollution, have not been included. In addition, although the opportunity cost of water was briefly mentioned as an important factor influencing water allocation and use, it has not been adequately accounted for within this model. The model can be enhanced to account for all of these issues when evaluating trade offs in the provision of water and sanitation. Such modifications, however, will increase its complexity and its data requirements and may detract from the advantages it currently provides.

Further improvements to the analysis could be achieved in terms of the accuracy of the input data used in the model. This may ensure that the results are a more precise representation of reality but the additional cost of doing so needs to be weighed against the benefits of having more accurate values. Also, the impact of location of the housing developments may affect the findings of this study, indicating that there is scope to re-apply the model to different areas and alternative scenarios. Finally, the model could be further enhanced by accounting for subsidies. This would provide a more complete picture of the total costs, particularly the cost to government.

Even though water-demand management, in the form of greywater, is more water efficient and cost-effective than traditional waterborne sewerage, it has still not been widely adopted. Barriers to its adoption are: 1) communities are unaware of the technology and its effectiveness; 2) it entails an additional upfront cost, over and above costs already being incurred; and 3) individuals' resistance to change. Suggested ways of overcoming these barriers and increasing the adoption rates of such technologies might involve:

1. once-off subsidies to low-income households, to help cover the large upfront capital costs of greywater sanitation or rainwater harvesting for example, could be provided on a means-test basis.
2. restructuring the existing water-tariff structure in the eThekwini municipality to create incentives for consumers to save water – even at lower consumption levels. For example, the City of Cape Town has a 6-block tariff structure (instead of the 3-block structure used by eThekwini municipality – see Table 4) and the price increases by almost three times when more than 12 kl is consumed.

Finally, it is recommended that the evaluation framework developed here is combined within a Multi-criteria decision framework (i.e. including non-monetary criteria) to evaluate adaptation strategies within the broader context of sustainable development. Sustainable development involves economic growth, social equity and environmental sustainability and should be pursued irrespective of the climate change debate. Therefore, environmental-economic tools and techniques capable of evaluating development options that consider both climate change adaptation and the social, environmental and economic co-benefits of sustainable development are vital in municipal (local government) planning processes. It is suggested that this pilot be extended into a national study to provide government with a clearer direction on: sustainable water supply and sanitation options; mainstreaming climate change adaptation in development planning; and "greening" government expenditure and revenue generation.

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