DOCUMENT NUMBER: CSIR/NRE/RBSD/EXP/2008/0156/A

Natural resources, environment and municipal service provision. Results of a participatory systems dynamics scoping model in Cape Town.

Paper presented at 10th Biennial International Society for Ecological Economics Conference, Nairobi, 11 August 2008.

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Abstract

Cities in developing countries often have to face a multiplicity of external shocks that impact on their operations. These changes include increased rates of migration from the rural poor, natural resource shocks such as droughts, decreased space for solid waste landfills, electricity supply disruptions, and polluted discharged water from wastewater treatment works into the environment. These shocks places huge pressure on municipal finance system and may be aggravated by a disconnect between planning for the physical flow of services and the financial budget process. Using a systems dynamics model for the City of Cape Town it is argued that supply constraints are real at high growth scenarios and that huge additional investments in increasing supply and reduced demand options are needed. It is argued in this paper that cities do have options available to respond to such shocks. Relatively simple options would be to move beyond simple parametric adjustments based on growth factors when projecting for the future demand for services. A better understanding of consumer behaviour, a more flexible tariff system to reflect natural resource scarcity and to send signals on conservation when required, and the integration of processes for planning budgets and actual service provision within the City itself. It is expected that such measures would improve the cities' flexibility in responding to external shocks.

Keywords: city management, municipal services, water, electricity, sanitation, solid waste, municipal finances, tariffs

Introduction

The City of Cape Town lies in a very beautiful natural setting and has a temperate Mediterranean climate. These features, as well as the extraordinary biodiversity in and around the City, contributes not only to Cape Town's image as a desirable location to live in and to visit, but also supports a diverse and export-orientated agricultural system. The aspiration of Cape Town to be globally competitive and continue to attract international tourists while at the same time overcoming its socio-economic challenges, continues to pose a dual challenge to the city's administration (Western 2002). Due to migration and the failure of economic growth to translate into a reduction of poverty or a sustained increase in employment, a rapidly increasing number of households are becoming indigent. This places increasing pressure on services backlogs in water supply, sanitation, electricity and solid waste services. The lack of investment in and maintenance of infrastructure combined with escalating housing backlogs places huge pressure on Cape Town's municipal administration. In recent years, natural resource supply-side shocks placed additional pressure on the ability to assure a continued supply of EWWS services and from a municipal finance perspective, a smooth income stream from the provision of these services. The municipality has increasingly become dependent on national government transfers and with a recent slowing of the economy, this substantially increases its vulnerability. To ensure sustainable service provision the City of Cape Town's management has to plan for and adapt to natural resource supply disruptions, the side-effects of environmental waste and pollution, pressure on housing and services backlogs aggravated by migration by mostly indigent people and an increasingly dependent municipal finance system.

Since the early 2000s, natural resources such as freshwater and land have become increasingly scarce due to severe droughts and higher demand due to population growth and a consumer-orientated economy. Electricity supply has become more erratic as the expansion of coal-fired power generation elsewhere in the country and transmission to the city came under stress due to infrastructure backlogs and increasing demand. Some wastewater treatment works are operating on full capacity and for three quarters of the time are not able to treat water up to local water quality guidelines. The generation of solid waste has mushroomed in recent years, placing severe pressure on existing landfills and pressure to develop landfills in far-away places which will increase the cost of transporting waste.

The city's response has so far been partial and reactive. Severe water restrictions were implemented, electricity load shedding and rationing occurs (although not only strictly a city problem), and in both cases small scale demand-side management programmes are implemented. Some pilot programmes have been launched to recycle solid waste. Planning for future services still occurs in isolation at different city departments, using different assumptions on the implications of population and economic growth and pricing on the demand for electricity, water, waste and sanitation (EWWS) services. Despite some experiments with demand-side management, the mindset that supply-driven solutions (e.g. dams, power stations, landfills, treatment works) are the most reliable and therefore preferable is still a persistent assumption.

This partial, uncoordinated approach to natural resource based service delivery will not be sufficient to steer the City onto a more sustainable development path. The delivery of EWWS services in the City are all reliant on the allocation of funds from municipal finance budgets, which in turn, is influenced by the scarcity of natural resources and the potential risks, liabilities and costs of services and service breakdowns on the environment. This research attempts to offer new insights by focusing on the dynamics of the provision of EWWS services and associated implications on municipal finances.

The paper is divided in six additional sections. Section 2 describes the EWWS system. Section 3 reports on data collected and processes followed to engage stakeholders. Section 4 reports on the model and section 5 discusses the results. Section 6 concludes and makes some recommendations for further work.

Describing the system

Natural resource dependencies

The natural diversity in and surrounding Cape Town not only has an important role to play in the agricultural and tourism economies, it also plays an important role in the ability of municipalities to deliver water, sanitation and solid waste services.

The bulk of the City's water is dependent on surface water, stored in dams over the wet winter months for use in the dry, hot summer months. Continued water supply is sensitive to prolonged droughts as was evident during the droughts of 2000/1 and 2003/4/5 - in both cases resulting in water restrictions and conservation measures. Only 20-25% of this water is directly managed by the City of Cape Town.

The longer term sustainability of sanitation services is dependent on the ability of the environment to absorb treated effluents and/or spillovers in case of system failure. There is not much room for error though. The ecological health of rivers downstream of final effluent discharges from Cape Town wastewater treatment works are already categorized as “poor” to “bad” (Pithey & Frame 2007). In addition, almost 6% of wastewater is already discharged directly via marine outfall sewers.

One of the key constraints facing the city with regards to the continued provision of solid waste services, is the availability of a suitable land space for landfills. There are only three landfills remaining in the City which are filling up very rapidly, mainly driven by waste from richer households (RMS 2007). A new landfill is considered either at Atlantis, almost 50 km outside of the City centre or at Kalbaskraal which may also serve smaller adjacent municipalities such as Stellenbosch. Atlantis would need to be supported by an adequate transport system and Refuse Transfer Stations (RTS). However, as oil prices rise to new heights, long-distance transportation of large quantities of solid waste becomes increasingly unaffordable.

Cape Town needs to buy most of its energy sources from external sources. The City is mainly dependent on the national utility Eskom for electricity provision which means that it is fully exposed to the risks of buying electricity from an under-capacitated and mainly fossil-fuel driven power generation system, which also has to deal with the transmission of electricity over more then 1500 km. Although the country’s only nuclear plant is close to the City, the power generated belongs to Eskom. The City has some capacity to manage peak demand through pumped storage schemes and a gas turbine. The City serves approximately 75% of the City’s customers, with Eskom servicing the remainder. Eskom, however, serves about half of the poor households in the City (IDP 2007).

Housing, services and maintenance backlogs

Over and above the challenges to manage a sustained supply of natural resources such as water and energy and to balance the environmental impacts of service delivery, net migration of mostly poor people to the City is placing further strain on sustained EWWS services provision. The City’s population has doubled from the early eighties to the early 2000’s (Western 2002) and currently stands at 3.3 million people. The rate of population growth has started to slow down from an average of 3.2% pa between 1996-2000 to 1.6% pa in 2006, and projected to grow by only 0.6% pa by 2021 (Romanovsky 2006).

Although overall population growth is expected to slow dramatically, migration, mostly from the much poorer Eastern Cape province and attracted by the relative socio-economic success of the City, accounted for 47% of population growth in 2005 and is projected to account for 87% of population growth by 2021 (Romanovsky 2006).

This migration pattern into the City is mirrored in the rapid growth in informal settlements from 28 300 in 1993 to 104 216 in 2006. Year on year growth in informal settlements started to level of from 2002-2005, but latest 2006 data suggest renewed stronger year on year growth of more than 6%.

Not surprisingly, the housing backlog (including informal settlements and backyard shacks) has risen from 150 000 units in 1998 to 265 000 units in 2006 (SACN 2007) and to an estimated 300 100 units in 2007 (PERO 2007). The housing backlog is not only driven by migration, but also by a decline in household size. Housing delivery, on the other hand, falls far short and is lower than an average of 5 000 dwelling units per annum as measured over the period 2000-2004 (SACN 2007, IDP 2007). These factors in turn place pressure on the extension of EWWS services to all households in the City beyond the existing backlogs and holds a significant risk that rapid and broader EWWS service delivery would be required once housing delivery accelerates.

Despite considerable progress that has been made on the roll-out of EWWS services since 1994, backlogs remain especially in sanitation (DWAF 2008), but also in electricity connections and water supply services.

In 2001, 88% of all households in Cape Town and 93% of al indigent households received at least a basic level of solid waste management (DEAT 2007). Currently, all households in Cape Town have access to weekly refuse removal services and all backlogs have been eliminated (DEAT 2007).

Sanitation backlogs are more than double those in water supply. An estimated 56 369 households or 204 449 people do not yet receive sanitation services at RDP service levels or higher. At the planned rates of sanitation service delivery (3 719 households in 2008/9) and assuming static household growth, the roll-out of sanitation services would take at least 15 years to achieve full coverage of current backlogs. The planned delivery target from 2008 onwards is to connect around 18 300 households per year to sanitation services, eliminating the sanitation backlog by the end of 2010. Recent data on actual delivery suggest that this may be too optimistic. Sanitation backlog delivery for the largest part of 2007 achieved only 12% (or 140 households per month) of a target to connect an average of 1200 households per month (DWAF 2008).

The number of households without electricity supply declined from 82 928 in 1998 to 39 715 (or to an estimated 145 000 people) in 2005 (Cape Town IDP 2007).

In April 2008, only an estimated 6 210 people or 1 712 households had no access to any form of formal water supply in the City. The estimated number of water needy households are much higher at 25 344, equal to 91 907 people who receive water supplies below the RDP service level (communal tap > 200m from dwelling, unacceptable quality and unacceptable flow).

The financial implications of dealing with the housing backlog and the free services associated with this, has been estimated for a housing backlog of 265 000 as an additional council CAPEX ‘top-up’ of R442m per annum plus R223m in OPEX on free basic services per year over a period of 15 years (SACN 2007). At current housing backlogs (300 100 units), and assuming constant prices, this cost to the council is now likely to be closer to an additional R750m pa over 15 years.

The sanitation backlog associated with the housing backlog of 300 100 is estimated at R6.4 billion, or an average unit cost of R21 300 per household (DWAF/DLGH 2007). Of this total, the backlog in bulk water infrastructure amounts to R2.016 billion, bulk sewer (treatment works) R1.984 billion and internal water and sewer backlogs of R2.4 billion.

Bulk electricity infrastructure backlogs are experienced in Medium Voltage infrastructure (switchgear) and fueled by new growth in certain areas. No unit cost estimates for bulk electricity infrastructure was available for this study.

Economic change, poverty and demand for services

The next question concerns the impacts of economic change on EWWS service delivery. These forces are not only important in a better understanding of increased demand for such services, but also the ability and willingness to pay for these services. The City of Cape is the economic powerhouse of the Western Cape accounting for more than three-quarters of the province's economic activity. The City's economy grew at an average annual rate of more than 4% between 2000-2006, reaching a high of 5.4% in 2004. The economy is increasingly orientated towards financial and business services as well as to wholesale and retail trade. From 2000-2004, the economy was mostly driven by expanding domestic consumption, but a shift towards fixed investment spending in areas such as construction, electricity, gas and water, finance, business services (in particular security services and IT) and trade is expected to set the stage for growth in the next few years.

Although employment and unemployment statistics are not considered to be very reliable, there is some optimism that overall unemployment in the City may be on the retreat. According to the annual Labour Force Survey, unemployment (in the age group 15-64 and excluding discouraged job seekers) was measured at 21% in September 2005, compared to 15% in September 2006. When including for discouraged job seekers this rate is higher at 26.5% in September 2005 and 23% in September 2006. It is interesting to note that this estimated drop in unemployment took place at the same time that the economy was slowing down from a high of 5.4% growth in 2004 to a 4% growth in 2006, possibly signaling that underlying structural factors were being addressed rather than growth itself creating new employment. The key point for this analysis is that absolute figures are still substantial though, amounting to almost 225 000 unemployed people in the City, compared to 212 000 in 2000 and 175 000 in 1995 (City of Cape Town 2006).

The relatively strong performance of the economy in recent years has not meaningfully contributed to a decrease in the amount of households rising above subsistence level. According to the City's own measure, the number of households living below the Household Subsistence Level (HSL) has *increased* from 25% or 163 000 households in 1996 to 38% or 333 000 households in 2005 (City of Cape Town 2006).

This trend is mirrored in the increased dependency on social grants in the City. In 2005, 390 000 people received social grants compared to 416 000 in 2006 - a 6.6% increase in one year. However, this could also be due, in part, to increased awareness amongst people who qualify for social grants of their rights followed by actions to access their grants.

Most planners in City Departments assume that there is a positive correlation between strong economic growth and size and extent of the revenue base for EWWS service delivery. In reality, this relationship is far more complex, non-linear and unpredictable that this common perception assumes is the case.

The City experienced large year on year changes in the use of most services, most notably waste and energy use, and most notably from 2003/4 onwards (Fig 1). This does not mean that economic and population growth necessarily translates into higher pressure on all EWWS services. When measured over the time period 2000-2006, stronger sensitivities to growth are apparent in energy use and solid waste generation, but lower sensitivities are apparent for electricity use and influent received at wastewater treatment plants (Fig 2 & 3)[1]. The percentage change in water used per one percentage change in economic and population growth is the most volatile, and even negative for five out of the ten years. An interesting disparity is that, although growth in energy use has strongly increased from 2004-2006, growth in electricity use has declined from a high year on year growth of 4.8% in 2001/2 to 2.1% in 2006/7, signaling increased use of liquid fuels and a possible substitution of energy sources from electricity to liquid fuels.

Figure 1: *Rates of year on year growth in GDP, population and EWWS services in the City of Cape Town, 1996-2006*

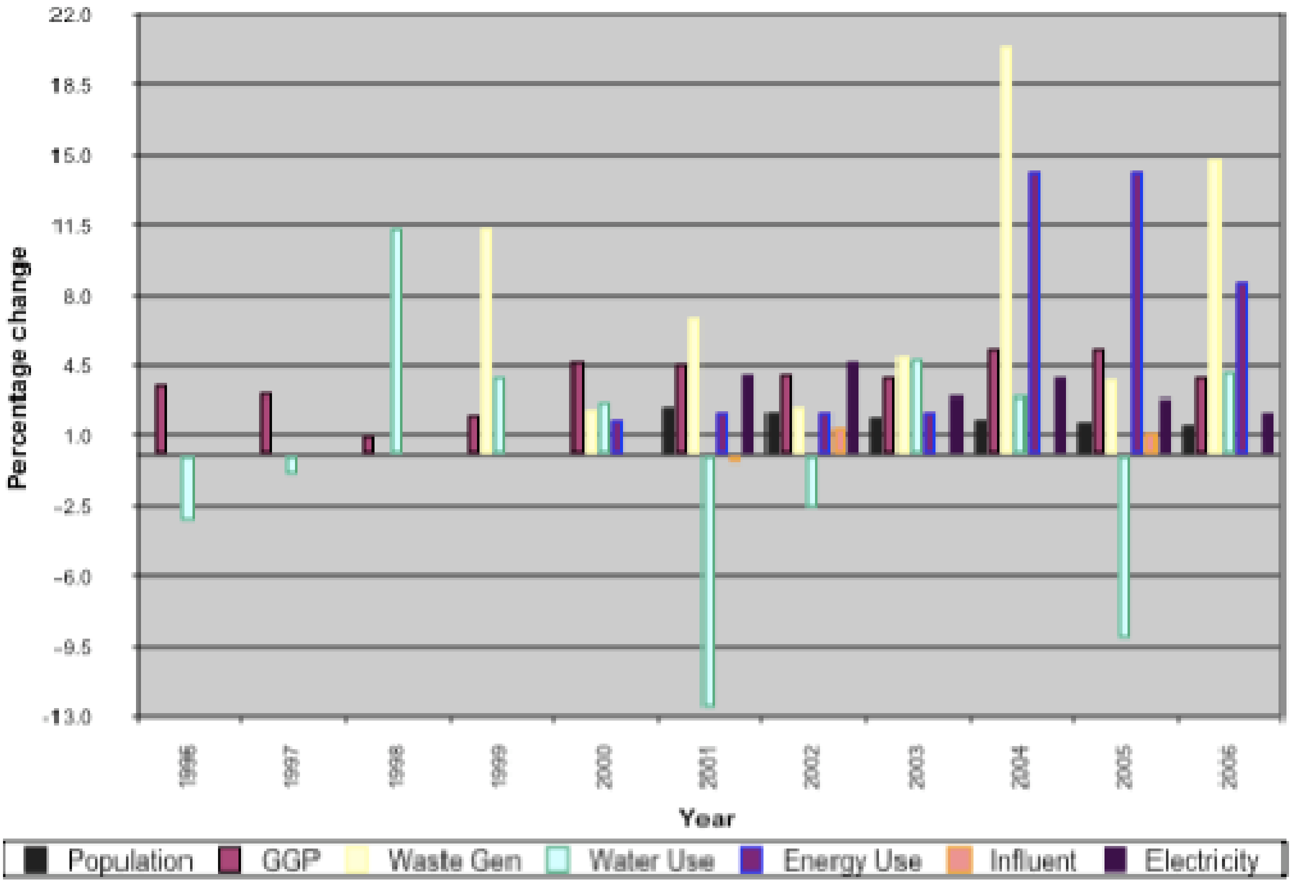

Figure 2: *Percentage change of EWWS use per one percent change in GGP*

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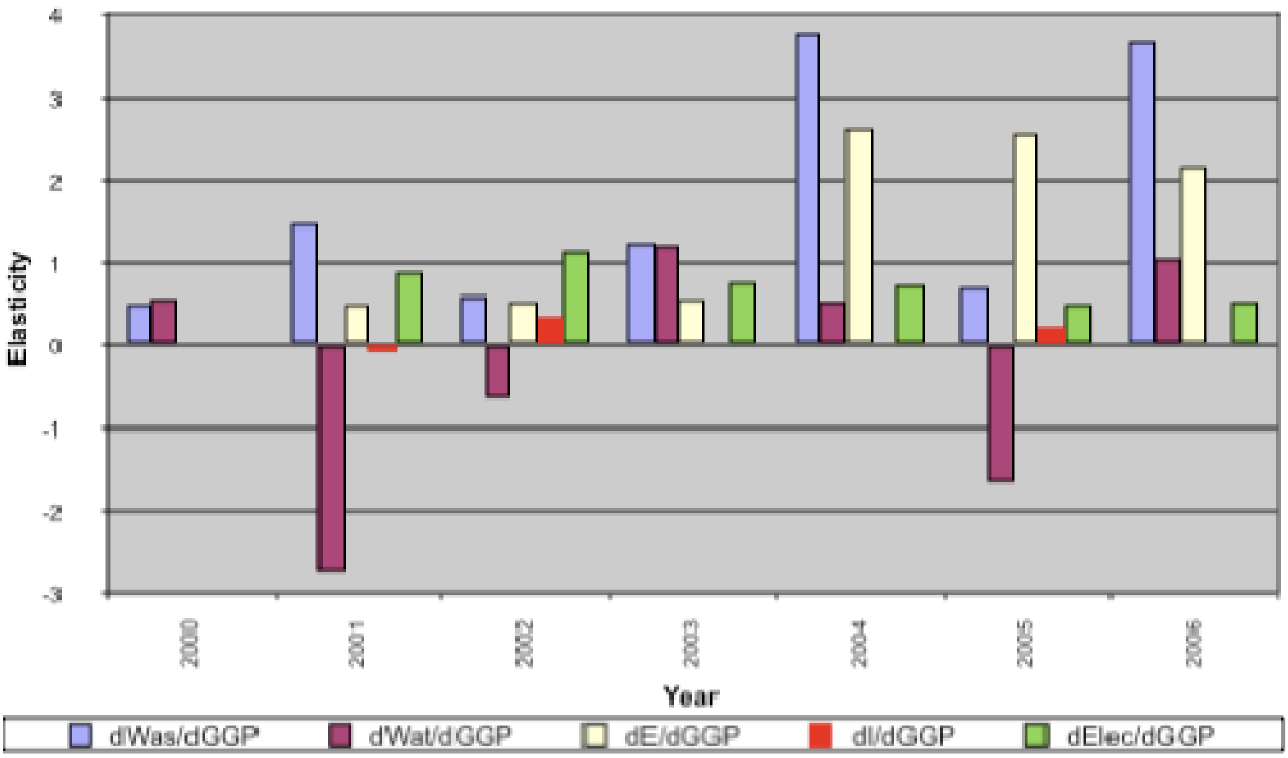
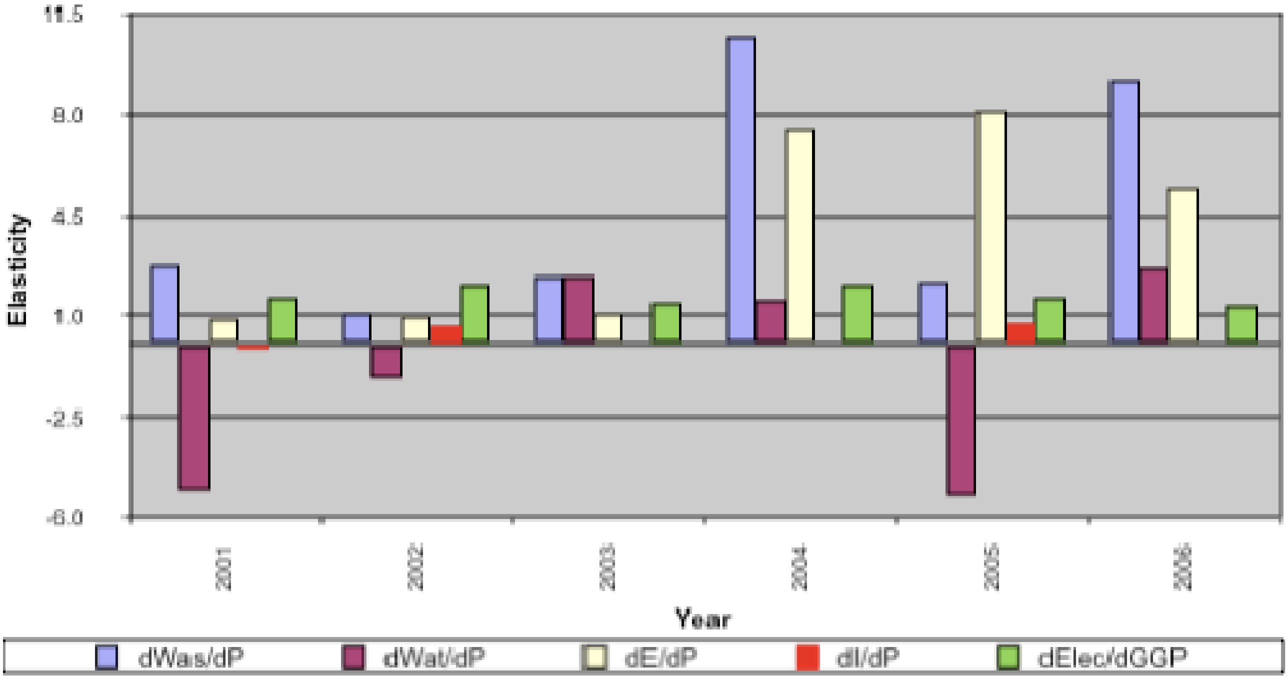
[1] In economics, the ratio of change in one variable with respect to change in another variable is referred to as ‘elasticity’.



Notes: Solid waste generated = Was; Water use = Wat; Energy use = E; Influent received = I; Electricity = Elec

Figure 3: *Percentage change of EWWS use per one percent change in population*



Notes: Solid waste generated = Was; Water use = Wat; Energy use = E; Influent received = I; Electricity = Elec

This analysis does suggest that future projections on the use of EWWS services cannot simply be made by extrapolating from a linear economic growth or a population coefficient. The growth factors that are used for projections by the City are as follows:

- For electricity use: 2.7% for 2007/8 and 3.5% after that (City of Cape Town 2007a, City of Cape Town 2007b, City of Cape Town 2007d). Note that the 2008 IDP review factored a 0% increase of electricity growth mainly due to the implementation of a energy savings plan.
- For water use: 3% pa unconstrained demand (Pithey & Frame 2007)
- For solid waste: 7% (without waste minimisation) (City of Cape Town 2007c)

The level and volatility of such growth factors are important because projections resulting from these factors drive projections of required expenditure on bulk infrastructure. This is especially the case for projections on water use. The average growth in water use from 2001-2006 was -2%, and for the ten years from 1996-2006 only 0.04%, compared to an average economic growth of 3.9% pa over the same period. It is the volatility in the growth of water use that complicates planning for future water use. Water use growth peaked at 4.9% in 2003/4 and hit a low of -12.4% year on year growth in 2000 to 2001.

The growth in electricity use over the last few years is also lower than the current growth factor used for projections. Growth in electricity use is expected to be even lower in the immediate future with supply constraints and much higher electricity tariffs from 2008 onwards.

In the case of water and electricity use the first signs of a decoupling between (economic and population) growth and demand may be imminent, but without more information on underlying consumer behaviour no definite conclusions can be made yet.

Solid waste grew by an average of 8.9% over the period 2001-2006, with a high of 20.4% in 2003/4 and a low of 2.6% in 2001/2. A growth factor of 7% may rather look on the low side than on the high side as with water and electricity use, but at this stage little is known about the categorisation of waste and the behavioural dynamics underlying solid waste generation and responses to waste minimisation.

Municipal finances

The municipal finance system had to adapt to these complex dynamics and it was required to continue to fund the provision of a sustained flow of EWWS services. The municipal finance system in Cape Town is itself complex and has only recently emerged from a process of fundamental restructuring. A few initial observations will be made about the context of the framework wherein city managers have to respond to these emerging risks. These observations are all based on a draft budgets released by the City in May 2007 (City of Cape Town 2007a).

First, despite the backlogs and increased pressures on EWWS services, the City's budgeted expenditure on EWWS services is fairly constant at around half the total budget. The City budgeted around R9.3 billion or 47% of its budget on capital and operational expenditures on EWWS services for 2007/8. This compares to R7.8 billion or 45% in 2005/6 and R8.5 billion or 50% in 2006/7. These numbers do mask a large variation in budgeted capital and operational expenditures and in expenditure on various services though. Contrary to what one would expect, budgeted operational expenditure on EWWS services is budgeted to *drop* from around 50% of all operational expenditure in 2005/6 to 45% in 2007/8, 2008/9 and 2009/10. The overall budgeted capital expenditure also is budgeted to drop substantially from R4.1 billion in 2005/6 to R2.8 billion in 2008/9. These budgeted figures do mask the fact that actual capital expenditure can be much lower than budgeted capital expenditure.

This brings us to the second observation. In 2005/6, Cape Town only spent 37% or R1.5 billion of its R4.1 billion capital budget, a situation mainly attributed to the slow delivery on the N2 Gateway low-cost housing project (SACN 2007). However, this trend of under-spending was persistent in the City over the last decade with actual expenditure within a range of roughly 60-70% of the capital budget (City of Cape Town, 2007). Despite this trend, capital expenditure on EWWS services is still budgeted to rise from R1 billion in 2005/6 to R1.8 billion in 2008/9. This amounts to 25% of total budgeted capital expenditure in 2005/6 and 64% in 2008/9.

Third is the question whether these budgeted capital expenditures are sufficient to deal with the EWWS services backlogs, to ensure bulk infrastructure and to ensure a sustainable provision of services. According to SACN (2007) housing alone in the City will need an estimated capital 'top-up' of R442m pa (at an assumed capital top-up funding of approximately R25 000 per dwelling unit) with an additional operational cost of R223m pa for the provision of free basic services (at a backlog at that time of 265 000 units). When adjusted in a linear way to the current backlog of 300 100 this figure is likely to be closer to R750m pa over 15 years. According to Cape Town's IDP (2006/7), solid waste would need capital expenditure of between R130m and R230m pa in the period 2007/8 to 2010/11. Water and sanitation services would need R1.1bn in 2007/8 and in 2008/9, R840m in 2009/10 and R690m in 2010/11 (IDP 2006/7), with large increases mainly driven by the need for new bulk water infrastructure, wastewater treatment extensions and sewer reticulation systems. The capital budget for electricity services is also in the order of R500m pa in the period 2007/8 - 2009/10. Assuming that these capital budgets were designed to take account of the backlogs and future growth and assuming these estimates are a good reflection of actual costs, rough estimated capital requirements for EWWS services are in the order of R2 - R2.3bn per annum over the next 3-4 years. This figure is probably conservative given the extent of the housing, services and infrastructure backlogs.

Fourth is the question whether the city can generate enough revenue to finance required operational and capital expenditure. It is apparent that the city has become increasingly dependent on government grants in recent years. Grants have increased from below 10% of total revenue before 2005/6 to 22% (R3.8bn) in 2007/8. In addition, income from EWWS service charges in 2007/8 are budgeted at R5.2bn, with 80% of service charges from electricity (R3bn) and water (R1.1bn) alone. Sanitation service charges are responsible for around R640m and refuse service charges for R480m. Property rates bring in an additional R3.5bn. Municipalities, in general, generate surpluses on the sale of electricity to their customers which in many instances is used to cross-subsidise other costs. National Treasury estimated that the City of Cape Town generated a surplus of 18.2% on the sale of electricity in 2000 (National Treasury 2004).

Fifth, the nature of these grants are important and not all can be attributed to revenue. Government grants consist of an equitable share or an unconditional grant and a conditional grant where the municipality has to fulfill the condition of the grant before it can be recognised as revenue (SACN 2007). Equitable share provisions are unconditional but mostly associated with free basic services for the indigent. These grants have risen sharply from R105m in 2003 to R464m in 2008/9 and, according to DORA 2008 allocations, to a provision of R831m in 2010/11 (City of Cape Town 2008). In per capita terms this is an increase from roughly R33 per person in 2003 to R140 per person in 2008 and R245 per person in 2010. The same rapid rise can be seen in total government grants, from R630m in 2004/5 to R1bn in 2005/6 and to a budgeted R3.8bn in 2008/9. In per capita terms this translates to roughly R325 per person in 2005/6 to R1165 per person in 2008/9. Grants are dependent on the performance of the national economy, and over-dependence poses a significant risk to the City in case of a national economic downturn.

Sixth, tariff increases are limited by several factors, most notably by the Total Municipal Account (TMA) payable by households. Tariff increases are usually aimed at increases not much higher then CPIX, but in case of exceptional external circumstances, such as Eskom's tariff increase to municipalities, higher tariff increases may be implemented (see Table 1 for proposed tariff increases for 2008/9). Eskom's tariff increases, in turn, are approved by the National Energy Regulator of South Africa (NERSA). Tariffs are further influenced by the projections for operational expenditure, consumer behaviour and affordability, legal and political balancing of the budgets and the 5 year cycle effects when new census results become available. All combined, this has the effect that the longer-term affordability of offering EWWS services are not well-configured into the current process and continues to fuel the need for cross-subsidies and dependency on government grants.

Table 1: *Proposed tariff increases 2008/9*

	Increase
Rates	7.3%
Refuse	7.5%
Electricity	15.0%
Water	9.2%
Sanitation	6.0%

Source: IDP Review 2008/9
Note: Electricity price increases does not include additional increase by Eskom.

In summary, the combined forces of unstable supply of natural resources such as water and mainly fossil-fuel based electricity, environmental pollution from inadequate sanitation and storm water, the rapid filling of landfill airspace, net migration, rising poverty, the commitment to free basic service provision, EWWS services backlogs, housing and infrastructure maintenance backlogs and high levels of unemployment creates massive and complex pressures on the City of Cape Town and the metropolitan economy as a whole. This is happening within the context of a relatively constant proportional budget allocation to the operational costs of EWWS services, and within the context of an under-spending of capital expenditure on such services. This situation has forced a longer-term, integrated reflection on the contextual diversity facing the City with a view to improve longer-term, strategic decision making in such a complex environment.

Participatory process

The process was participatory in nature and modelled on the basis of a mediated modelling process suggested by van den Belt (2004), but limited by the time and resource constraints of the project. Several resource experts, city managers and city administrators were involved in the conceptualisation and qualitative modelling phases of the project. The quantification and evaluation of the model was done off-line when opportunities were created for these groups to provide feedback on reports at set intervals throughout the process.

Thanks to several years of preparation and despite political changes in the city on more than one occasion, the project received high-level mayoral support. At the start of the modelling process, a general introduction to the overall process and approach was done with city managers as well as experts on EWWS services within the control of the city involved. It was agreed at this meeting in May 2007 to follow a participatory and system dynamic modelling approach to the integrated analysis of natural resource flows and service provision in the city.

During fourteen separate meetings, each lasting between two and three hours, more specific discussions and interviews with key experts and key decision makers were held during June-August 2007. These meetings were focused on an introduction to the system dynamics modelling software PowerSimTM, problem identification, current scenarios and forecasts used in the city and key questions generated by the participants. The purpose of these discussions was to map the problems that the City of Cape Town was facing, to identify key questions, to validate the modelling process, and to establish inputs on a baseline with respect to the socio-economic, institutional, energy, waste and water situation in the city.

The leading questions that guided these meetings were:

- What are the main problems facing the city of Cape Town now?
- What causes these problems?
- What are the main effects of these problems?
- What are the current forecasts and scenarios?
- How are forecasts and scenarios done in the city of Cape Town? (e.g. models, procedures)

A start was made during these meetings to identify key stocks and control variables, a process that was continued via desk-top studies. At the same time, the modelling team engaged off-line with the sectoral experts responsible for the baseline review with the purpose of filling anticipated data gaps and to better understanding the linkages within and between the EWWS sectors. A key missing piece of information at this stage was an expert baseline review of the municipal finances of the city, but a more general discussion with a financial-economic expert in the City was included to better understand the socio-economic context.

Given this initial feedback the modelling team prioritised the key research questions that the model should be able to address, and decided to start with more macro questions moving steadily to more detailed questions subject to available time and resources. . The team also followed up with experts and decision makers on information and data that was needed to address these questions. A high level preliminary model linking economic and population drivers to EWWS use was developed and used as an introduction to a next round of meetings with experts and decision makers. A smaller group of people per sub-sector did proceed with the further development of an initial qualitative model in five separate modelling workshops held during September and October 2007. During these workshops the focus was on the confirmation of stocks and flows in the model, as well as a facilitated discussion about the main controlling variables that govern the various EWWS subsystems. Participants were encouraged to speak freely about how they see the system interacting, facilitated by a qualitative interpretation of system stocks, flows and linkages drawn on flip-charts.

The integrated analysis was highly enriched through this process at least on two distinct levels. First, it proved to be very valuable to let experts and decision makers speak on their interpretation of the challenges facing Cape Town and then generate their own key research questions. This avoids the trap that the modeler or analyst focuses on certain aspects of the problem that have little or no relation to perceived problems in the City. Although hard to measure, it is believed that the participatory approach also took attention away from the model as such while enriching the process of establishing common ground and trust between officials/managers from different Departments. The back-up of sector experts was vital to provide deeper insights into and interpret the data of the various EWWS subsystems.

The interplay between the dynamic, diverse, open and creative participation process and the structured, focused and more disciplined approach to modelling continued to be a source of tension for the project team throughout the study. The sheer complexity of the work forced prolonged periods of time of structured off-line work, without any meaningful engagement of participants. The single biggest drawback was the amount of time and effort that had to be spent on collecting data that described the various aspects of the system and the lack of baseline information within the municipal finance system at the start of the study, as well as the participation of designated municipal finance experts throughout the study. This was the real-world context wherein the study was done and came at the expense of a more effective process-structure balance in the modelling process.

Model

This project used a systems dynamics modelling approach. In this approach the system is observed as a whole before certain parts of it are optimized. There is no attempt to solve or optimize a solution towards a particular problem, but rather to expose systematic relationships and simulate possible futures.

This ‘stocks and flows’ approach taken in this work relies on the intellectual roots of systems thinking and has been developed and applied in many areas such as ecological economics, organizational learning, group dynamics and the science of complexity, amongst others. Systems dynamics thinking studies the changes in systems over time that emerges from the interrelatedness of the parts (Van den Belt 2004:22). The inclusion of such dynamic relationships leaves space for time lags and feedback loops, concepts ignored in linear thinking processes.

This project makes use of a well-known software tool in systems dynamics modelling, namely PowerSim[2]. PowerSim is an object orientated programming language where features are depicted as stocks (state variables), flows (in and out of state variables), auxiliary parameters (variable algebraic or graphical relationships containing calculations based on other variables), constants (fixed parameters), and links (giving information to auxiliary variables about the value of other variables). Initialising links provide information on the start-up information to level or state variables (see Costanza & Voinov 2001, PowerSim Constructor). Stocks can best be described as reservoirs, flows as the rates of change, and auxiliary parameters as constants, mathematical or graphical functions.

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[2] www.powersim.com

PowerSim relies on a user-friendly interface that facilitates the building of system dynamics models either as an individual modeler or in group settings.

Technical modelling steps, information needs and involvement of decisions makers, experts and the modeler (or modelling team) per step are described in Table 2. The definition of problems (step 1) facing the City of Cape Town was done through (i) an expert baseline review on the EWWS sectors in the City (Sustainability Institute, 2008; Resource Management Services, 2007; Pithey & Frame, 2007; Sustainable Energy Africa, 2007) and through (ii) a process of consultation with City decision makers in the EWWS sectors (see De Wit 2008 for a more comprehensive report on the results of this process). State and control variables (step 2) were identified with smaller groups of experts and decision makers in sectoral mediated modelling workshops. During these workshops key stocks that need to be managed and controlling variables were identified and qualitatively discussed in a group setting. Key relationships were identified (step 3) and a list of parameters that would describe such variables identified (step 4). Prototype models for each EWWS sector were developed in PowerSim (step 5), which helped convey the nature, purpose and limitations of the project. With relational maps drawn, the next phase was to source data on the many stocks and control variables in the respective EWWS sectors. This was a long-drawn process resulting in an Excel database finalised in January 2008 (De Wit 2008). On the basis of the problems identified, the expert description of relationships in the system and the supporting database, the prototype models were further developed into an enhanced prototype EWWS model (step 5). This model was developed in PowerSim and contains total energy, electricity, liquid fuel, water, sanitation and solid waste and municipal finance submodels. The municipal finance model includes submodels for income as well as CAPEX and OPEX models for water, electricity, sanitation and solid waste.

Table 2: *Modelling steps, information needs and involvement*

Steps	**Questions**	**Involvement**
1. Define problem and goals of the model	What are the system boundaries in terms of space and time? Who will be the ultimate user?	Decision makers Experts Modelling team
2. Define state variables	What are the “stocks” (bathtubs) in the system? What are the initial values for these stocks?	Decision makers Experts Modelling team
3. Designate control variables	What flows into/ fills up the stock? What flows out of / drains the stock? How are the rates of flow measured? Do these flows come from or go to any other key stocks? Are there feedbacks between the level of the stocks and the flows?	Modelling team, with inputs from decision makers and experts
4. Select parameters that describe control variables	How are rates of flow controlled?	Modelling team, with inputs from decision makers and experts

5. Examine prototype model for violations of physical, economical, ecological laws	Does the model work? Are the units consistent? Are there continuity requirements on variables? Does the model produce negative volumes/prices or other outcomes that do not make sense? Does the model attempt to divide by zero?	Modelling team
6. Test model for expected outcomes	Does simulation of two variables over a specific time frame compare to expectations? Can surprises by explained?	Modelling team
7. Vary parameters with reasonable extremes	Do results match expectations? Are there identifiable thresholds where behaviour of system changes?	Modelling team
8. Validate with historical data, experimental results and other models	Does the model yield comparable results?	Modelling team
9. Increase model complexity	Link to other submodels. Repeat steps 5-8.	Modelling team, with inputs from decision makers and experts
10. Frame new questions	Repeat steps 1-9.	Decision makers Experts Modelling team

Source: First two columns from Hannon, Bruce and Matthias Ruth, Dynamic Modeling (New York: Springer-Verlag, 1994) as further described on http://www.uvm.edu/~jfarley/237/wkbk/EEWkbk-Ch7.doc

The further examination of the model, testing for expected outcomes, simulation of model within extremes and the validation of the model (tasks 5-8) were performed with an international expert in mediated systems modelling during May 2008.

The overall objective of the modelling work was to improve the effectiveness of decision making in the EWWS sectors in the City of Cape Town. It was decided to develop the model on a 20 year time frame, to be focused on Cape Town only, to be highly complex and integrative rather than exclude specific sectors and to be inclusive in its approach. The model is not spatially explicit and was built with the involvement of at least 40 people from various departments in the City as well as several sector experts. No specifications were given on the variables that had to be included in the model. This, by definition, yielded the space for the development of a high level scoping model that can be used for simulations on a macro level. Such simulations focus on the interplay between aggregate supply and demand of EWWS services, their associated cost to municipalities and the impact of targeted intervention options.

Data for the model was gathered from a huge variety of sources, including City documents, expert baseline reviews, national and provincial statistics, academic publications, grey literature and personal communications.

Five model sectors were identified which are all interdependent. The sub-sectors - water use, sanitation, electricity and solid waste - were included by design, but it was felt that a separate model would be needed for municipal finance, transportation and spatial patterns (in particular densities and densification). Transportation, liquid fuels and spatial patterns were not included in this stage of the modelling as the work increasingly focussed on EWWS services delivery. The general approach was to simplify the model as far as possible, and supplement the dynamic interaction of supply and demand with static, linear controlling variables. This approach limited the amount of non-linear feedback that could be achieved in the model, but did introduce time into otherwise static representations of EWWS service delivery. For example, a socio-economic sub-model was not explicitly modelled in PowerSim, but controlling variables such as the elasticities of service use to economic and population growth as well as estimates on the price elasticity of use was supported by Excel spreadsheet work, and used as a linear controlling function on the rate at which services are used.

The choice of a model baseline was not easy. Without the benefit of long-term time series on all the data, testing historical validity of the model was not achievable. We opted to model the baseline and do simulations with averaged input data for the periods 2000-2003, 2004-2006, and only 2006.

The purpose of each submodel is governed by the key questions raised by the participants in the process. These questions were generated in a series of small participatory workshops and are the combined result of the leading questions on the problems facing Cape Town, the perceived causes and impacts of these problems, and what the prognosis for the future is thought to be. For the purpose of providing more structure and priority to the modelling effort, these questions were categorised on three levels.

First are the questions that relate to the macro-dynamics of the system - focussed on the total supply of and demand for services, the implied sensitivity of supply and demand to growth in population and the economy and to price changes, as well as overall expenditure on services and the overall income to support the provision of these services. On the second level are questions focussed on the meso and micro level dynamics of the system - those related to the increased complexity associated with a categorisation of service types (e.g. different types of waste, service users (e.g. different income levels of users) and behavioural responses to changing costs of these services (e.g. effects of price changes on use). On the third level are questions related to an appropriate response to the challenges posed by the respective service systems - financially, technologically and behavioural.

The EWWS model can best be described as a scoping model. The focus of this phase was to have a group of city managers and experts interactively explore the complex problem of EWWS service delivery, natural resource shocks and municipal finances. It is by no means definitive and by definition focussed on generality and consensus-building rather then specific predictions (see van den Belt 2004:12). It is the first step of a three-step modelling process, with subsequent steps focussed on (i) targetted research models on more detailed sensitivities and identified gaps and (ii) a management model based on strong stakeholder buy-in and high expert content provided by the first two phases. This model therefore aims to set the stage for targetted research intervention which paves the way for a credible management model.

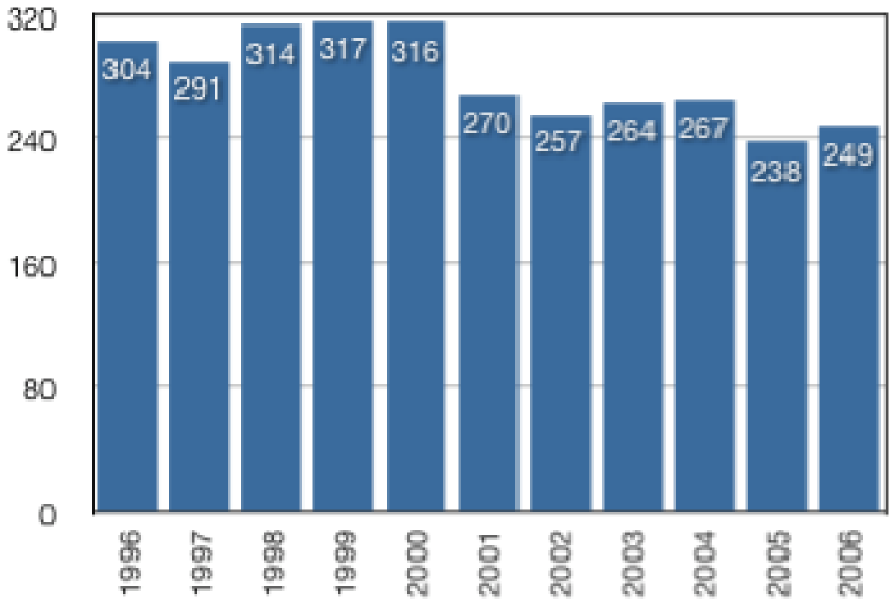
Data

Water model and parameters

The water model consists of two key stocks: ‘Water Supply’ and ‘Water Use’. Changes in water supply are modelled through the ability to include water supply options and by an increase of the re-use fraction of treated effluents over time. The model further allows for additional water savings, which in effect increases water supply. Water use is modelled as a function of economic growth, population growth and changes in water tariffs, using economic growth, population and price elasticities to water use. The required operational and capital expenditure to support water use is included in the finance sub-model.

Table 4 summarizes the parameters used in the water model. The total amount of water available to the City was 317Mm^3 per annum. An additional 81Mm^3 per annum from 2007 onwards, with the newly finished Berg River Dam, was included in the model. Total water use stabilized in recent years with 2006 levels of 294Mm^3 per annum, almost the same as those in earlier periods (an average of 295Mm^3 per annum over the period 2000-2003). Water use as measured in litres per person per day declined from an average of 277 litre per person per day (l/pp/day) over the period 2000-2003, to 252 l/pp/day over the period 2004-2006 and 249 l/pp/day in 2006. This contrasts even more sharply with the high water use years preceding the turn of the century (Fig 4).

Figure 4: *Water use, City of Cape Town, 1996-2006 (l/pp/day)*



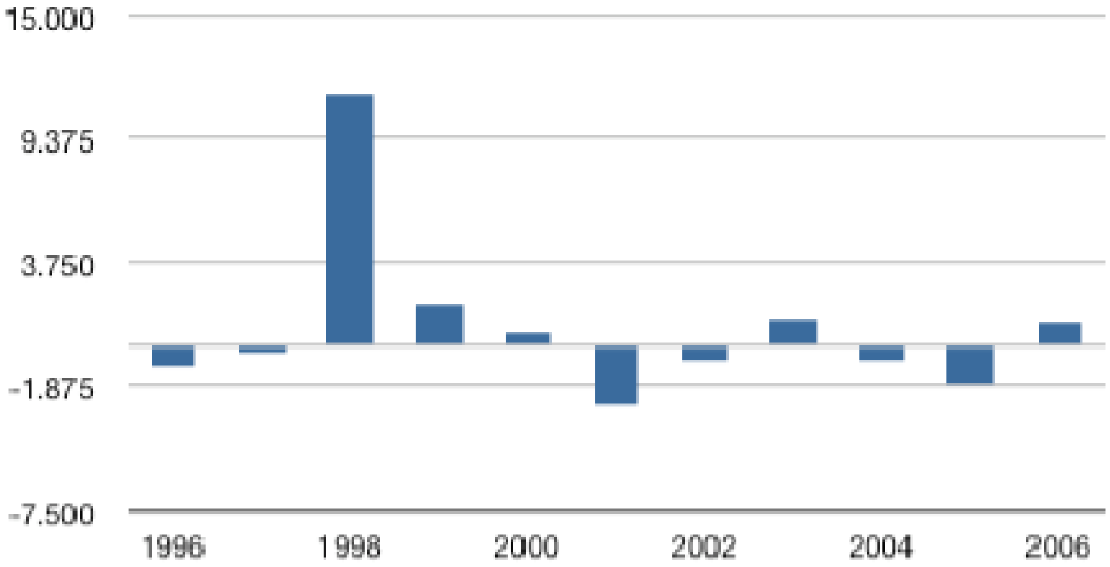
Historical growth in water use was an average of -0.6% for the period 2004-2006 and -1.82% for the period 2000-2003. Water use increased again in 2006 at a rate of 4.26%. When attributing this growth in water use to growth in economy and population as well as changes in tariffs, the average elasticity to economic and population growth was negative in the periods 2000-2003 and 2004-2006. For the year 2006 the results were different: a 1% increased in economic growth increased demand for water by 1.06% and a 1% increase in population increased demand for water by 2.64%.

Table 4: *Parameters used in the baseline ‘Water’ sub-model*

Parameter	**2006**	**Average 2004 - 2006**	**Average 2000 - 2003**	**Units**	**Source**
Water supply	317	317	317	Mm^3	Pithey & Frame (2007)
Water use	294	304.7	295.3	Mm^3	Pithey & Frame (2007)
Water use	249	252	277	l/pp/day	Calculated
Water use growth	4.26	-0.6	-1.82	%	Calculated
Population growth	1.61	1.75	2.27	%	Romanovsky (2007)
Elasticity of water use to population	2.64	-0.34	-0.74		Calculated
GGP growth	4	4.9	4.4	%	City of Cape Town (2006a)
Elasticity of water use to GGP	1.06	-0.12	-0.42		Calculated
Average water tariff	3.17	3.45	2.35	R/m^3	Calculated, based on City of Cape Town (2007a)
Elasticity of water use to tariff	-0.28	-1.13	-0.39		Calculated

There is no clear trend though, with five out of ten years over the period 1996-2006 reflecting a negative elasticities of water use to GGP growth and five years positive elasticities to GGP growth (Figure 6). The same volatility is observed for population elasticities. This high volatility suggests that any projections of water use on the basis of fixed economic growth and population growth coefficients is dubious. The model therefore simulates three sets of sensitivities to economic growth and population, one based on 2006 data only, one based on the average of 2004-2006 data and one based on the average of 2000-2003 data.

Figure 5: *Sensitivity of quantity of water used (Qw) to economic growth (GGP)*



Note: dQw/dGGP = percentage change in percentage water used divided by percentage change in GGP

The quantity of water used is relatively inelastic to tariff changes in the year 2006 and the period 2000-2003, with a 1% change in price resulting in a change of water use of 0.28% and 0.39% respectively. Water use became sensitive to water price changes over the period 2004-2006 with a price elasticity of -1.13, meaning that a 1% rise in price led to a 1.13% decrease in water use over this period. This means that historically the amount of water used is relatively inelastic to increases in price, except for the 2004-2006 period where strong increases in price was accompanied with reduced water use[3]. Time series on water tariffs are preliminary and improved data-sets are needed before conclusions on price elasticities can be made.

Sanitation model and parameters

The sanitation model has six main stocks: ‘Influent received’, ‘Effluent treated’, ‘Effluent reused’, Effluent to marine’, Effluent to environment’ and ‘Compliant effluent’. The rate at which influent is received at wastewater treatment works is modelled as a fraction of water use over time. Effluent treated is a function of measured influent received as well as stormwater ingress into the system, and constraints caused by the levels of treatment capacity. Treated effluent is discharged directly into the environment (water bodies), or directly discharged as marine outfall or formally re-used. Apart from the quantity of influent received and treated effluent, the model also makes provision for the quality of treated water through the stock ‘Compliant effluent’. The fraction of treated water that is compliant with local water quality standards is used to force the amount of treated water that adheres to quality standards.

The parameters that were used in the ‘Sanitation’ sub-model are as shown in Table 5. The amount of influent received at water treatment works remained fairly stable since 2000. The average rate of growth in influent received over the period 2001-2005 was only 0.6% pa, but still much higher than the average rate of growth in water use of -3.2% pa over the same period. The ratio of influent received to water used increased from 58% in 2000 to 71% in 2005. In years with water use restrictions this ratio was the highest: 68% in 2002,

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[3] These strong price increases was also accompanied by more traditional water restrictions as documented in the City’s Water Restrictions Bylaw.

66% in 2001 and 71% in 2005. The difference between the amount of effluent treated and the influent received was modelled as stormwater ingress.

The total theoretical treatment capacity was 609 Mm^3 per annum in 2005. Treatment capacity has to be at least 1.6 times average water demand to cater for peak demand in summer months (Pithey & Frame, 2007). Actual treatment capacity is therefore modelled at 381 Mm^3 pa (i.e. 609 divided by 1.6).

Table 5: *Parameters used in the baseline 'Sanitation' sub-model*

Parameter	**2006**	**Average 2004-2006**	**Average 2000-2003**	**Units**	**Source**
Influent received/Water use	68	67	64	%	Calculated, 2006: assumption
Influent received	196	198	195	Mm^3 pa	Pithey & Frame 2007
Effluent treated	207	207	207	Mm^3 pa	Pithey & Frame 2007
Actual treatment capacity	381	381	381	Mm^3 pa	Pithey & Frame 2007
Effluent discharged to marine	11.7	11.7	11.7	Mm^3 pa	Pithey & Frame 2007
Effluent discharged to environment	164.2	164.2	164.2	Mm^3 pa	Calculated
Effluent re-used	21.1	21.1	21.1	Mm^3 pa	Frame, pers. comm.
Compliant effluent	51.75	51.75	51.75	Mm^3 pa	Calculated

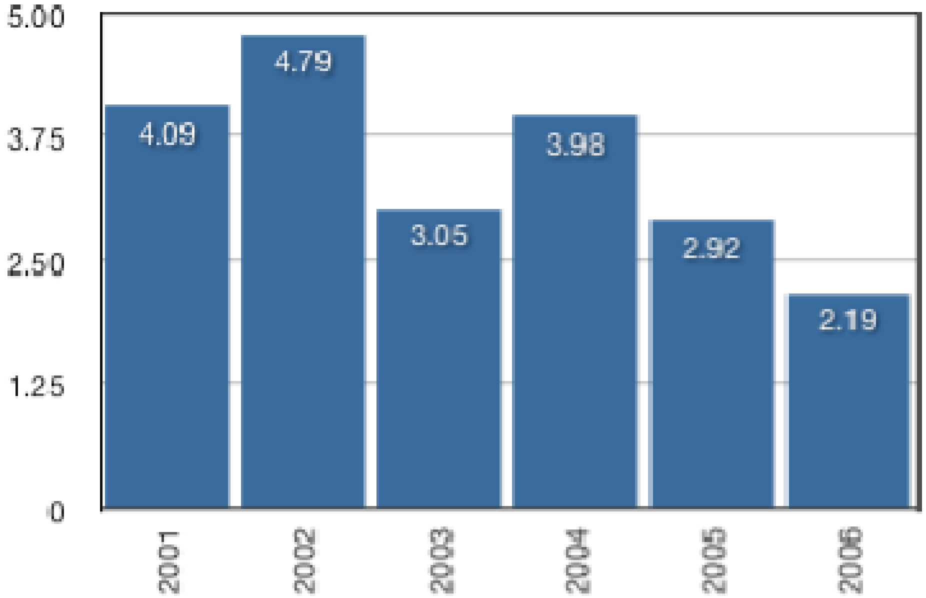
Six per cent of treated effluent is disposed through marine outfall sewers, 10 per cent is re-used and the residual 84% discharged into the environment after treatment, while recognizing that in a number of cases treatment quality is below minimum standards. Re-use includes treatment at wastewater treatment works as well as other private and informal wastewater treatment. The baseline re-use fraction is modelled to increase to 12% in 2012 and to 14% in 2020.

Electricity model and parameters

The electricity sub-model consists of two key stocks, namely 'Electricity supply' and 'Electricity use'. Electricity supply is modelled as the supply of Eskom's coal fired power stations (transmitted over long distances via high voltage transmission lines), supply from the Koeberg nuclear reactor and supply from other sources (pumping schemes, gas turbine and wind). Electricity conversion factors were used to calculate net electricity supply. A capacity factor for all these sources was used to convert supply, as measured in megawatts, to use, as measured in megawatts per hour.

Table 6 lists the main parameters used in the energy model. From 2000 onwards electricity use increased between 2-4% per annum, but with a decrease in recent years. From 2005 to 2006, electricity use increased by 2.2% compared to an average of almost 4% in the period 2000-2003 (Fig 6).

Figure 6: *Growth in electricity use, City of Cape Town (YoY%)*



Overall electricity use in the City was almost 10 000 000 MWh in 2006. Peak demand is modelled as this amount plus a reserve fraction of 15%. As in the case of water use, the sensitivity of this growth to economic and financial variables was modelled through income, population and price elasticities of electricity use. There is a consistent trend of positive elasticities to economic and population growth, with a relative (but declining) inelasticity to economic growth and a relative (but also declining) elasticity to population growth. The sensitivity of electricity use to price changes is also declining - from -1.1 over the period 2000-2003 to -0.27 in 2006. Nominal electricity prices did not change much during the period 2000-2006, staying within the range of 26-27 c/KWh.

The model relied on provincial electricity supply figures adjusted for the city's share of electricity use to provincial electricity use. The Western Cape Province's own installed capacity as well as installed capacity from national utility Eskom amounted to 4939MW in 2005: 2400 MW (48.5%) imported from coal fired power stations elsewhere in the country, 1800MW (36%) from the Koeberg nuclear power plant and 739MW from two pumped storage peak schemes and a gas turbine. The following supply options were included in the baseline model: an open cycle gas turbine (OCGT) (1050 MW, 2007); Darling Wind Farm (5.2MW, 2008), Eskom Wind Farm (100MW, 2010), and savings achieved by solar water heaters (4.2MW, by 2020). Capacity factors were used to adjust the theoretical installed capacity for the amount of MW produced in reality - between 0.72 and 0.83 for Koeberg based on real data and an assumed 0.85 for coal fired power stations and 0.15 for other sources. This adjusted installed capacity was subsequently modelled in terms of MWh to compare to electricity demand, using 8 760 hours per year, a city (vs province) electricity use factor of 0.56 and randomised capacity conversion factors between a maximum of 0.9 and a minimum of 0.6 (van den Belt, pers. comm.).

Table 6: *Parameters used in the baseline 'Electricity' model*

Parameter	**2006**	**Average 2004-2006**	**Average 2000-2003**	**Units**	**Source**
Electricity supply	4939	4939	4939	MW	SEA (2007)

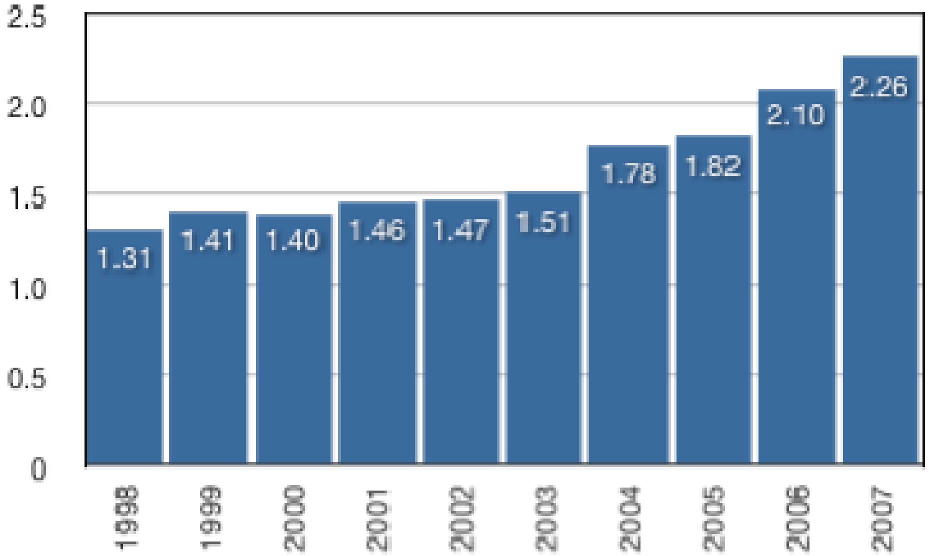
Electricity use	9 982 000	9 747 000	8 640 000	MWh	City of Cape Town (2007d)
Electricity use growth	2.19	3.03	3.98	%	Calculated
Electricity price	27	26	26.61	c/KWh	City of Cape Town 2007a, City of Cape Town 2007e
Electricity price change	8	1.1	1.2	%	Calculated
Elasticity of electricity use to population	1.36	1.73	1.62	%	Calculated
Elasticity of electricity use to GGP	0.55	0.61	0.91	%	Calculated
Elasticity of electricity use to tariff	-0.27	-0.71	-1.1	%	Calculated
City vs province electricity use factor	0.56	0.56	0.56		Calculated based on DEADP (2007)
Electricity supply_coal fired (province)	2400	2400	2400	MW	SEA (2007)
Electricity supply_nuclear (province)	1800	1800	1800	MW	SEA (2007)
Electricity supply_other (province)	739	739	739	MW	SEA (2007)
Coal fired supply conversion factor	0.85	0.85	0.85		Van den Belt, pers. comm.
Nuclear supply conversion factor	0.72	0.83	0.77		SEA (2007)
Other supply conversion factor	0.15	0.15	0.15		Van den Belt, pers. comm.

Solid waste model and parameters

The solid waste sub-model consists of two main stocks, namely the ‘Total amount of waste generated’ and ‘Recycled waste’. ‘Net landfill space available’ is modelled as a controlling variable and calculated as the remaining airspace (expressed in Mt) multiplied with a landfill density factor and a compaction ratio. The baseline density factor is set at 0.45, but will change with the composition of the solid waste stream. A compaction ratio is set at 1.1 meaning that the landfill increases its capacity with 10% due to compaction. This is also a variable that can change with management intervention. Remaining airspace was estimated in 2007 at 21.8Mt. With existing landfill expansion plans this is expected to increase to 29Mt in 2013, to 34Mt in 2017 and to 54Mt in 2020 and included in the baseline solid waste sub-model (RMS 2007).

The City generated almost 2.5 Mt of solid waste going to landfills in the year 2005/6, an equivalent of 2.1 kg/pp/day up from an average of 1.6 Mt/a over the period 2000-2003, or an equivalent of 1.51 kg/pp/day (Fig. 7). The amount of solid waste increased at an average of 4.2% per annum over the period 2000-2003, 13.1% per annum over the period 2004-2006 and 14.9% in 2005/6 alone[4]. The long-term historical growth rate in solid waste to landfills is 8.5%, as measured over the period 1998/8 to 2006/7.

Figure 7: *Solid waste generation, City of Cape Town (kg/pp/day)*



During 2003, 330 000 tons of solid waste was recycled - close to 14% of total waste generated. Compared to the target of 50% of all waste to be recycled set by the Polokwane Declaration, a more modest baseline recycling target rate of 15% by 2010, 25% by 2020 and 30% by 2025 is included as an option in the model.

Table 7: *Parameters used in baseline 'Solid Waste' model*

Parameter	**2006**	**Average 2004-2006**	**Average 2000-2003**	**Units**	**Source**
Total amount of waste generated	2.47	2.23	1.61	Mt/a	RMS (2007)
Waste generation historical growth	14.9	13.1	4.2	% pa	Calculated
Remaining airspace	21.8 (2007)	21.8 (2007)	21.8 (2007)	Mt	RMS (2007)
Landfill conversion factor	0.45	0.45	0.45		Assumption
Landfill compaction ratio	1.1	1.1	1.1		Assumption
Net landfill remaining capacity	10.8	10.8	10.8	Mt	Calculated

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[4] The 2004/5 figure was adjusted upwards from an initially reported 2.0Mt (RMS 2007) to a more realistic 2.15Mt (Engledow, 2008).

Recycled waste	0.33	0.3	0.23	Mt/a	Calculated based on RMS (2007)
Solid waste tariff	0.2	0.2	0.21	R/t	Calculated based on City of Cape Town (2007a), RMS (2007)
Elasticity of waste generated to population	9.25	7.45	1.72		Calculated
Elasticity of waste generated to GGP	3.72	2.65	0.96		Calculated
Elasticity of waste generated to tariff	2.12 (2007: 0.61)	6.15	-12.61		Calculated

Based on data from 1998 onwards, solid waste generation is very sensitive to both population and economic growth, especially in recent years. The rate of growth in solid waste generation was much higher then economic and population growth rates. Although based on limited data, solid waste generation appears to be very elastic to tariff changes as well. Historically, aggregate tariffs per volume of solid waste fell from R0.21/ton in 2005 to R0.20/ton in 2006, and according to anticipated tariff income in City budgets to decrease to R0.16/ton in 2009 (given an increase of 7% pa in solid waste generation used for future projections and budgeted tariff incomes). The problem is that price elasticities of solid waste generation could only be measured for decreases or very small increases in prices. There is no concrete evidence that price increases will also have such a large effect on the amount of solid waste generated. In this case, therefore, the baseline growth rates were not controlled by growth in the economy and population and changes in solid waste tariffs, but based on a long-term historical growth rates.

Municipal finance model and parameters

The municipal finance model was developed through an analysis of draft city budgets for the period 2005-2009 (City of Cape Town 2007a)[5]. Baseline values for capital and operational expenditure for the electricity, water, waste and sanitation services were calculated as the average over the period 2005-2008. Capital expenditure included direct expenditure on EWWS services as well as EWWS expenditures in other categories (e.g. ‘integrated human settlements’, ‘maintain and improve health of city’, ‘internal asset management’, enabling institutional frameworks’ and ‘building strong communities’). Baseline average CAPEX and OPEX unit costs of service delivery were calculated by using budgeted figures divided by the City’s actual and projected service use over the period 2005-2008. (Figures 8-11). CAPEX expenditure was very volatile over this period and the model included options to select different rates of growth in CAPEX expenditure. Total tariff income for the EWWS services is modelled as the multiplication of annual EWWS use with EWWS tariffs. The shortfall between total costs (OPEX + CAPEX) and tariff income is modelled as other income required.

Table 8: *Parameters used in the baseline ‘Municipal finance’ model*

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[5] Final audited financial statements for the City for a few years and detailing expenditure and income on EWWS services were not available for this study.

Parameter	**Average 2005 - 2008**	**Units**	**Source**
CAPEX_water	456.8	R Million pa	Calculated based on City of Cape Town (2007a)
OPEX_water	2083.5	R Million pa	Calculated based on City of Cape Town (2007a)
CAPEX_water_unit cost	1.53	R/m^3	Calculated based on City of Cape Town (2007a)
OPEX_water_unit cost	7	R/m^3	Calculated based on City of Cape Town (2007a)
Tariff income_water	3.55	R/m^3	Calculated based on City of Cape Town (2007a)
CAPEX_sanitation	377.8	R Million pa	Calculated based on City of Cape Town (2007a)
OPEX_sanitation	897.2	R Million pa	Calculated based on City of Cape Town (2007a)
CAPEX_sanitation_unit cost	1.89	R/m^3	Calculated based on City of Cape Town (2007a)
OPEX_sanitation_unit cost	4.5	R/m^3	Calculated based on City of Cape Town (2007a)
Tariff income_sanitation	3.05	R/m^3	Calculated based on City of Cape Town (2007a)
CAPEX_electricity	499.7	R Million pa	Calculated based on City of Cape Town (2007a)
OPEX_electricity	3396.7	R Million pa	Calculated based on City of Cape Town (2007a)
CAPEX_electricity_unit cost	0.05	R/Kwh	Calculated based on City of Cape Town (2007a)
OPEX_electricity_unit cost	0.33	R/Kwh	Calculated based on City of Cape Town (2007a)
Tariff Income_electricity	0.27	R/Kwh	Calculated based on City of Cape Town (2007a)
CAPEX_solid waste	105.5	R Million pa	Calculated based on City of Cape Town (2007a)
OPEX_solid waste	1035.9	R Million pa	Calculated based on City of Cape Town (2007a)

CAPEX_solid waste_unit cost	0.04	R/t	Calculated based on City of Cape Town (2007a)
OPEX_solid waste_unit cost	0.41	R/t	Calculated based on City of Cape Town (2007a)
Tariff income_solid waste	0.18	R/t	Calculated based on City of Cape Town (2007a)

Figure 8: *Water unit costs, CAPEX and OPEX, 2005-2008, City of Cape Town (R/m3)*

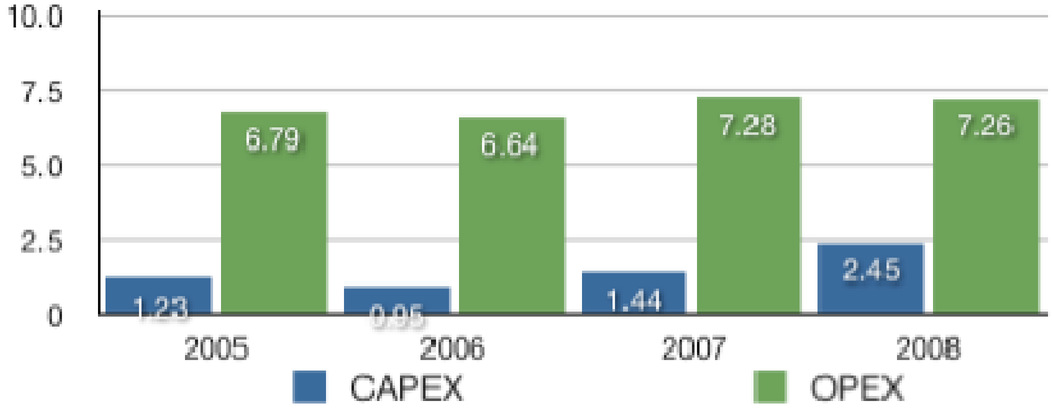


Figure 9: *Influent unit costs, CAPEX and OPEX, 2005-2008, City of Cape Town (R/m3)*

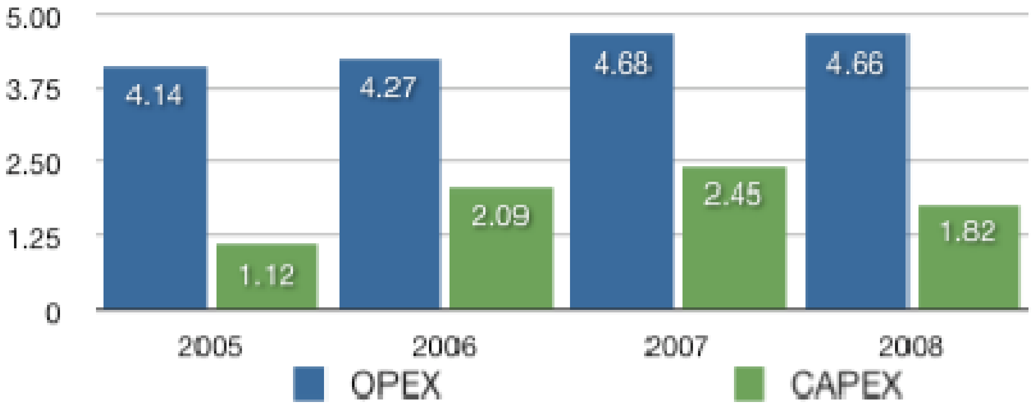
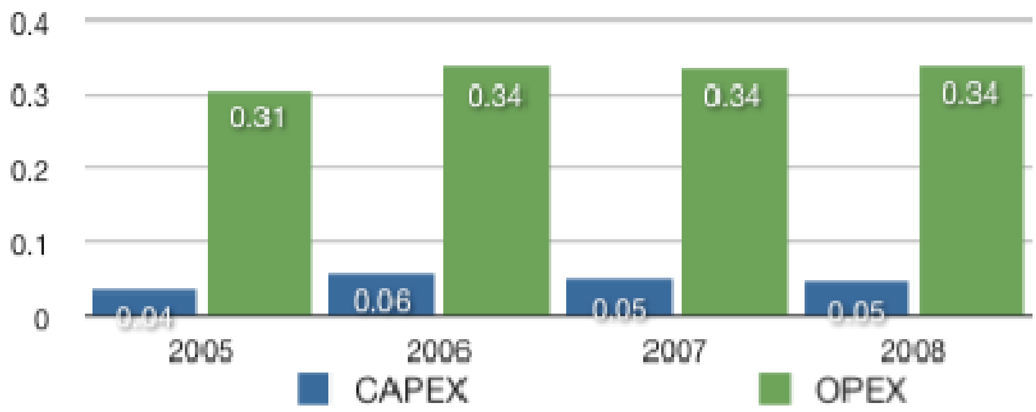


Figure 10: *Electricity unit costs, CAPEX and OPEX, 2005-2008, City of Cape Town (R/Kwh)*


0.4
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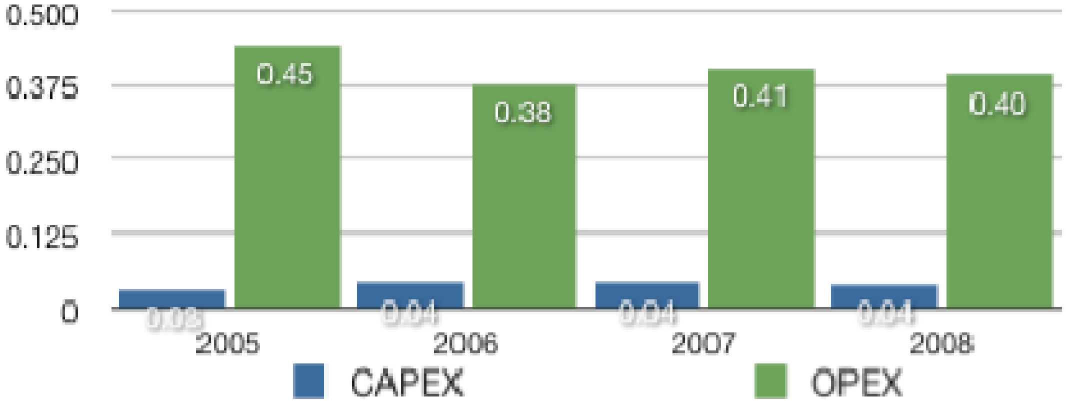
2005
2006
2007
2008
CAPEX
OPEX

Figure 11: *Solid waste unit costs, CAPEX and OPEX, 2005-2008, City of Cape Town (R/ton)*



Model simulations

Given the key questions that were identified with City managers and experts (see Table 3), the model focussed on key overarching themes in each of the EWWS services sectors. These themes were:

- The balance between projected growth for EWWS services and the physical ability to supply these services
- The income from service delivery and the expenditure required to maintain or improve EWWS services
- The effect of prices/tariffs on EWWS services
- The effect of supply and demand interventions on EWWS services

These simulations focus mainly on a better understanding on the relationship between EWWS services and municipal finances on a macro level. The micro-dynamics of each EWWS sector would need further research before linking to the overarching EWWS model developed in this study. To answer questions on more complex features of the system would require a more detailed categorisation, for example categories on the types of waste, EWWS supply and use according to spatial categories, household categories and income categories as well as categories of impact on the environment.

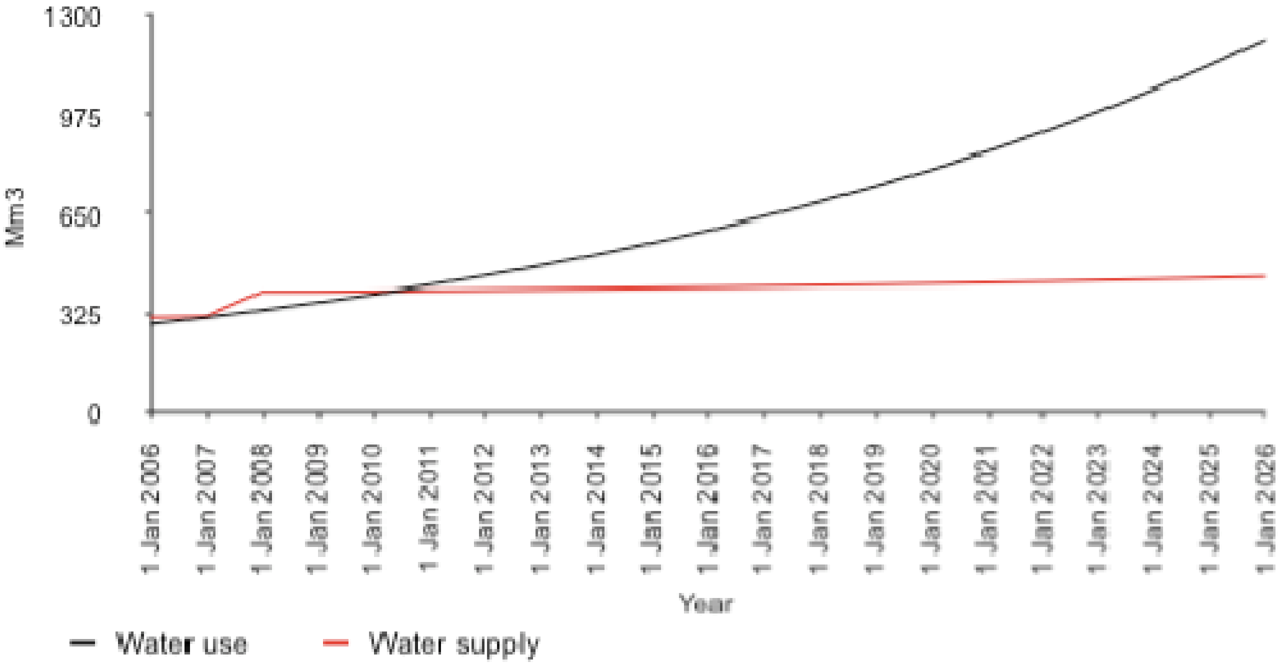
Water services

Simulations on supply of and demand for water services

The baseline simulations on water supply and demand for services is given in Figure 12. Using the 2006 initial datasets, the water supply is only capable of meeting the growing demand up to around 2010/2011 and the gap between the water supply and demand is increasing over the simulation period.

Using the datasets for 2004-06 and 2000-03 averages, the water demand is easily met. The difference in the last two scenarios with the 2006 one is because the elasticity of water use to population and GGP are negative while for 2006 is positive (see Table 4).

Figure 12: *Baseline simulations: Water supply and demand, City of Cape Town (Mm3)*


1 300
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650
325
0
Mm3
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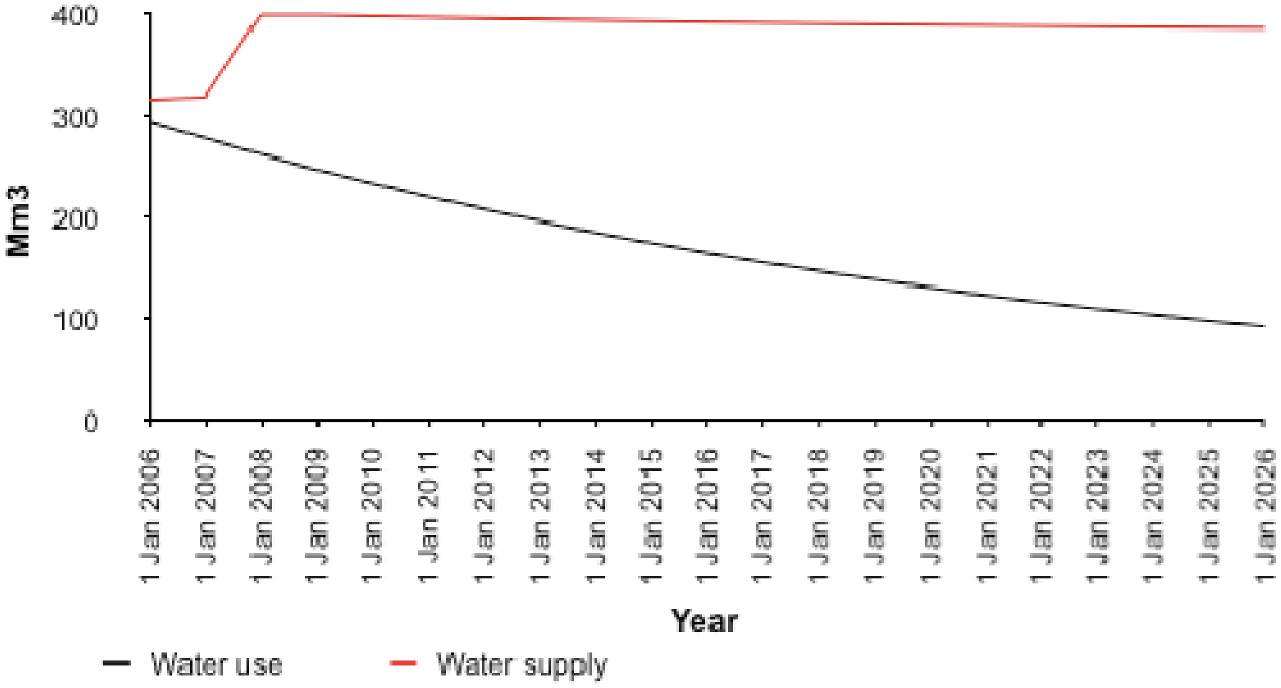
1 Jan 2007
1 Jan 2008
1 Jan 2009
1 Jan 2010
1 Jan 2011
1 Jan 2012
1 Jan 2013
1 Jan 2014
1 Jan 2015
1 Jan 2016
1 Jan 2017
1 Jan 2018
1 Jan 2019
1 Jan 2020
1 Jan 2021
1 Jan 2022
1 Jan 2023
1 Jan 2024
1 Jan 2025
1 Jan 2026
Year
Water use
Water supply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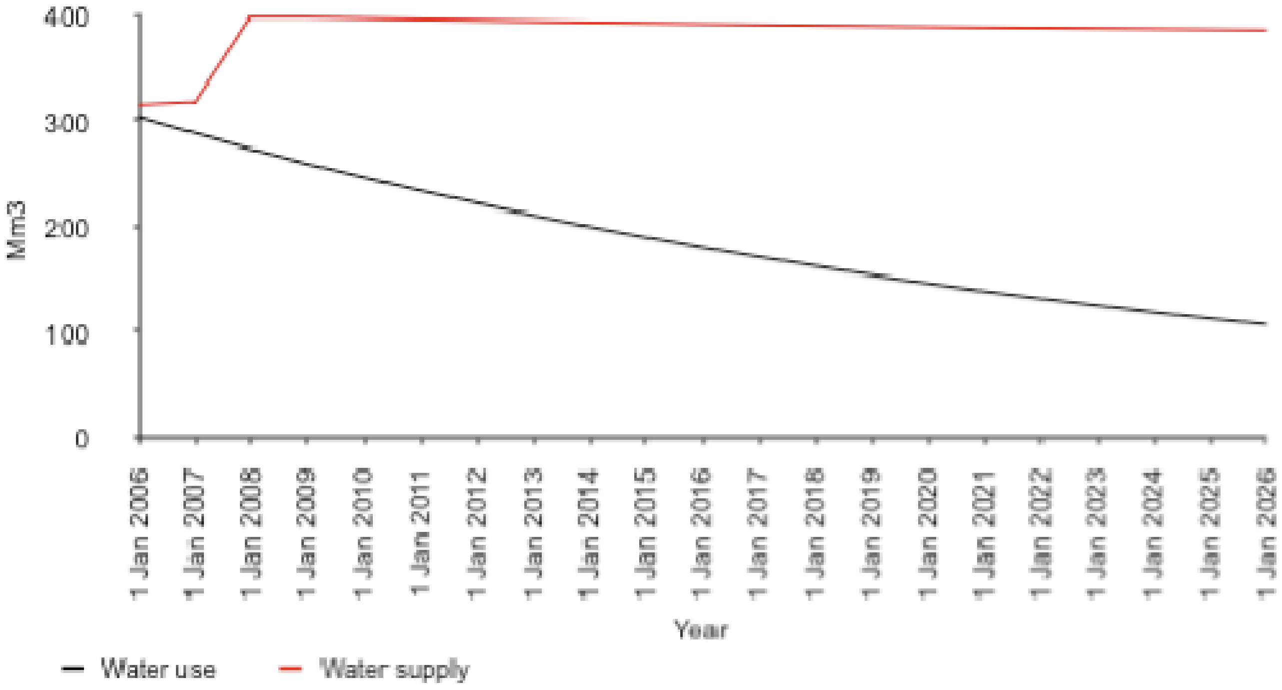
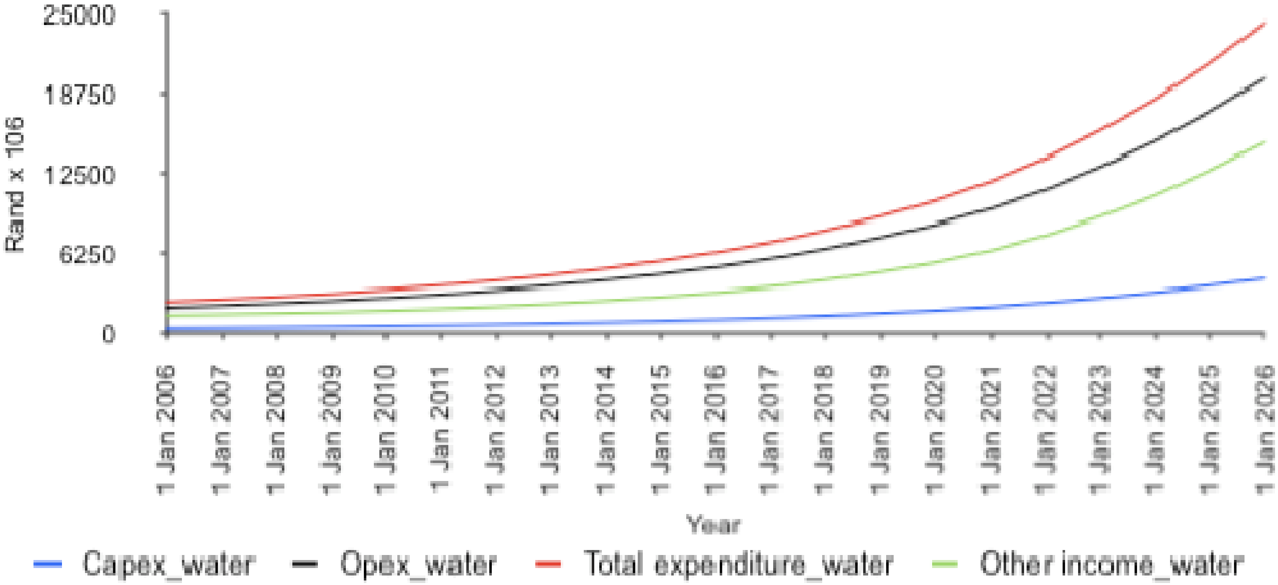


Simulations on income and expenditure from water services

As demand for water services change, the required expenditure to supply water also change. The rate at which required expenditure is expected to change when demand for services increase could not be calculated given an absence of a good time series on expenditure. Using fixed unit costs (see Table 4) it is simulated using the 2006 case that total required expenditure on service provision is simulated to increase from around R2.5 billion per annum in 2006 to R5 billion in 2014, almost R11 billion in 2020 and almost R25 billion in 2026 (Fig 13). CAPEX accounts for around 20% of the total expenditure. Income from tariffs are not sufficient to cover expenditure and required ‘other income” is simulated to increase from R1.5 billion in 2006 to R3.3 billion in 2016 and R15 billion in 2026.

Using the 2004-2006 and 2000-2003 cases, required expenditure is simulated to decrease over time. Other income required also decreases with no additional income required from 2018 onwards (Fig 13).

Figure 13: *Baseline simulations: Water income and expenditure, City of Cape Town (R million)*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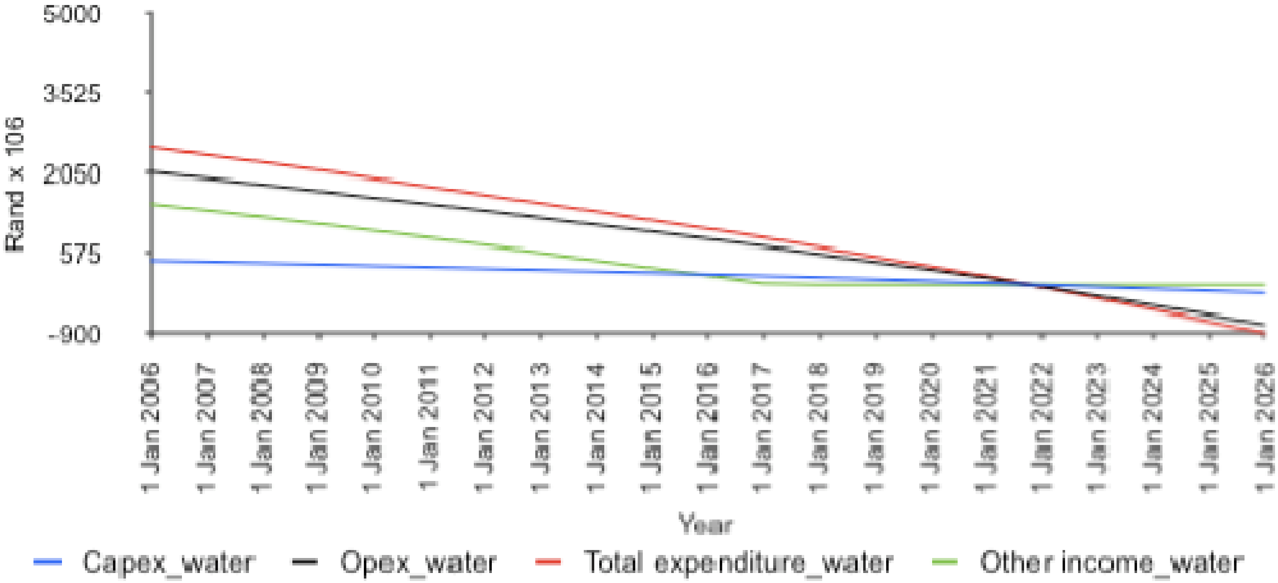
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Opex_water
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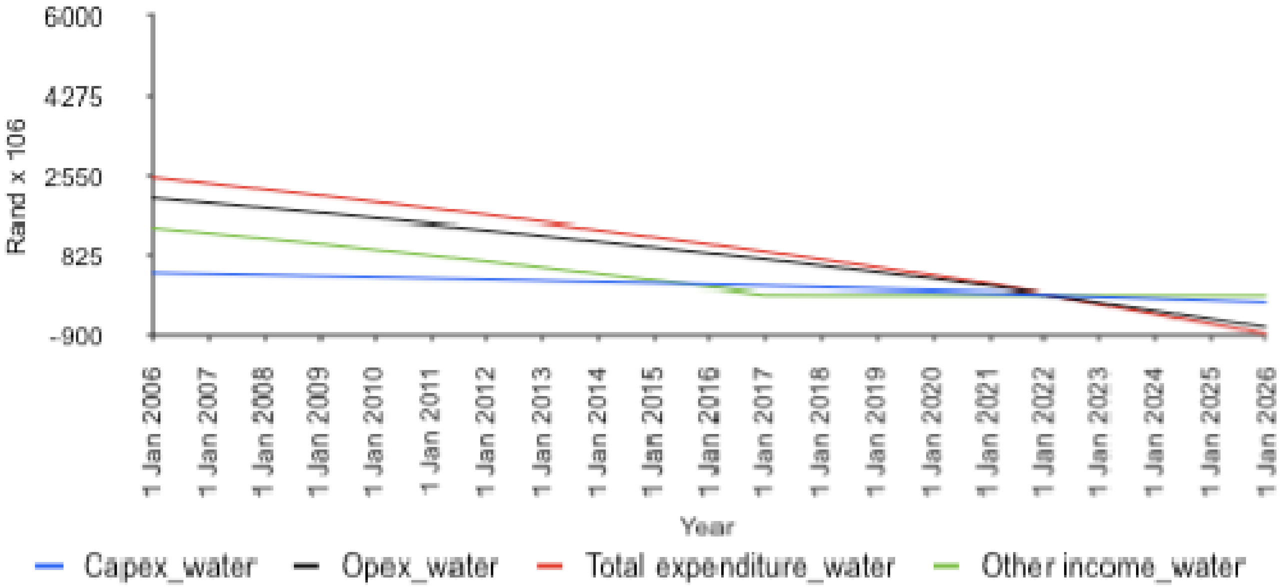
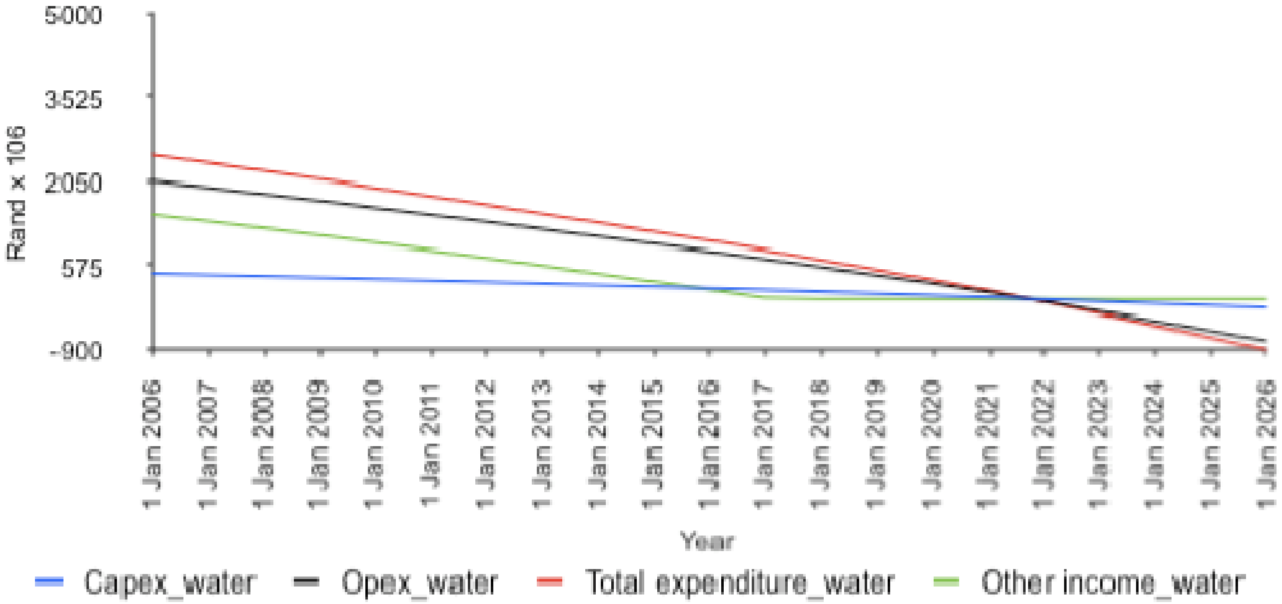
Other income_water

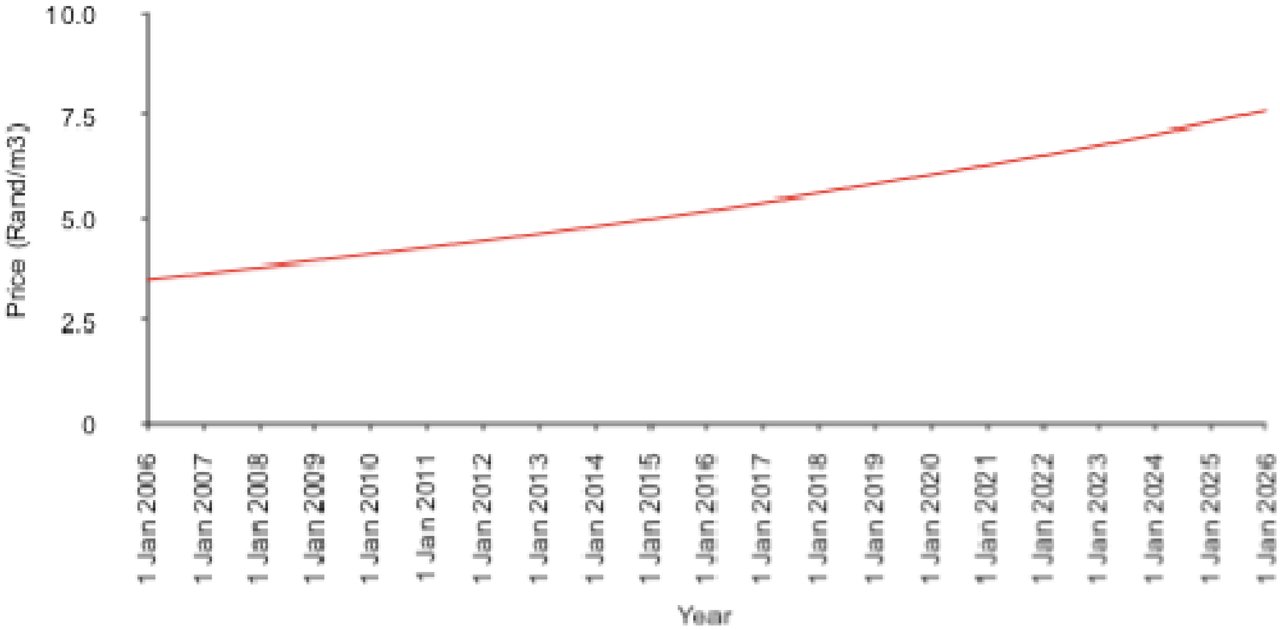




Simulations on water tariffs

The baseline water tariff increases at an average of 3.9% per annum (Fig 14). This is the average budgeted rate of increase in water tariffs given the 3% unconstrained demand growth factor for water use. This means that tariffs are simulated to increase from an average of R3.55/m3 in 2006 to R5.21/m3 in 2016 and R7.64/ m3 in 2026.

Figure 14: *Baseline simulations: Water tariffs, City of Cape Town (R/m3)*



Simulations on water management interventions

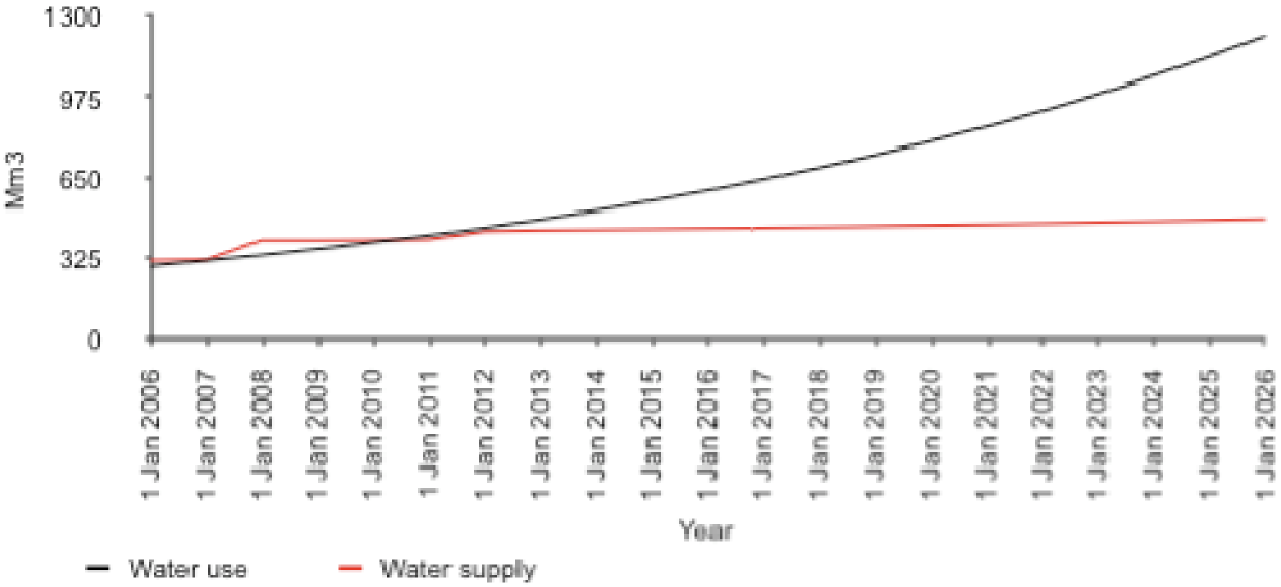
Three water management options were chosen for the simulations namely a reduction in non-revenue demand, a reduction of water wastage and an increase in water tariffs. The intervention and simulations are subsequently described.

Goal Wi: Reduce non-revenue demand

By 2010, the City of Cape Town reduce and maintain the non-revenue water to 15% of the total average demand and within accepted international norms. The non-revenue water use is currently estimated at around 23% of all water use (Pithey & Frame 2007). Therefore by 2010, the change in the additional water that will be charged will be the difference between current non-revenue demand and accepted international norms (8%). The results on taking account of this option on supply, demand, income, and expenditure are presented in Figures 15-16.

The amount of water supplied increases by 32Mm^3 from 2012 onwards. In the 2006 case this will not be a sufficient adjustment for water supply to meet demand over the simulation period while in the 2000-2003 and 2004-2006 cases this will add to an existing oversupply. In the 2006 case this water management option, it is interesting to note that the resulting increase in supply from this option may help alleviate the pressure on water supply at a crucial time (Fig 15).

Figure 15: *Intervention simulations: Water supply and demand: Non-revenue water, City of Cape Town (Mm3)*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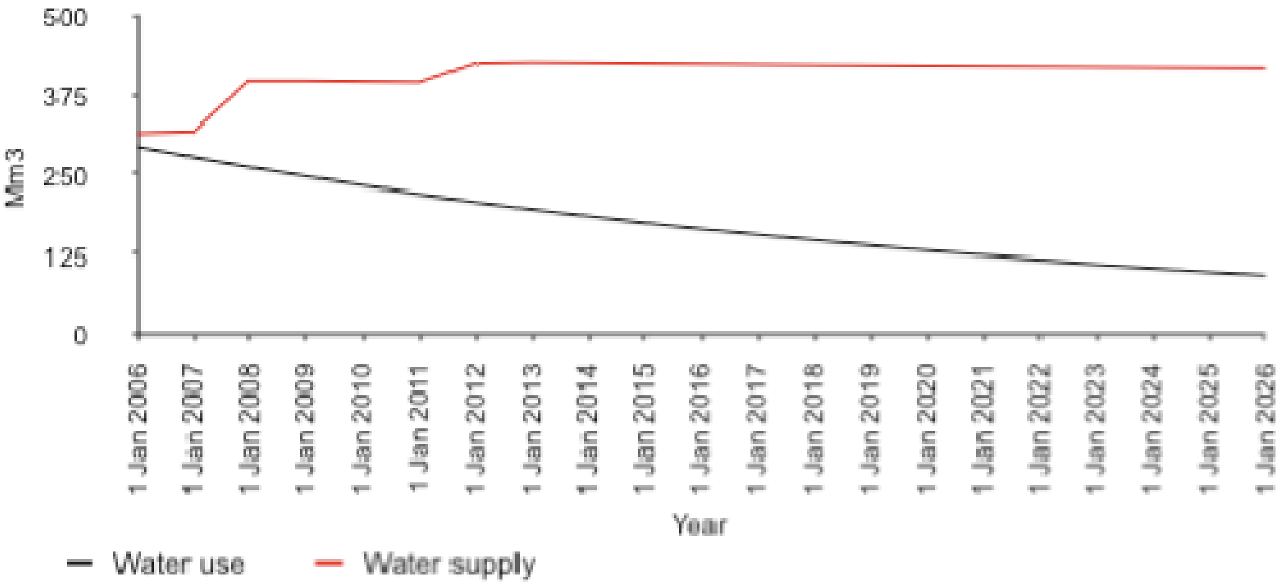
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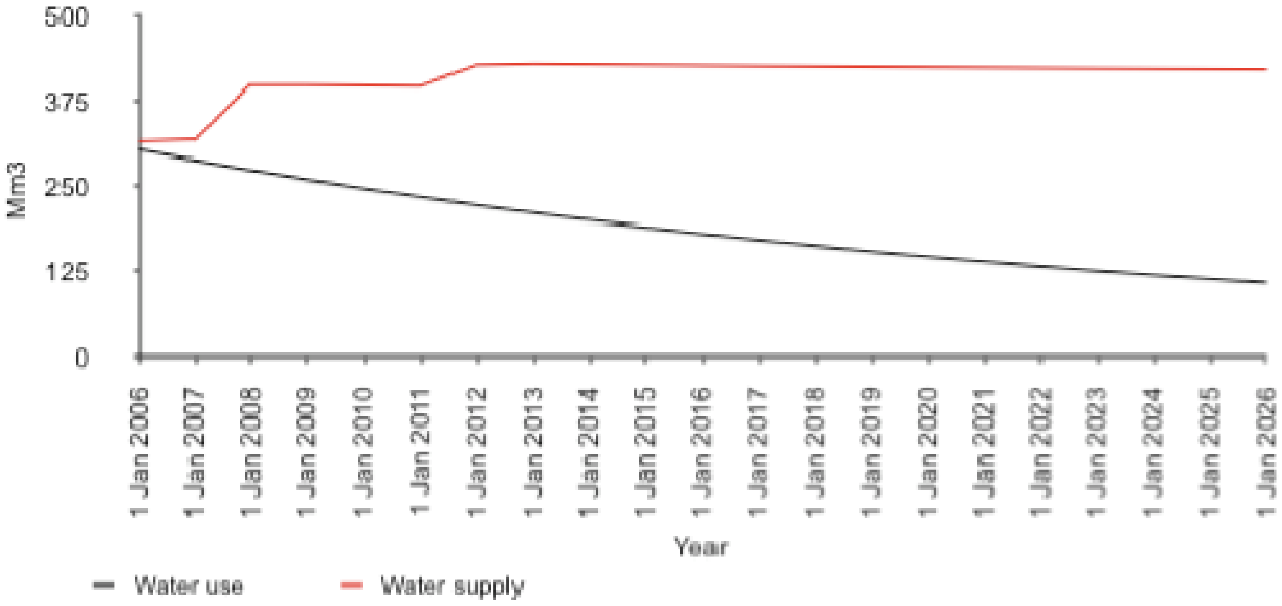
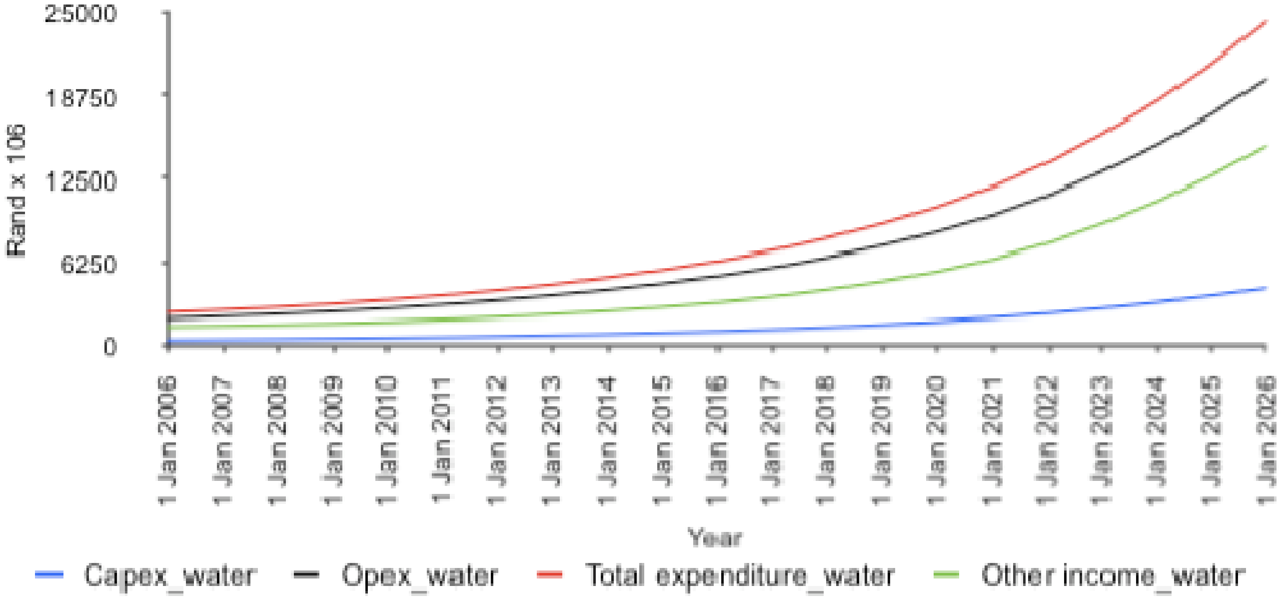
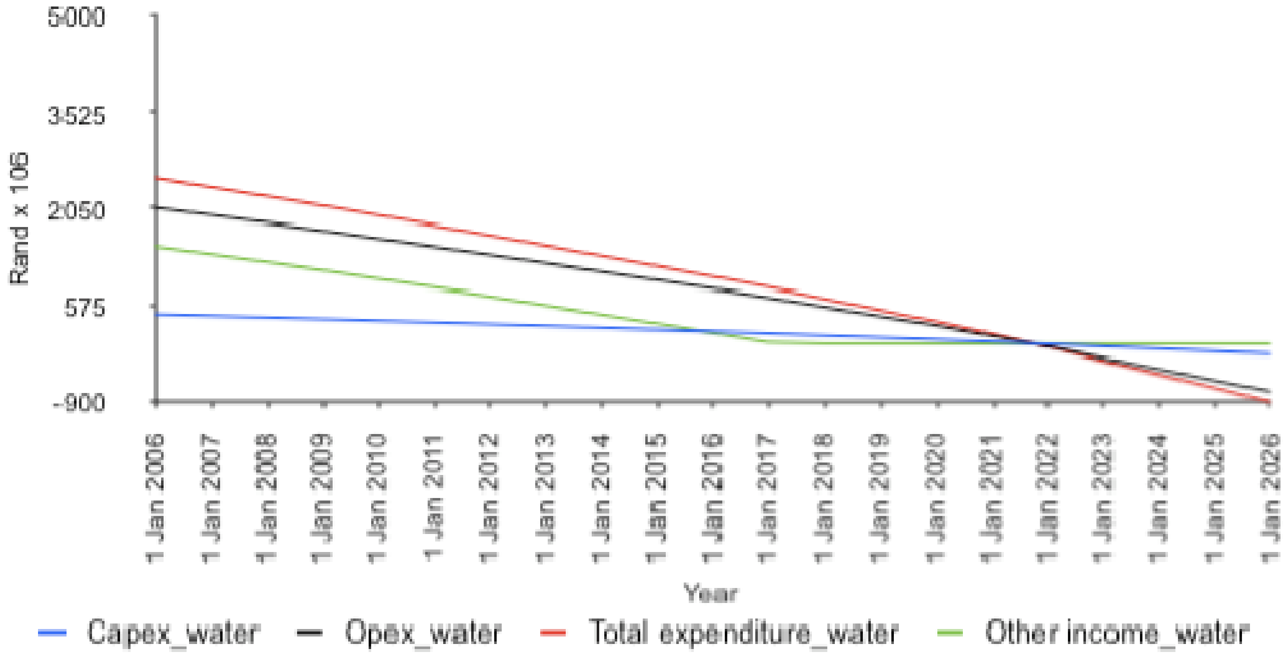
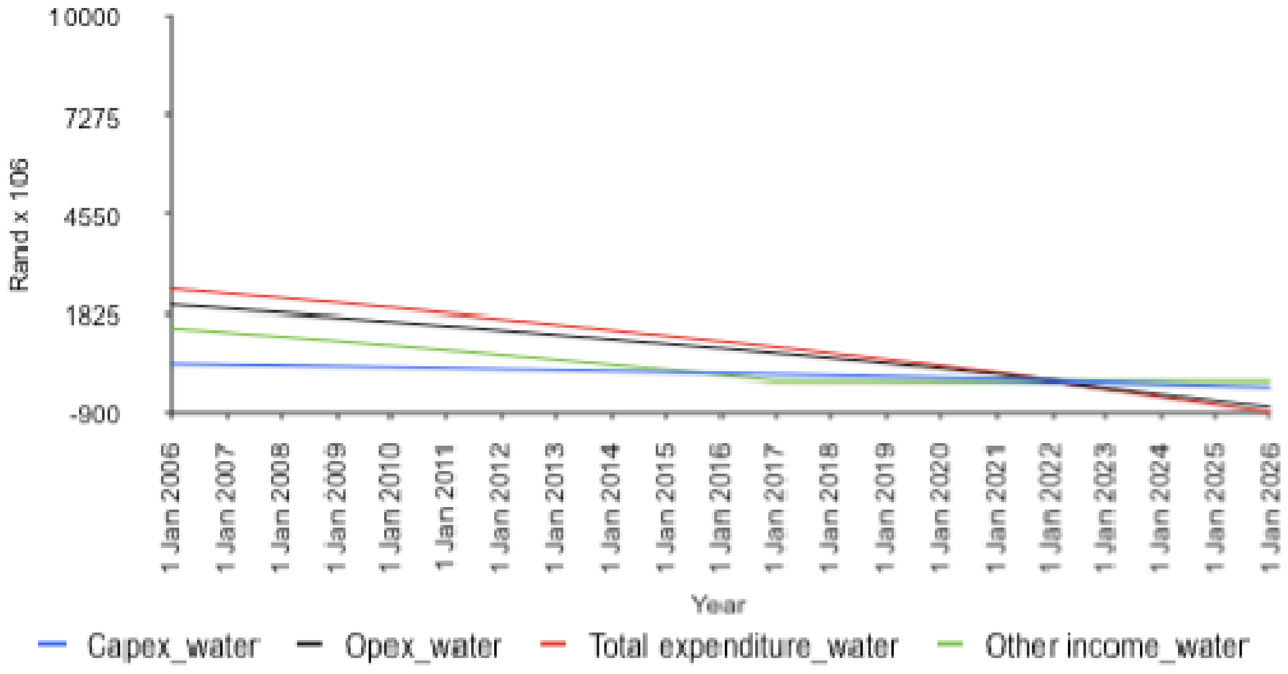


There is no change in the required expenditure when compared to the baseline simulation as water use has not changed (Fig 16).

Figure 16: *Intervention simulations: Water income and expenditure: Non-revenue water, City of Cape Town (R million)*



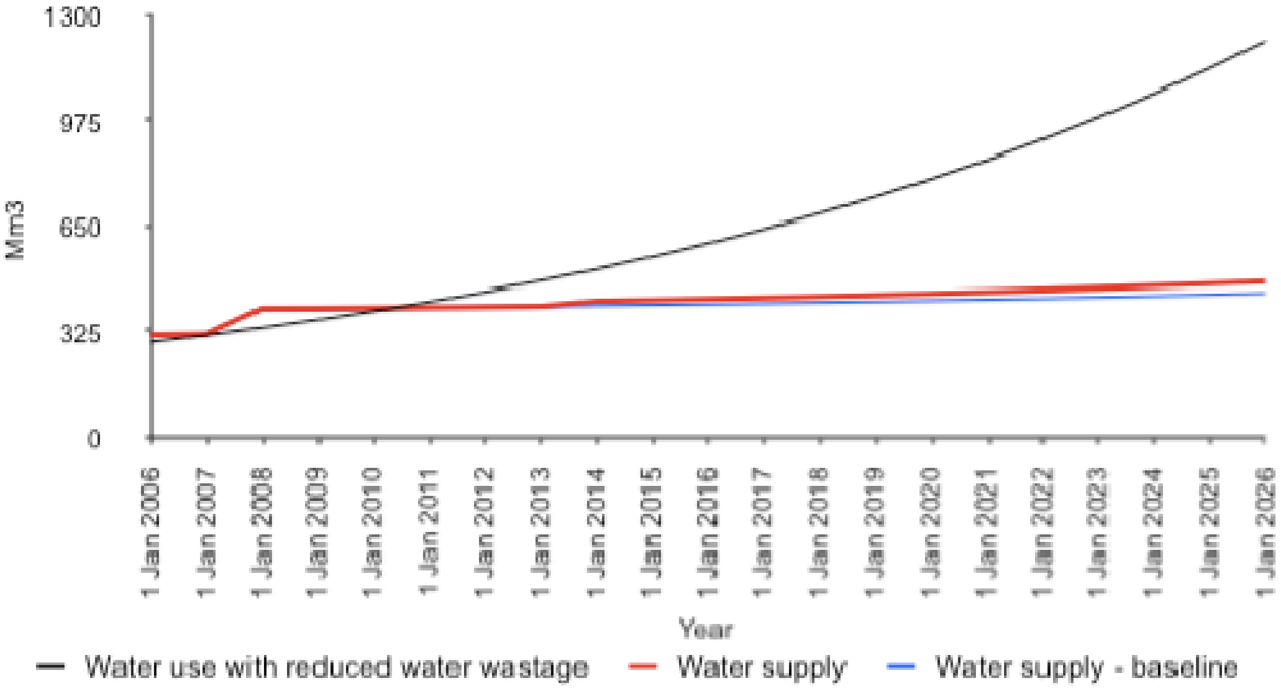


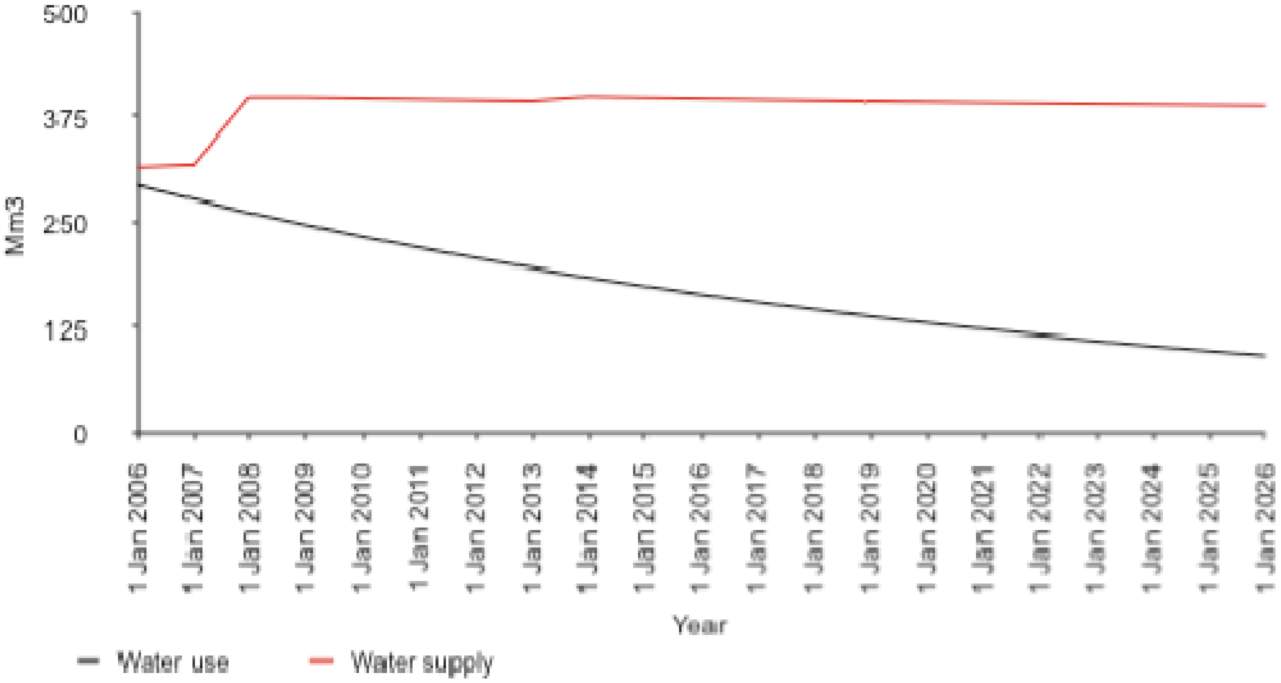


Goal Wii: Reduce water wastage

Water wastage is reduced and maintained to below 2% of the total water used. The results from this strategy are presented in Figure 17. Comparing these results with the standard simulation, water supply is increased with 14Mm^3 in 2014 to 22Mm^3 in 2020 and 34Mm^3 in 2026. In the 2006 case, although water supply effectively increases, this is only a small amount when compared to increased demand for water.

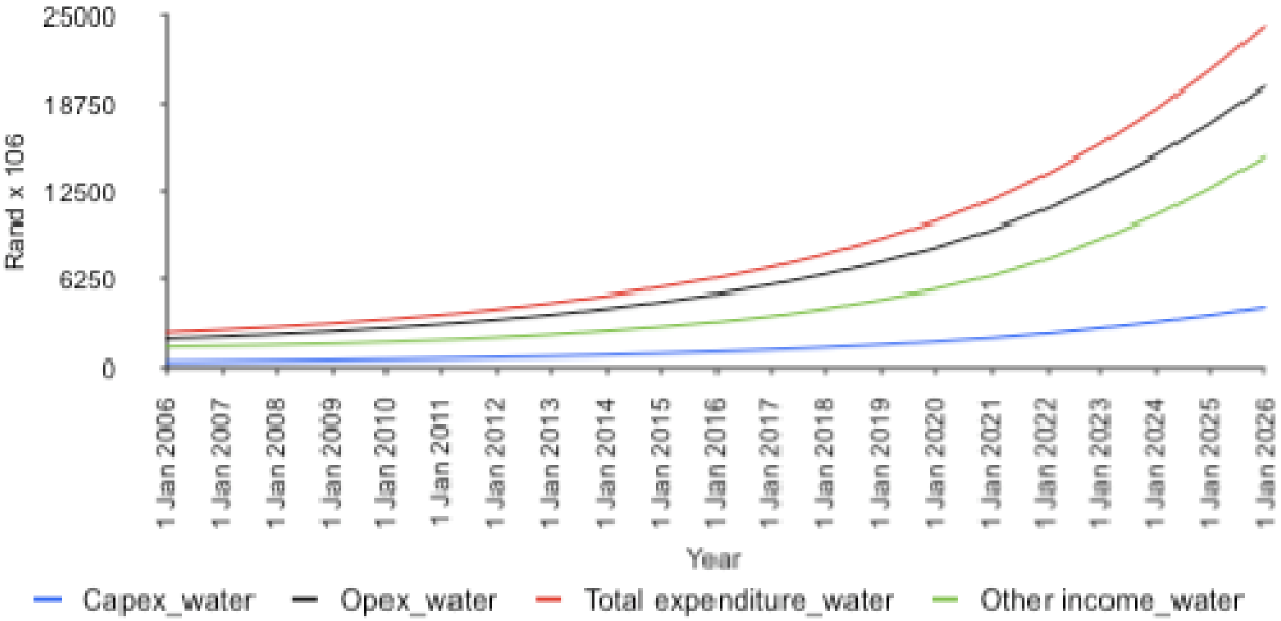
Figure 17: *Intervention simulations: Water supply and demand: Reduce water wastage, City of Cape Town (Mm3)*





There is no change in the required expenditure when compared to the baseline simulation as water use has not changed (Fig 18).

Figure 18: *Intervention simulations: Water income and expenditure: Reduce water wastage, City of Cape Town (R million)*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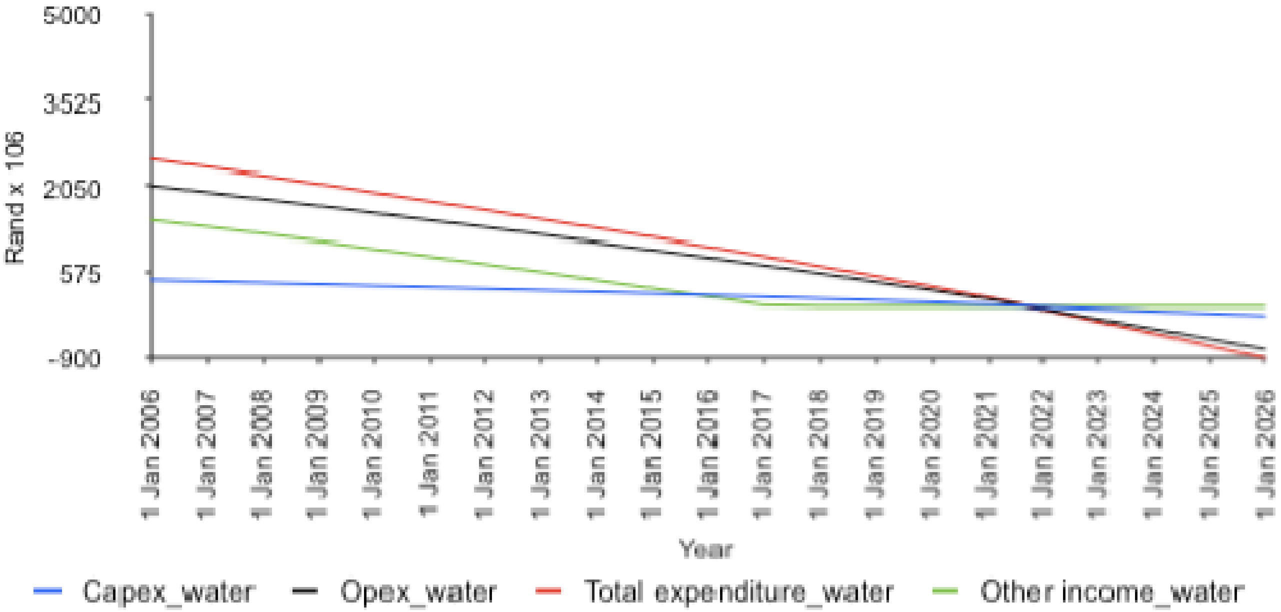
Other income_water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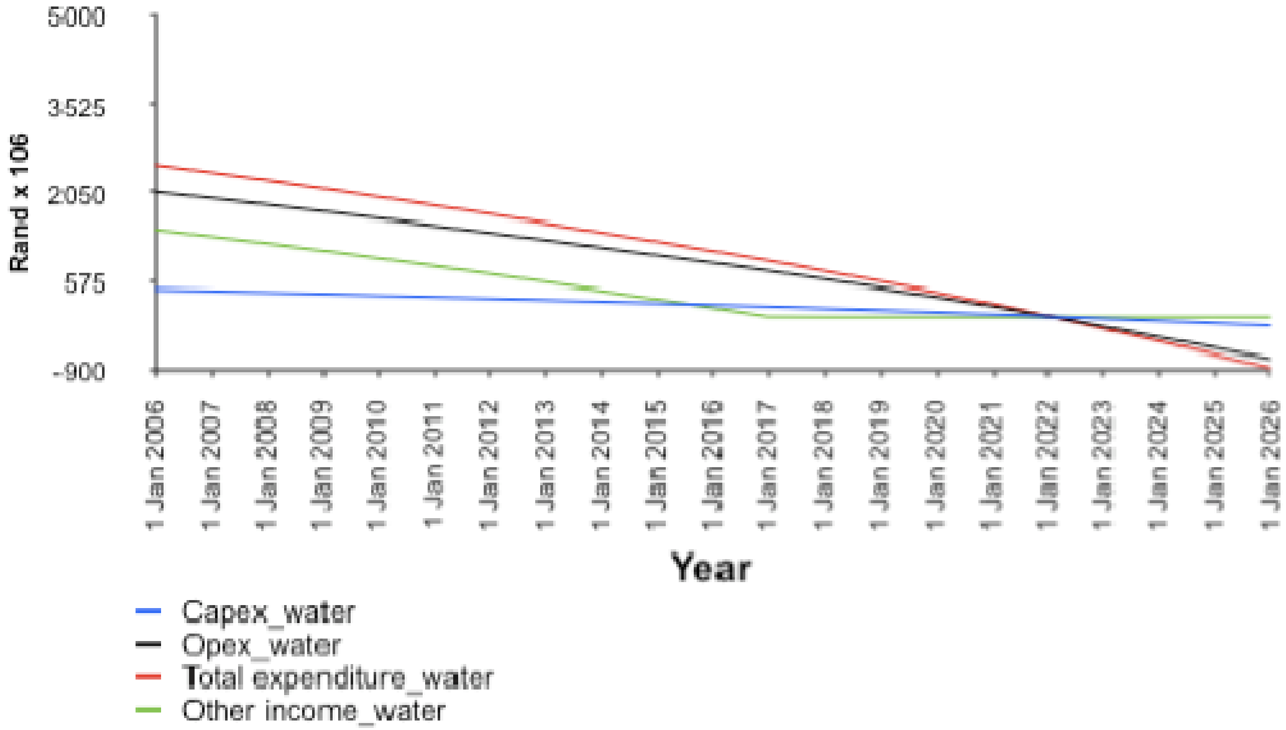
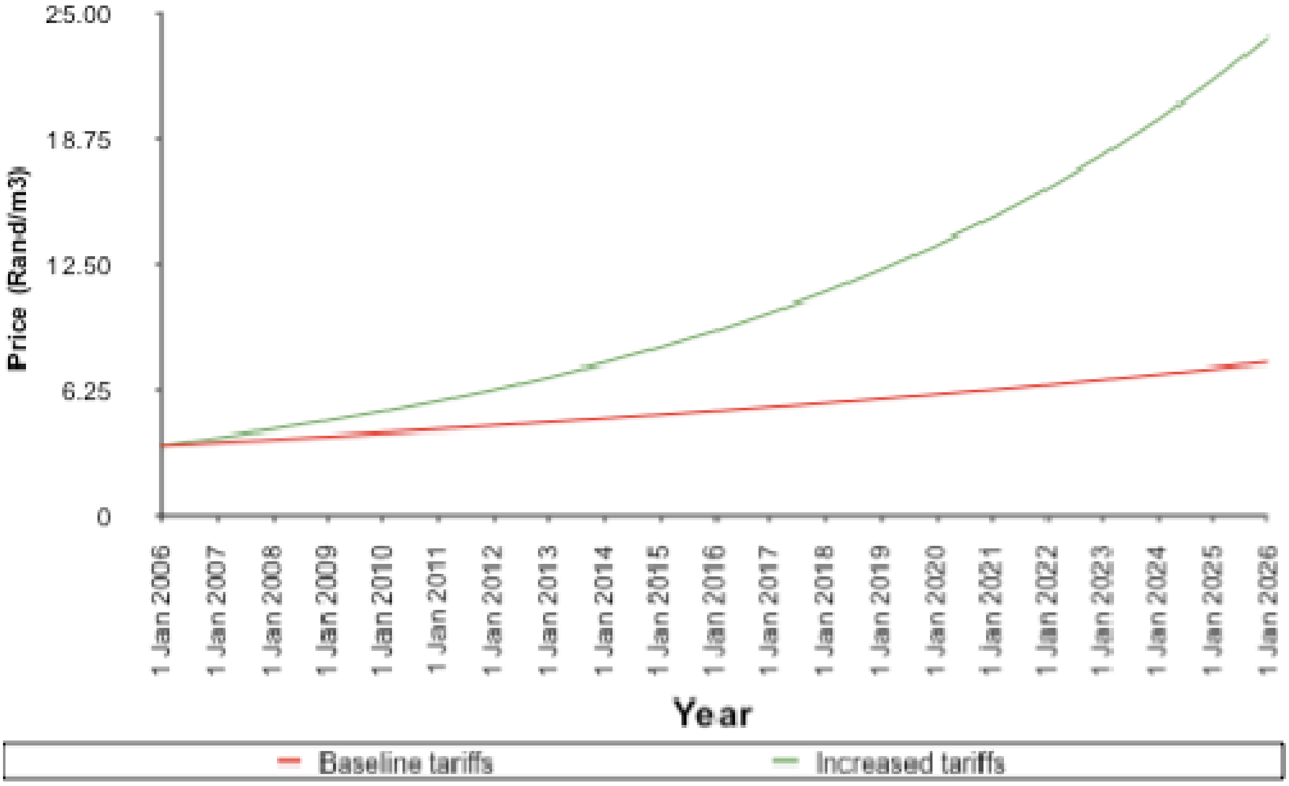


Goal Wiii: Increasing water tariffs with 10% per annum

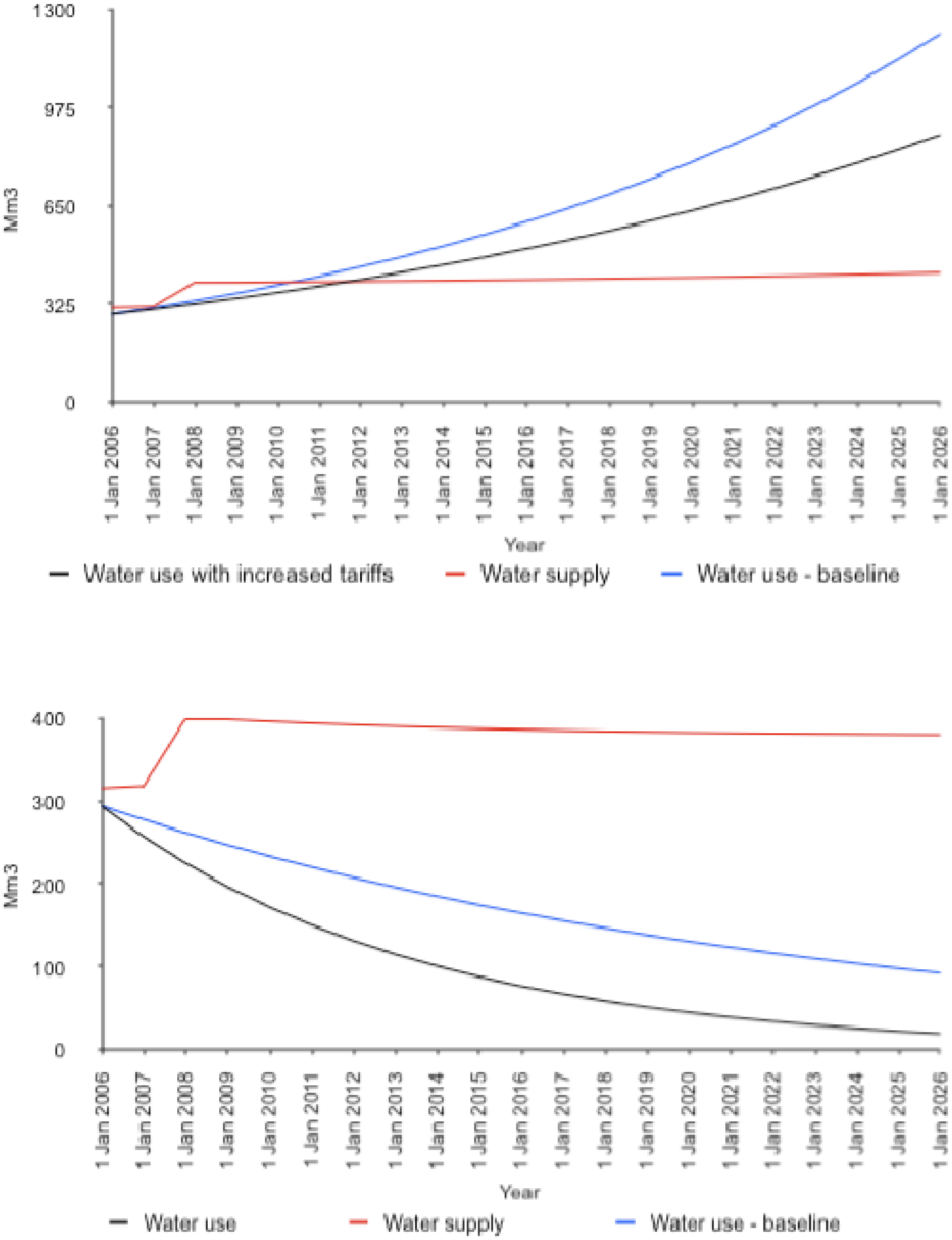
The third simulated option is to increase water tariffs with an average of 10% per annum, compared to the baseline 3.9%, which in turn is expected to decrease water use. This means that tariffs are simulated to increase from an average of R3.55/m^3 in 2006 to R9.21/m^3 in 2016 and R23.88/ m^3 in 2026 (Fig 19).

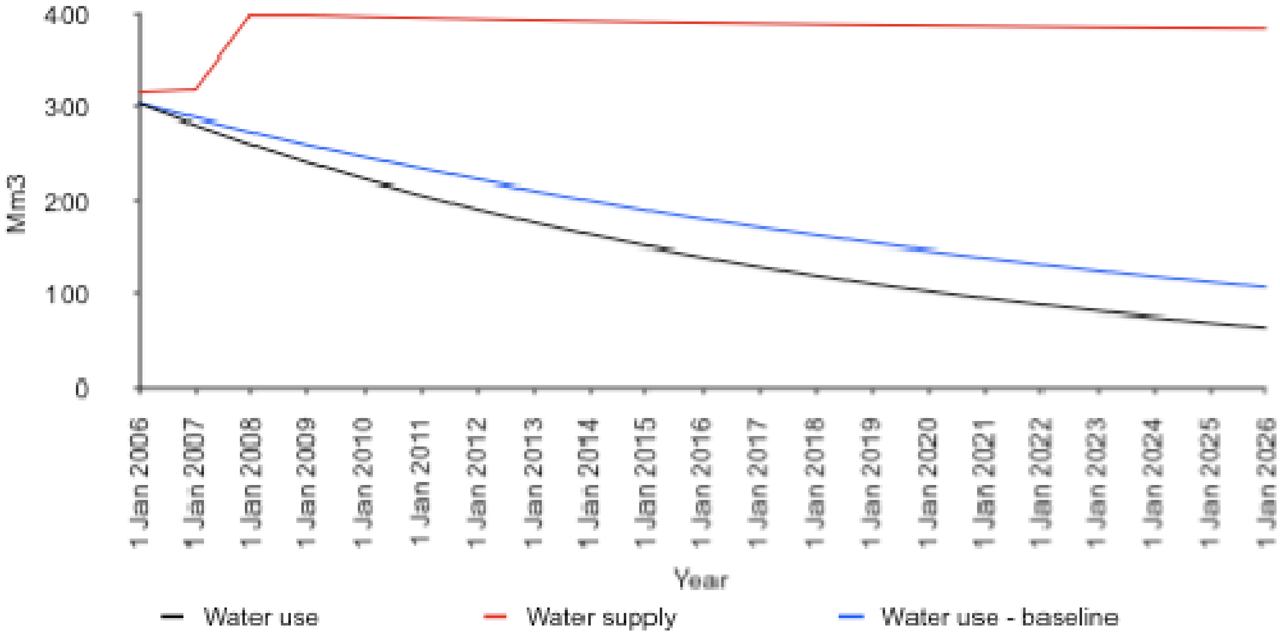
Figure 19: *Intervention simulations: Water tariffs: Increase water tariffs, City of Cape Town (R/m3)*



In the 2006 case, an increase in the rate at which tariffs increase is expected to reduce demand for water. It is simulated that a 10% annual increase in tariffs would lead to a 10% reduction in water demand in 2012, 25% in 2020 and 38% in 2026 when compared to baseline water demand in the same years. In the short to medium term an annual increase in water tariffs of 10% extents the ability of water supply to meet demand with one year, from 2010/11 to 2011/12. In the 2004-2006 and 2000-2003 cases, an increase in water tariffs will only further suppress water use (Fig 20).

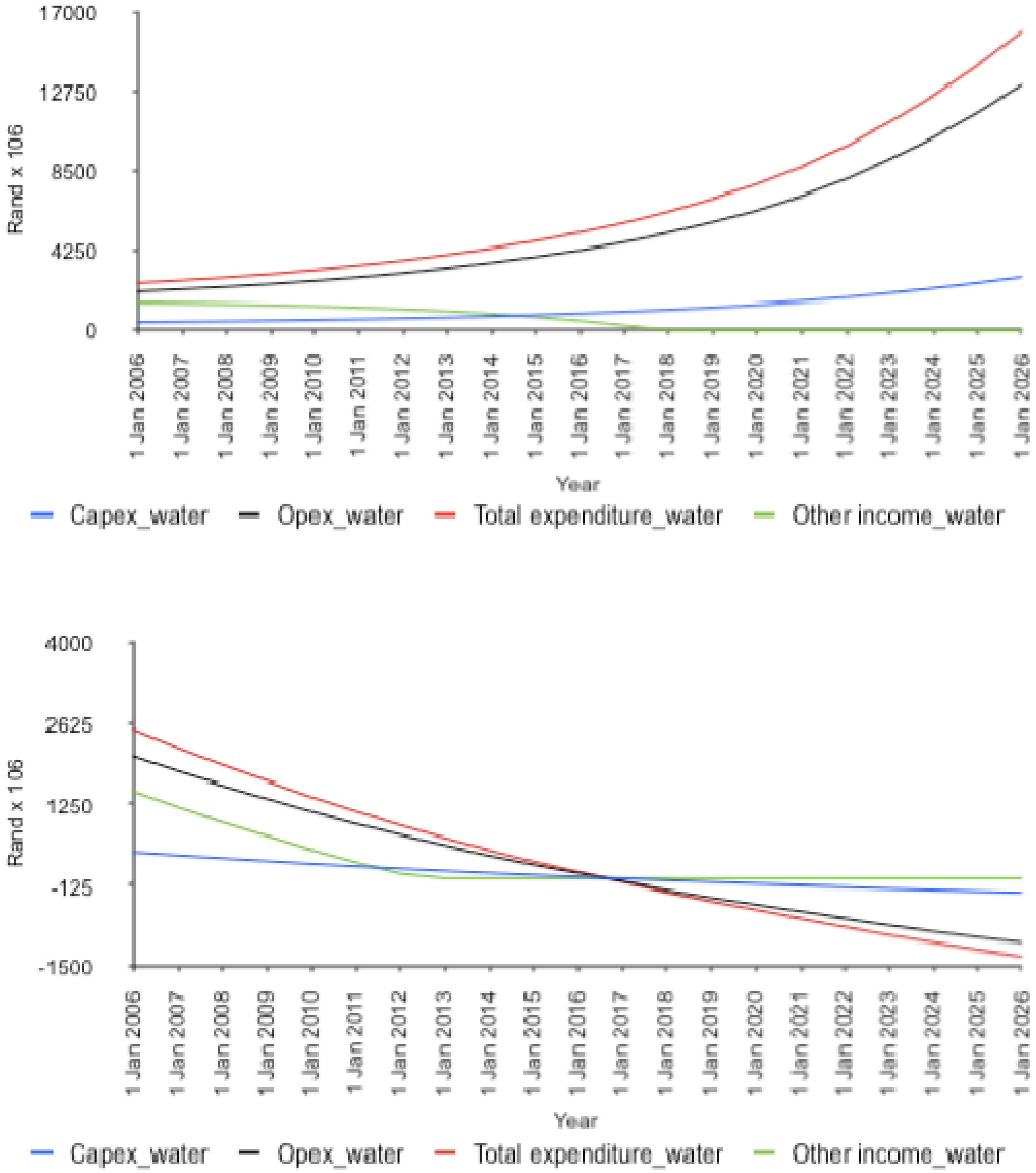
Figure 20: *Intervention simulations: Water supply and demand: Increase water tariffs, City of Cape Town (Mm3)*

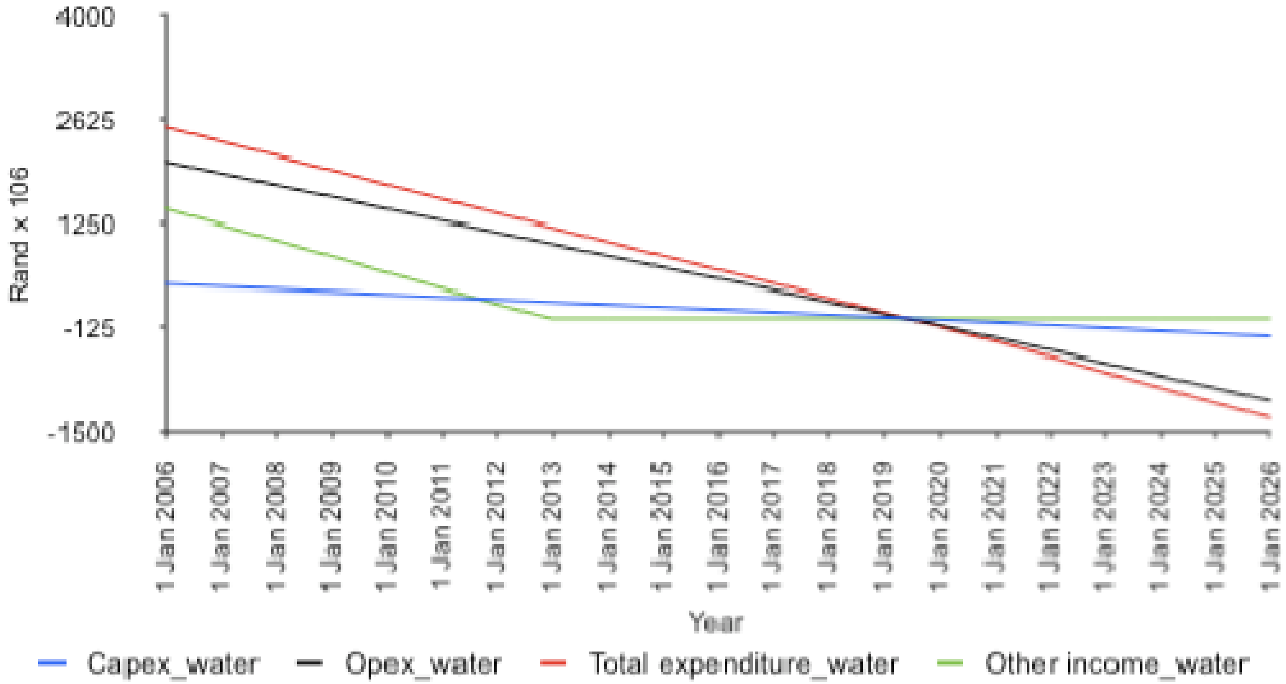




With decreased demand due to increasing tariffs, expenditure is also expected to decrease. For the 2006 case the total required expenditure on service provision is simulated to increase from around R2.5 billion per annum in 2006 to R4.4 billion in 2014, almost R7.8 billion in 2020 and almost R16 billion in 2026 (Fig 21). Using the 2004-2006 and 2000-2003 cases, required expenditure is also simulated to decrease over time.
In this simulation, with less water use, tariff income decreases and no additional income is required from 2019 onwards (compared to 2018 in the base case).

Figure 21: *Intervention simulations: Water income and expenditure: Increase water tariffs, City of Cape Town (R million)*





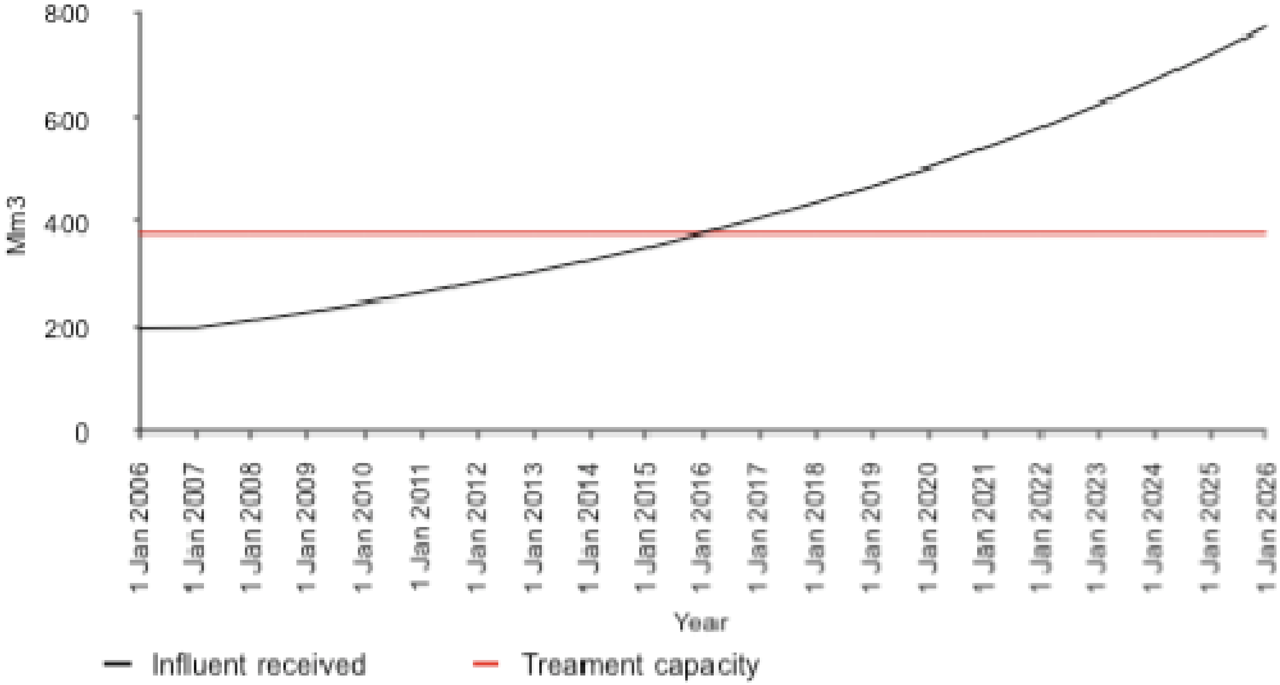
Sanitation services

Simulations on supply of and demand for sanitation services

The standard simulation results are presented in Figure 22. Using the 2006 case, the system reaches its carrying capacity for treating waste around year 2016. In such a case of stretched capacity, the effluent discharged to the environment will increase sharply and water quality problems are expected to increase.

Using 2000-2003 and 2004-2006 cases the capacity of effluent treatment is not stretched over the simulation period.

Figure 22: *Baseline simulations: Sanitation treatment capacity and demand, City of Cape Town (Mm3)*

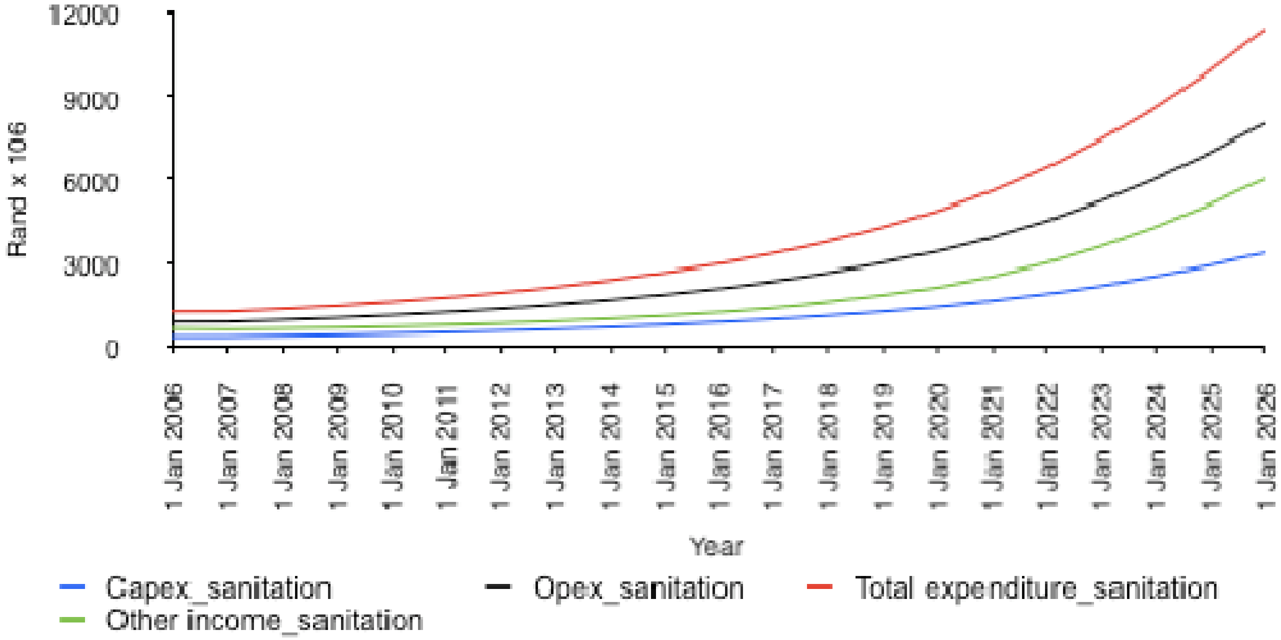


Simulations on income and expenditure from sanitation services

As demand for water services change, and demand for sanitation also changes, the required expenditure to treat waste water also change. The rate at which required expenditure is expected to change when demand for services increase could not be calculated given an absence of a good time series on expenditure. Using fixed unit costs (see Table 5) it is simulated using the 2006 case that total required expenditure on sanitation service provision is simulated to increase from around R1.3 billion per annum in 2006 to R3 billion in 2016, and almost R11.5 billion in 2026 (Fig 23). CAPEX accounts for around 30% of the total expenditure. Income from tariffs are not sufficient to cover expenditure and required ‘other income” is simulated to increase from R0.6 billion in 2006 to R1.3 billion in 2016 and R6.1 billion in 2026.

Using the 2004-2006 and 2000-2003 cases, required expenditure is simulated to decrease over time. Other income required also decreases with no additional income required from around 2017 onwards.

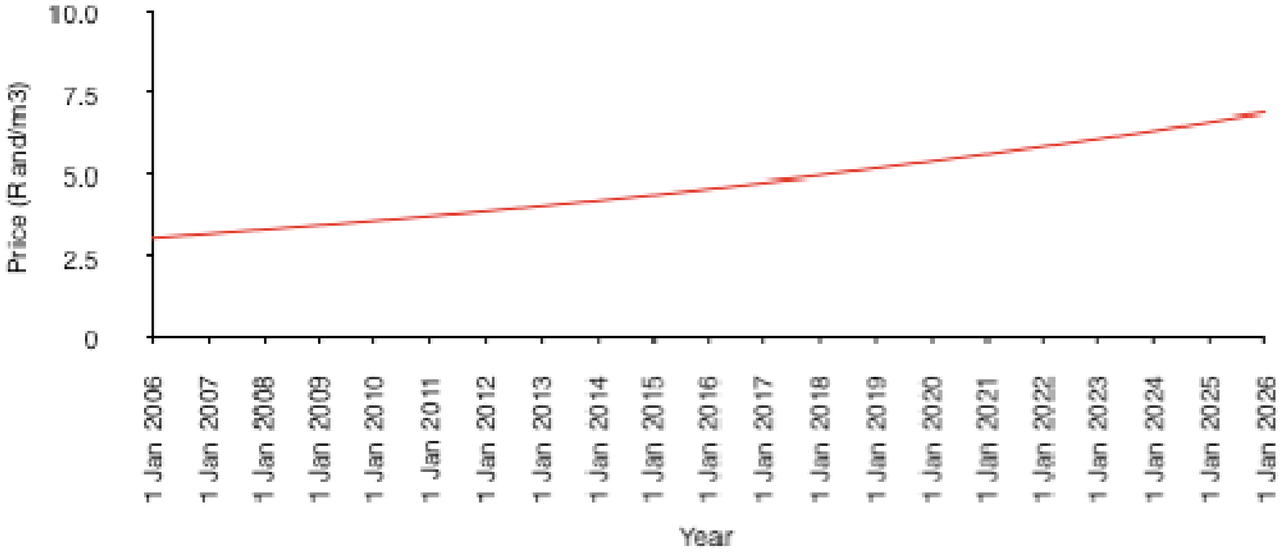
Figure 23: *Baseline simulations: Sanitation income and expenditure, City of Cape Town (R million)*



Simulations on sanitation tariffs

Sanitation tariffs are simulated to increase at 4.19% per annum, the average for the period 2005-2008 and assuming that 67% of all water used reach water treatment plants. In this case sanitation tariffs are simulated to increase from R3.05/m^3 in 2006 to R4.60/m^3 in 2016 and R6.93/m^3 in 2026 (Fig 24).

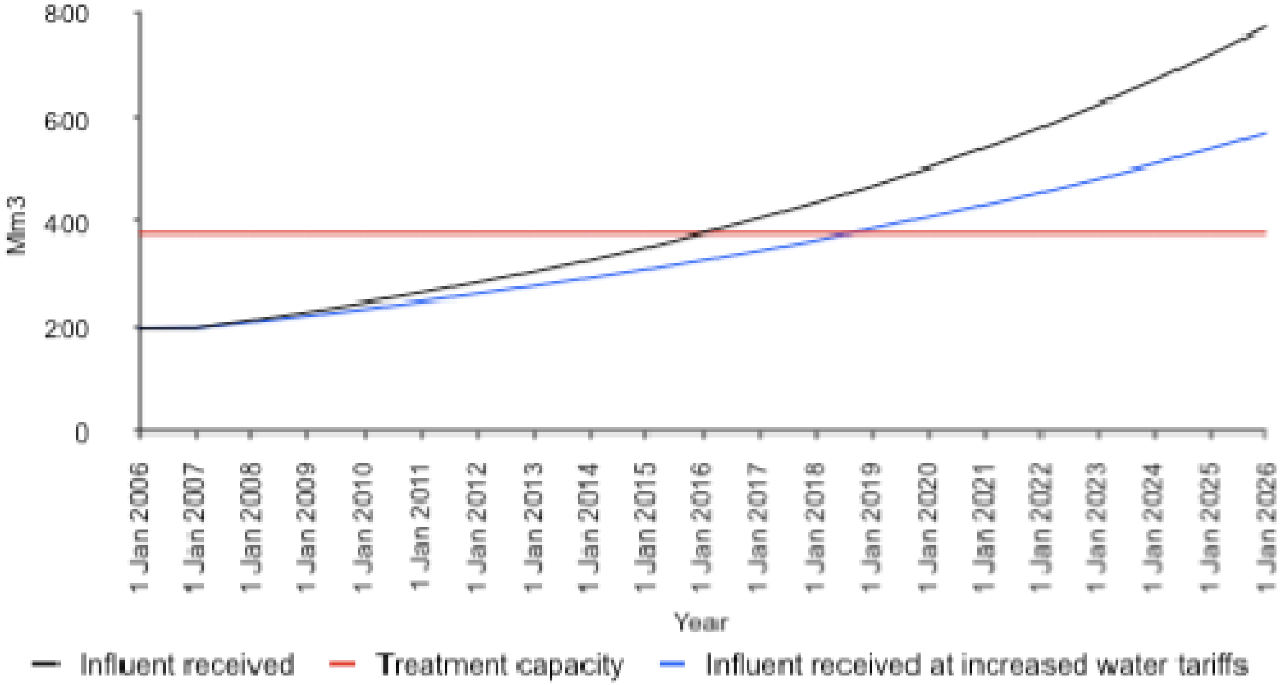
Figure 24: *Baseline simulations: Sanitation tariffs, City of Cape Town (R/m3)*



Simulations on influent management interventions

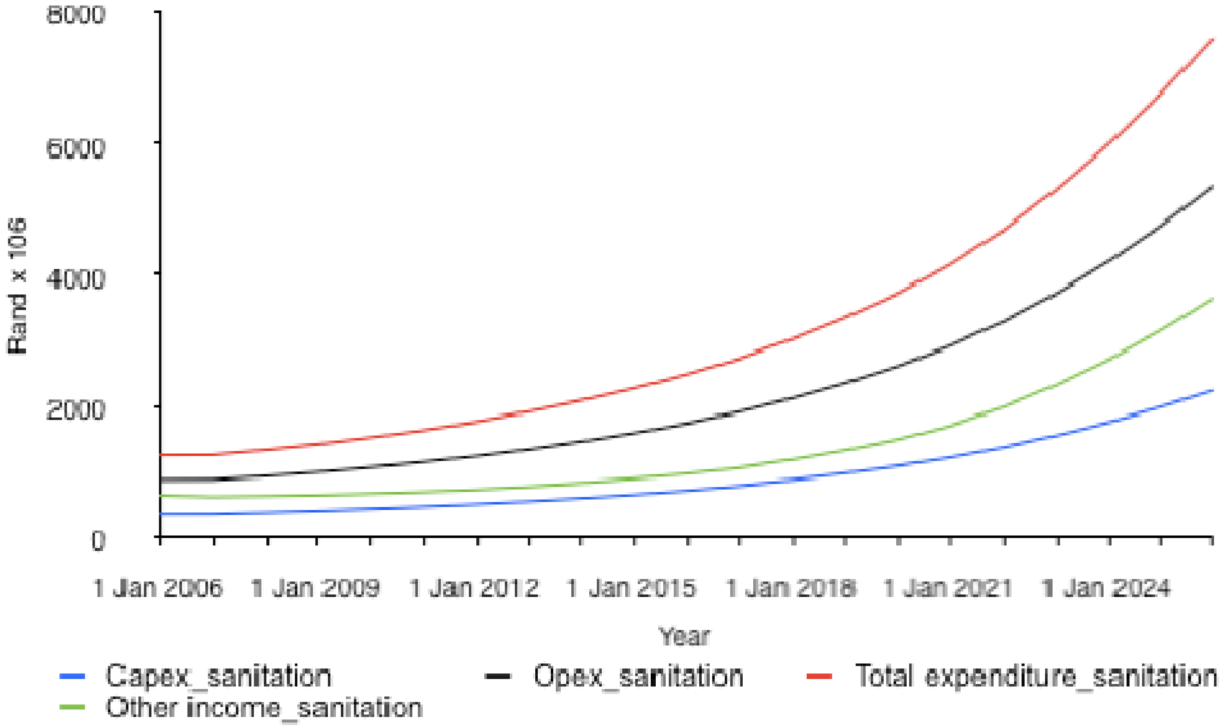
Since the rate of influent received is depended on water use, the three water management options were used to understand the effects of these changes on the sanitation system. The first two simulated management options, namely a reduction in non-revenue demand from 23% to 15% and a reduction of water wastage to 2% will not change water use and therefore has no impact on demand for sanitation (jnfluent received at treatment plants). It is only the third option, an increase in water tariffs, that would lead to reduced demand for water, and thus, a reduced demand for sanitation services (Fig 25). Increasing water tariffs with 10% per annum, will prolong the overall capacity to treat waste water with between 2 and 3 years.

Figure 25: *Intervention simulations: Sanitation supply and demand: Increased water tariffs, City of Cape Town (Mm3)*



With a decrease in demand, the required expenditure to provide sanitation services is also expected to be R0.5 billion less in 2016 and R3.9 billion less in 2026 then the base case. Total required expenditure is expected to be R2.5 billion by 2016 and R7.6 billion by 2026. With simulated sanitation tariffs (Fig 26), the need for income from other sources would increase from R0.7 billion in 2006 to R1 billion in 2016 and R3.7 billion in 2026. This is R3 billion (in 2016) and R2.4 billion (in 2026) less then the base case.

Figure 26: *Intervention simulations: Sanitation income and expenditure: Increased water tariffs, City of Cape Town (R million)*

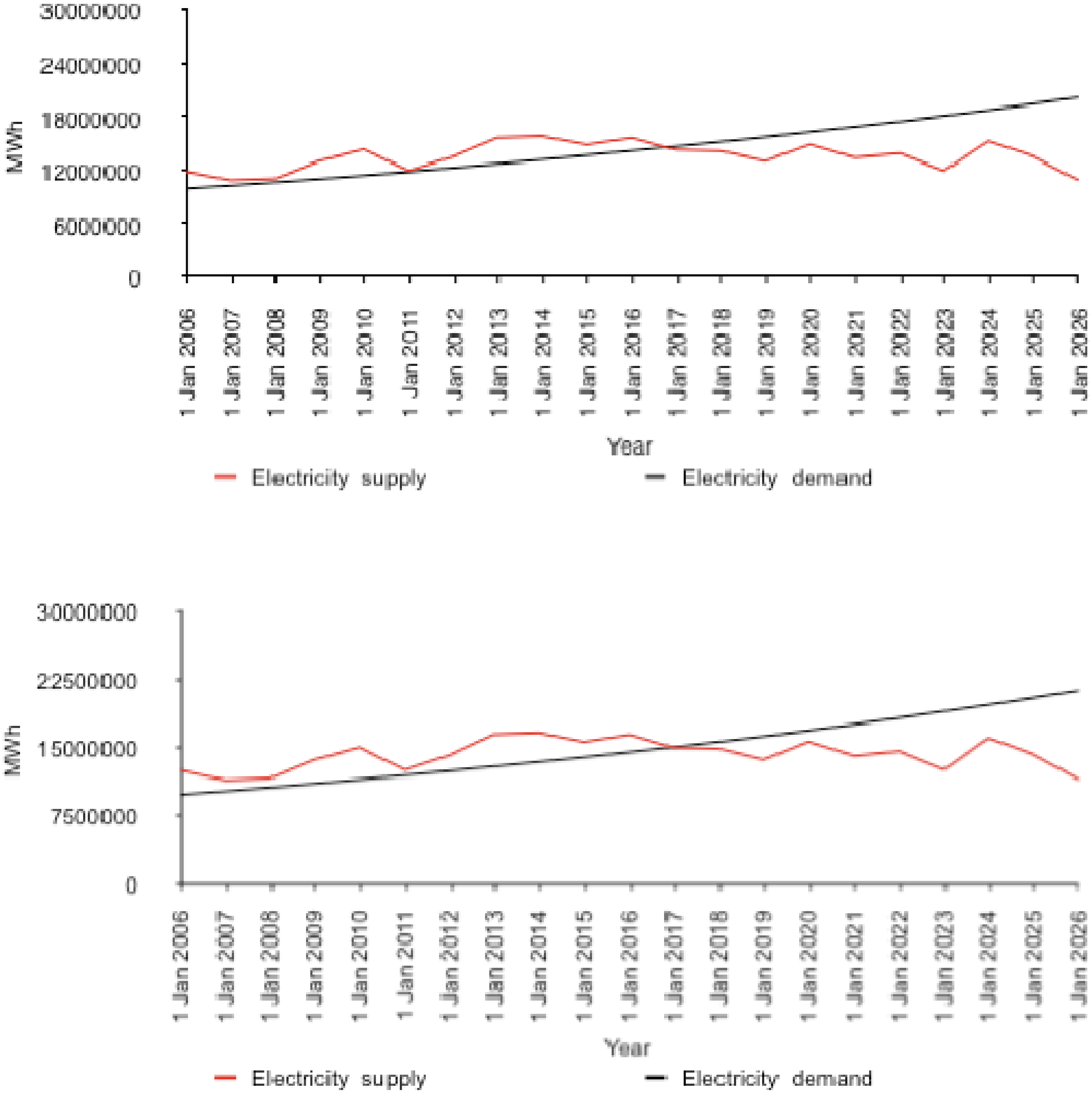


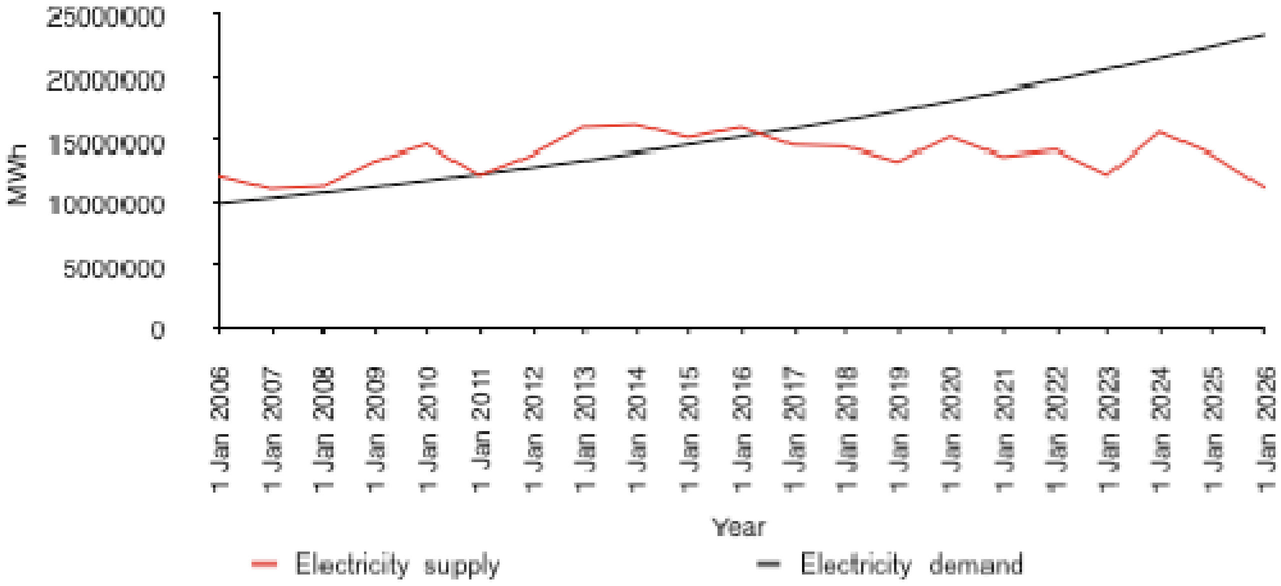
Electricity services

Simulations on supply of and demand for electricity services

The baseline simulations are given in Figure 27. In all cases (2006, 2000-2003 and 2004-2006) the chances of supply constraints are highest in in 2007/8, 2011 and after around 2016. Electricity demand is simulated to grow at 3.6%, 3.9% and 4.4% per annum respectively for the different cases. Since these cases are so close to each other, only the 2006 case is simulated further.

Figure 27: *Baseline simulations: Electricity supply and demand, City of Cape Town (MWh)*

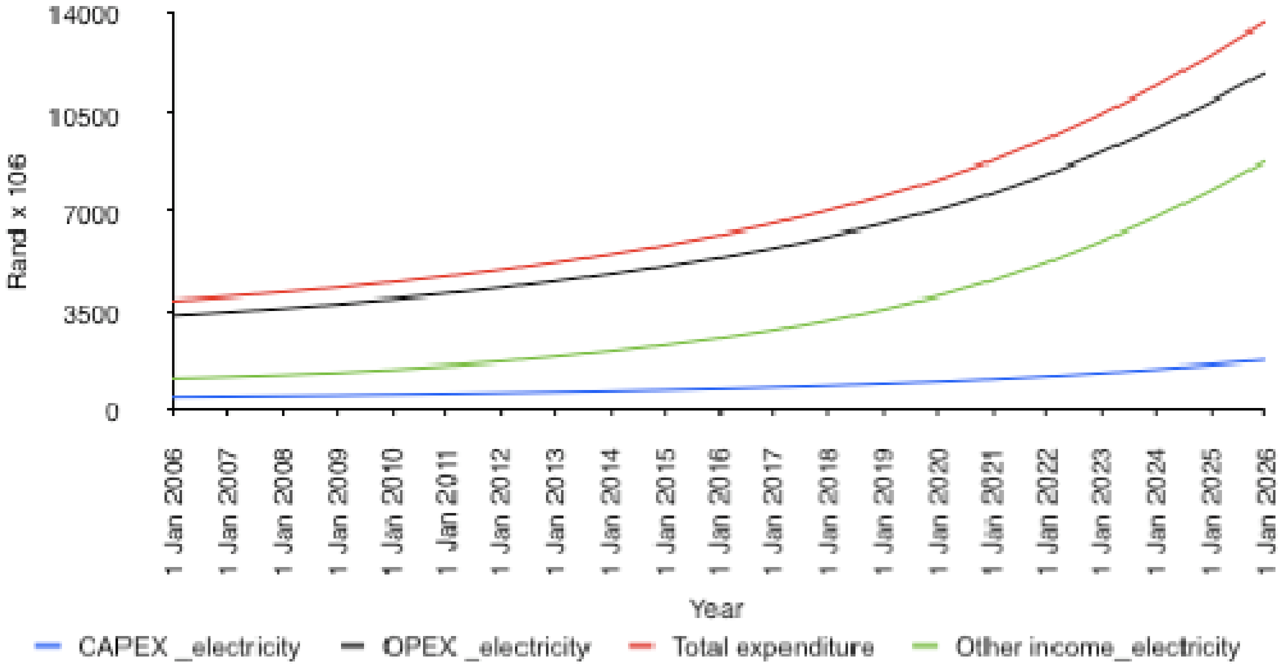




Simulations on income and expenditure from electricity services

Using fixed unit costs (Table 6) it is simulated, using the 2006 case, that total required expenditure on service provision is simulated to increase from around R3.9 billion per annum in 2006 to R5.9 billion in 2016, and R13.7 billion in 2026 (Fig 28). CAPEX is simulated to account for 13% of the total expenditure. Income from tariffs are not sufficient to cover expenditure and required ‘other income” is simulated to increase from R1.2 billion in 2006 to R2.6 billion in 2016 and R8.8 billion in 2026.

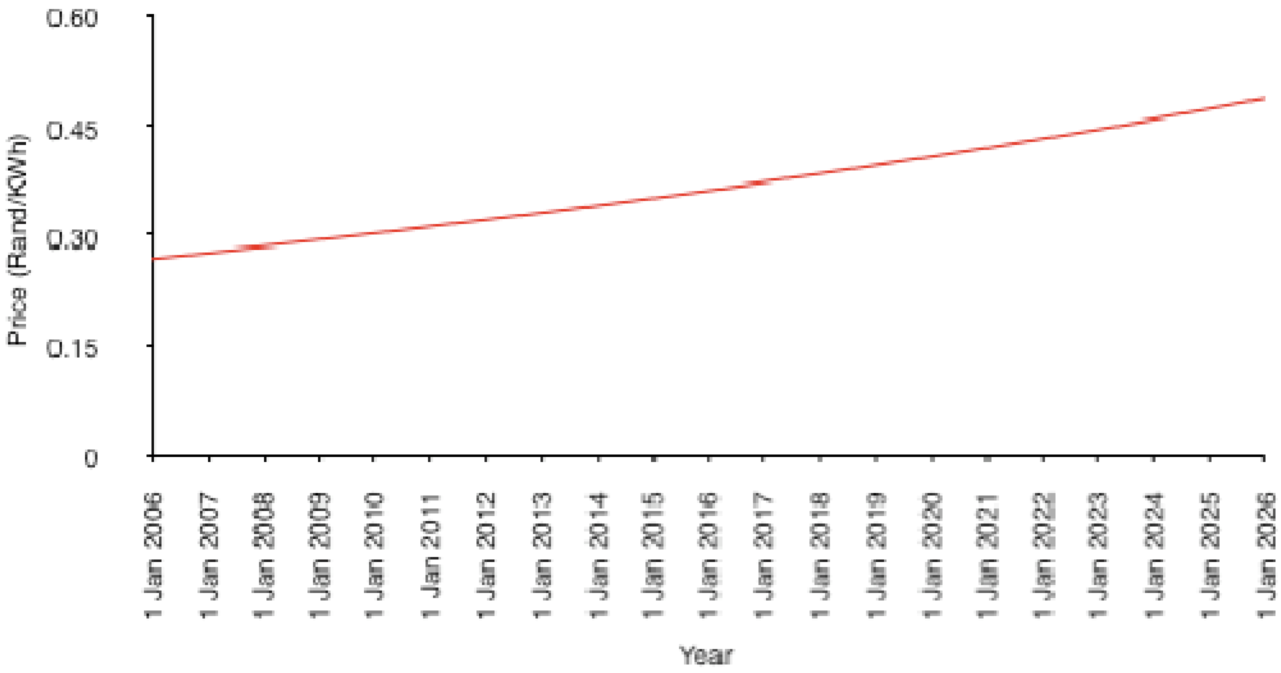
Figure 28: *Baseline simulations: Electricity income and expenditure: City of Cape Town, (R million)*



Simulations on electricity tariffs

Base case electricity tariffs are simulated to increase at 3% per annum, which is based on the average of budgeted electrcity service charges divided by the average electricity use as based on City’s own electricity growth projections. In this case electricity tariffs are simulated to increase from R0.27c/Kwh in 2006 to R0.36c/Kwh in 2016 and R0.49c/Kwh in 2026 (Fig 29).

Figure 29: *Baseline electricity tariffs, City of Cape Town (R/Kwh)*



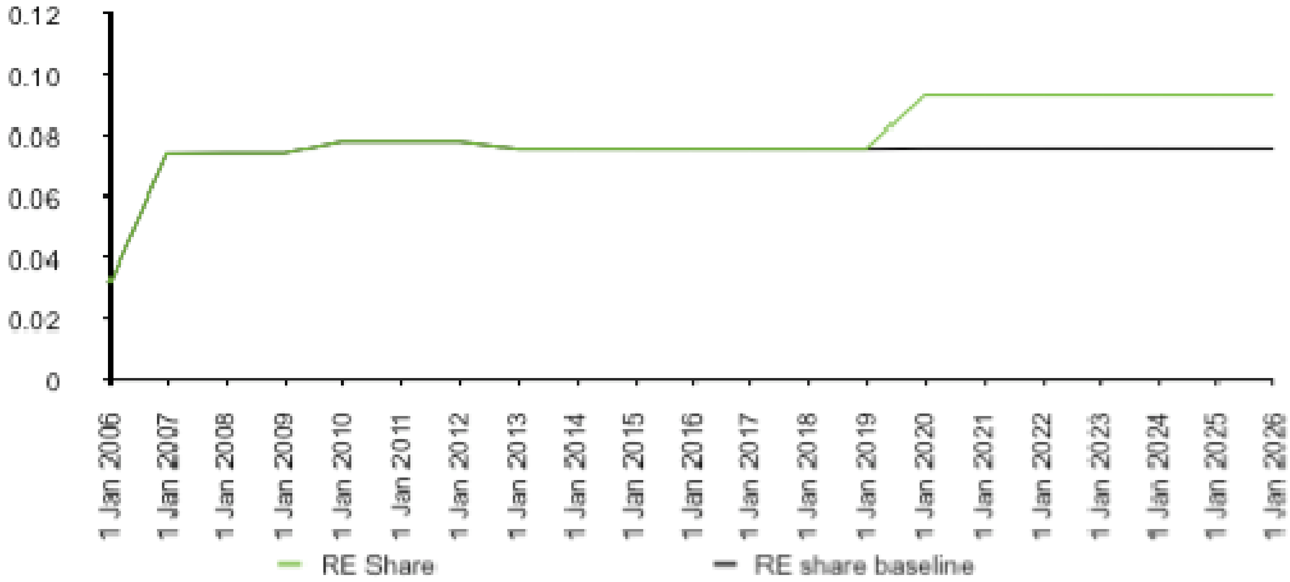
Simulations on electricity management interventions

Three electricity management simulations are done, namely an increased provision of electricity from renewable energy sources (goal Ei), an increase in the efficiency of electricity use (goal Eii) and an increase in electricity tariffs (goal Eiii).

Goal Ei: Increase proportion of renewable electricity supplies to 10% in 2020

An increase in the proportion of renewable energy (Fig 30) would not change the overall supply or demand for electricity and will have no impact on the required expenditure to provide electricity services. There may be changes in the cost of supply, but these were not included in the simulations yet.

Figure 30: *Increased share of renewable energy, City of Cape Town (%)*



Goal Eii: Increased efficiency in electricity use to 10% by 2020

A (very steep) increase in efficiency of electricity use by 10% per annum would drastically reduce demand (Fig 31) and reduce demand on required expenditure and total income required.

Figure 31: *Intervention simulations: Electricity supply and demand: Increase efficiency in use, City of Cape Town (Mwh)*

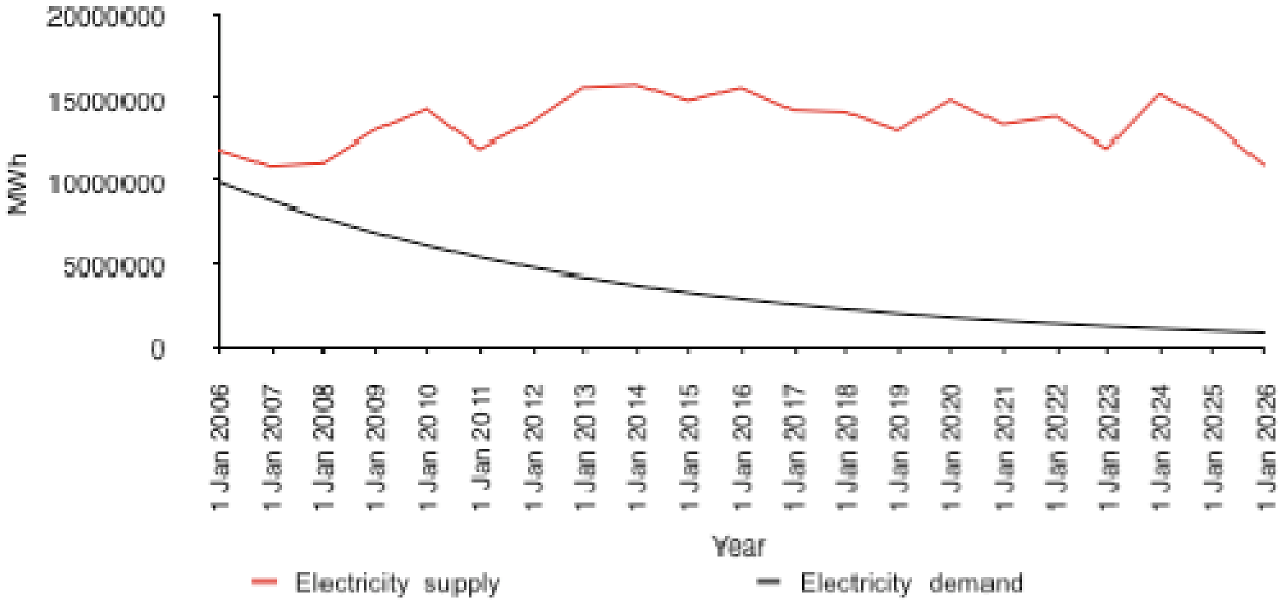
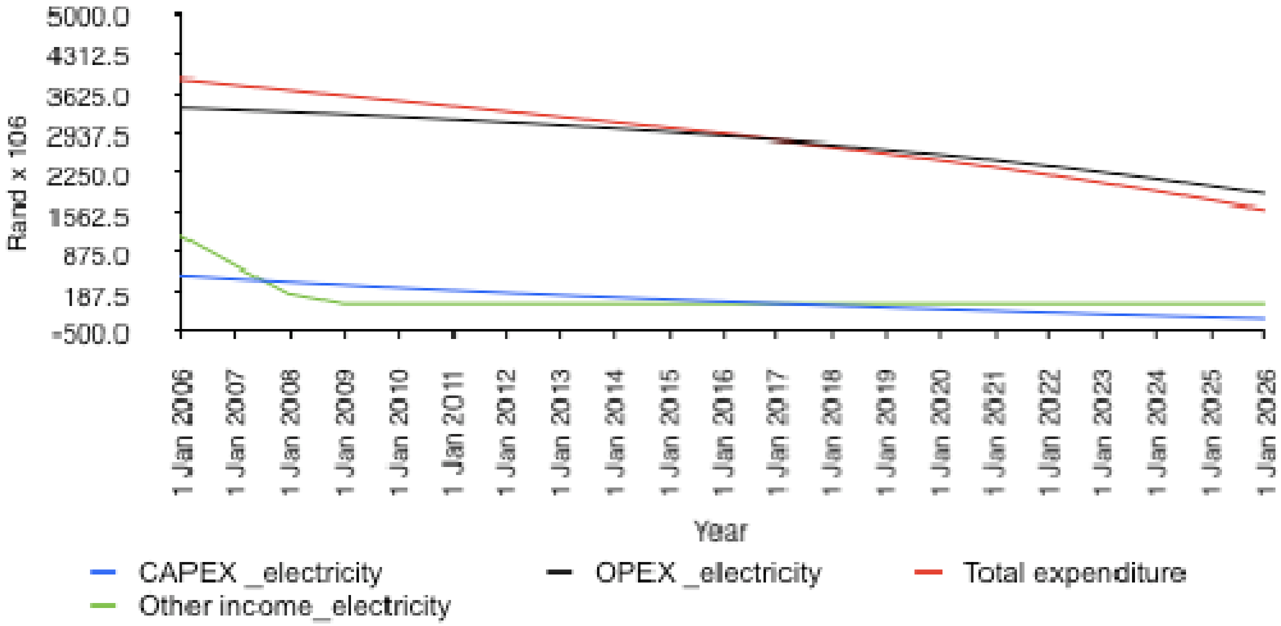


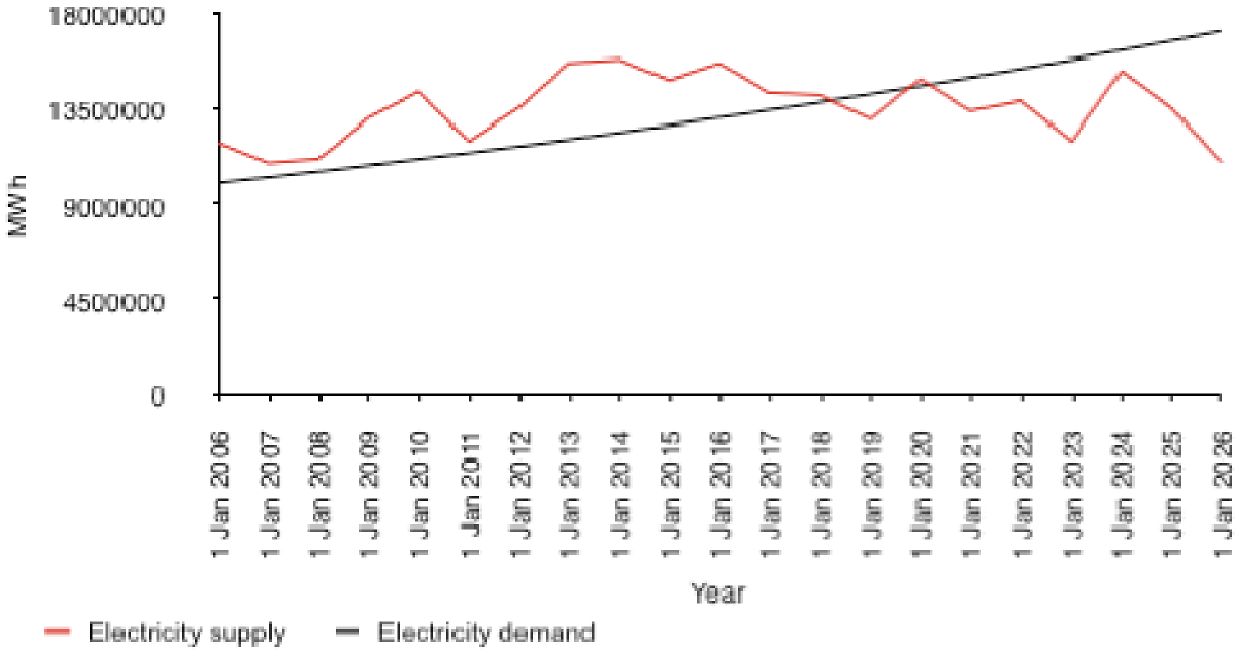
Figure 32: *Intervention simulations: Electricity income and expenditure: Increase efficiency in use, City of Cape Town (R million)*



Goal Eiii: Increase electricity tariffs to 10% per annum

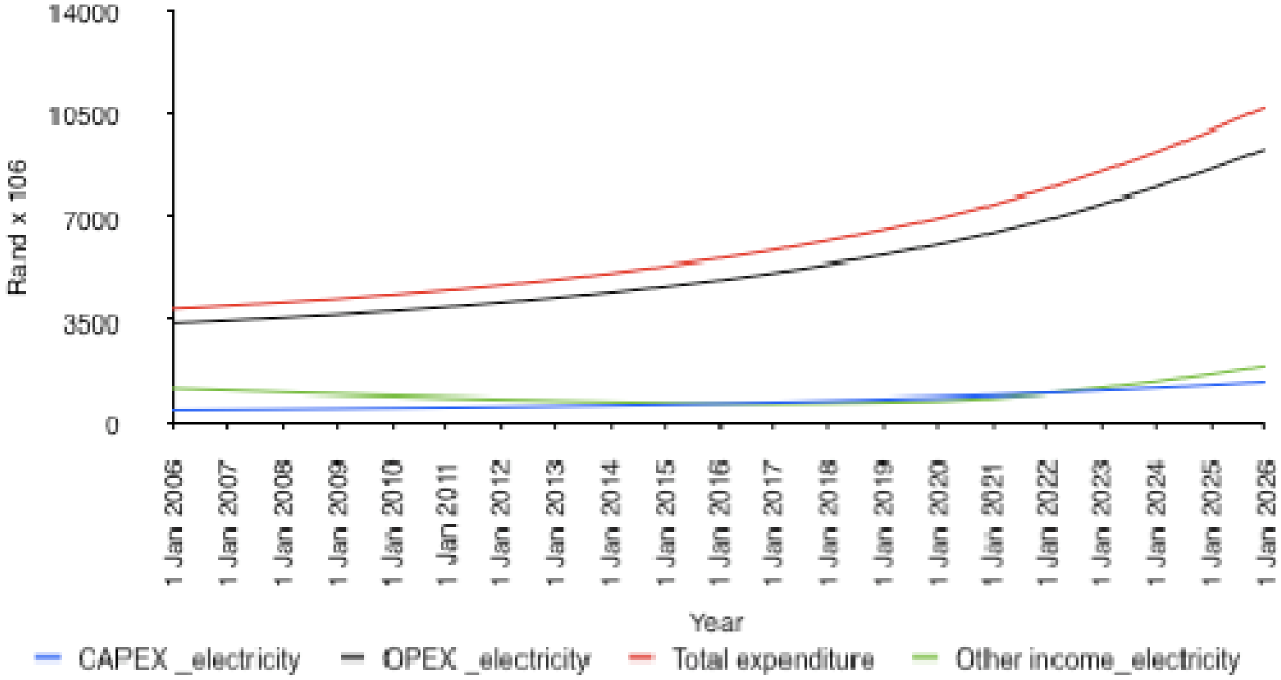
An annual increase of electricity tariffs of 10% is expected to relief pressure on short and medium term supply constraints, but will not be sufficient to reduce demand enough by around 2018 (Fig 33).

Figure 33: *Intervention simulations: Electricity supply and demand: Increase tariffs, City of Cape Town (MWh)*



With an increase in electricity tariffs with 10% pa, the required expenditure to provide electricity services is also expected to be R0.6 billion less in 2016 and R3.0 billion less in 2026 then the base case. Total required expenditure is expected to be R5.6 billion by 2016 and R10.7 billion by 2026. With simulated increases in electricity tariffs, the need for income from other sources would first decrease from R1.2 billion in 2006 to R0.7 billion in 2016 and the increase to R1.9 billion in 2026. This is R1.8 billion (in 2016) and R6.9 billion (in 2026) less then the base case (Fig 34).

Figure 34: *Intervention simulations: Electricity income and expenditure: Increase tariffs, City of Cape Town (R million)*

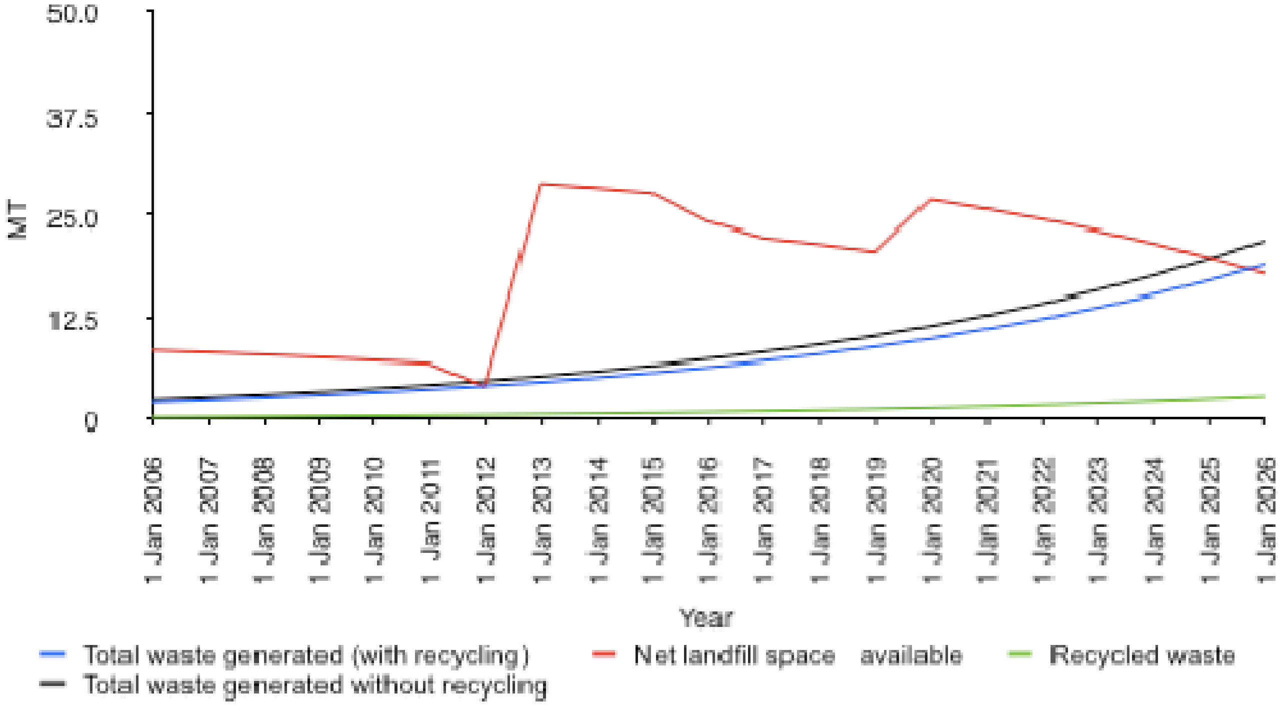


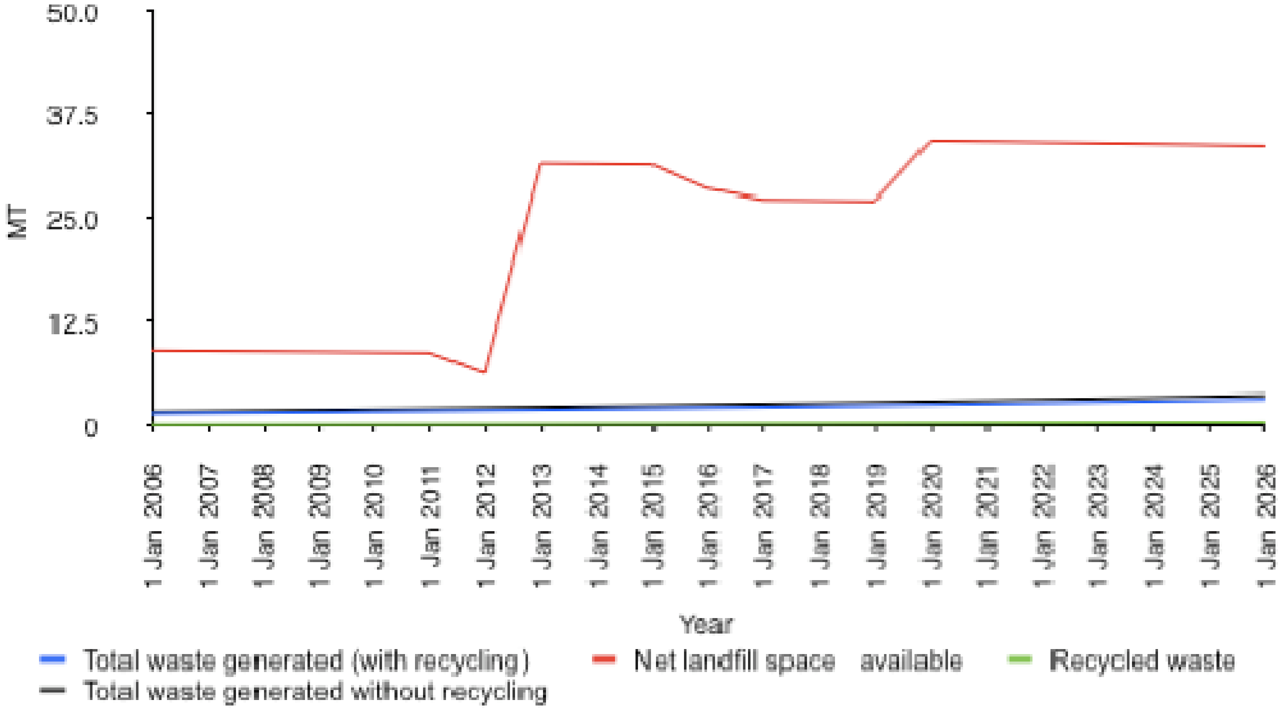
Solid waste services

Simulations on solid waste generated and landfill capacity

The results based on the standard simulation are shown in Figure 35. The total amount of waste generated exceeds the landfill space around 2011/12 when the 2006 and 2004-06 cases are simulated and again around 2025 in the 2006 case. In the 2004-2006 case the net landfill space in 2012 may just be sufficient if existing recycling is continued, but there is no space for any increase in waste generation. In the 2000-2003 case there is an overcapacity of net landfill capacity available.

Figure 35: *Baseline simulations: Solid waste generated and landfill capacity, City of Cape Town (Mt)*

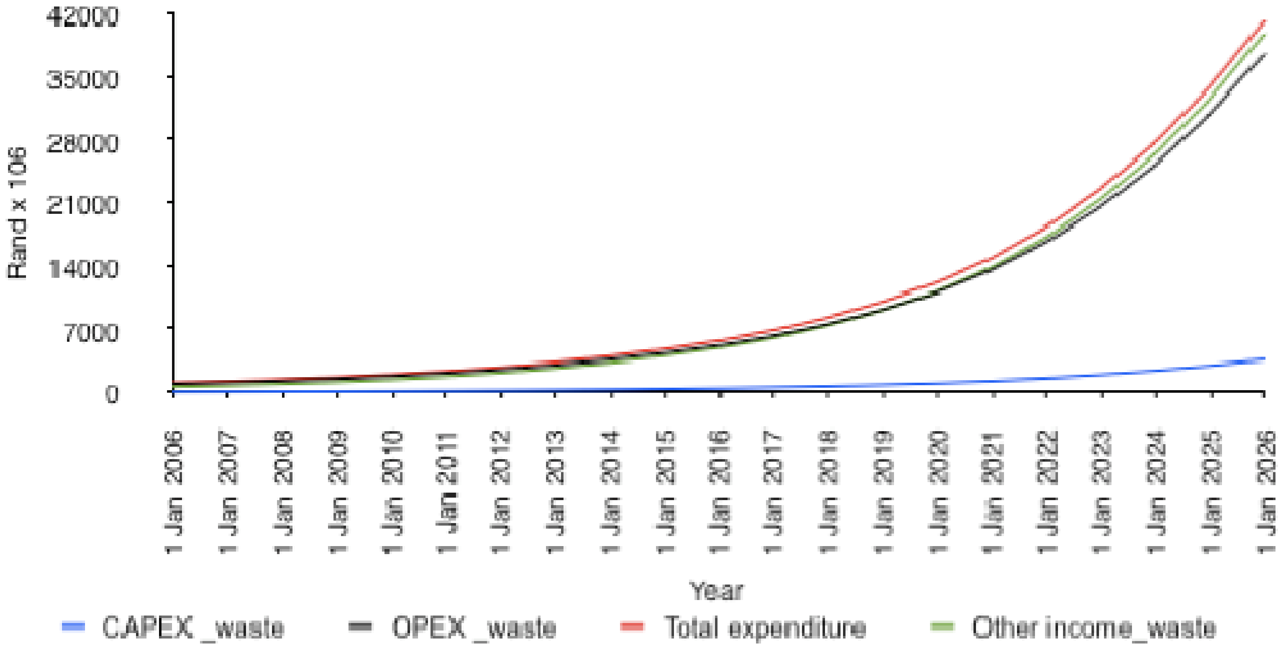


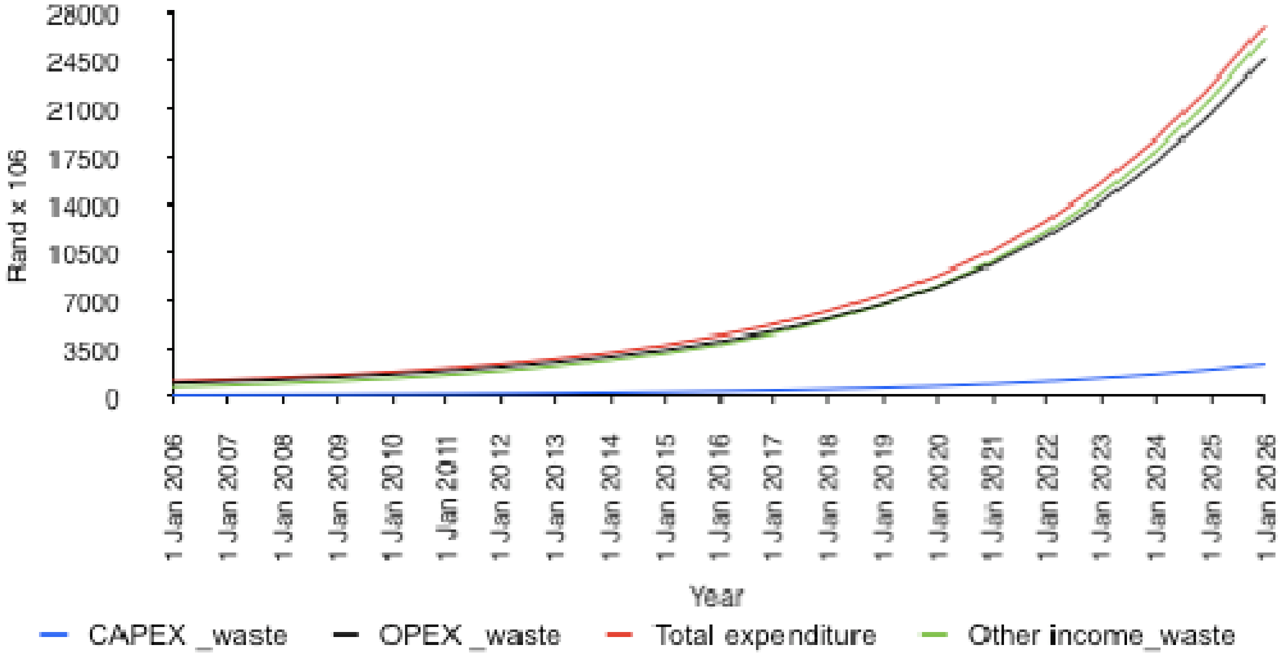


Simulations on income and expenditure from solid waste services

Using fixed unit costs (see Table 7) it is simulated using the 2006 case that total required expenditure on service provision is simulated to increase from around R1.1 billion per annum in 2006 to R5.7 billion in 2016 and R41 billion in 2026 (Fig 36). CAPEX accounts for around 9% of the total expenditure. Income from tariffs are not sufficient by far to cover expenditure and required 'other income" is simulated to increase from R0.7 billion in 2006 to R4.9 billion in 2016 and R40 billion in 2026. Using the 2004-2006 and also the 2000-2003 case (not shown), required expenditure and other income required is simulated to be lower over time.

Figure 36: *Baseline simulations: Solid waste income and expenditure, City of Cape Town (R million)*

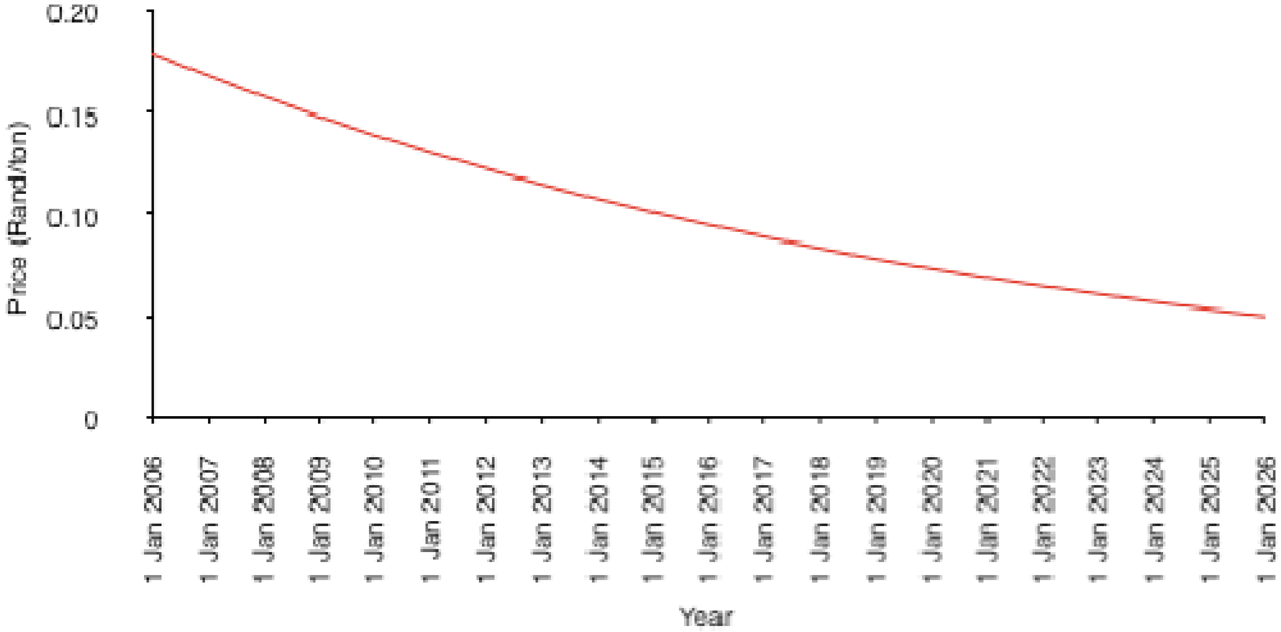




Simulations on solid waste tariffs

Base case solid waste tariffs are simulated to decrease at 6% per annum. This decrease is based on real budgeted income from solid waste and projected increases in solid waste generated at 7% per annum. In this case solid waste tariffs are simulated to decrease from R0.18c/t in 2006 to R0.10c/t in 2016 and R0.05c/t in 2026 (Fig 37).

Figure 37: *Baseline simulations: Solid waste tariffs, City of Cape Town (R/t)*



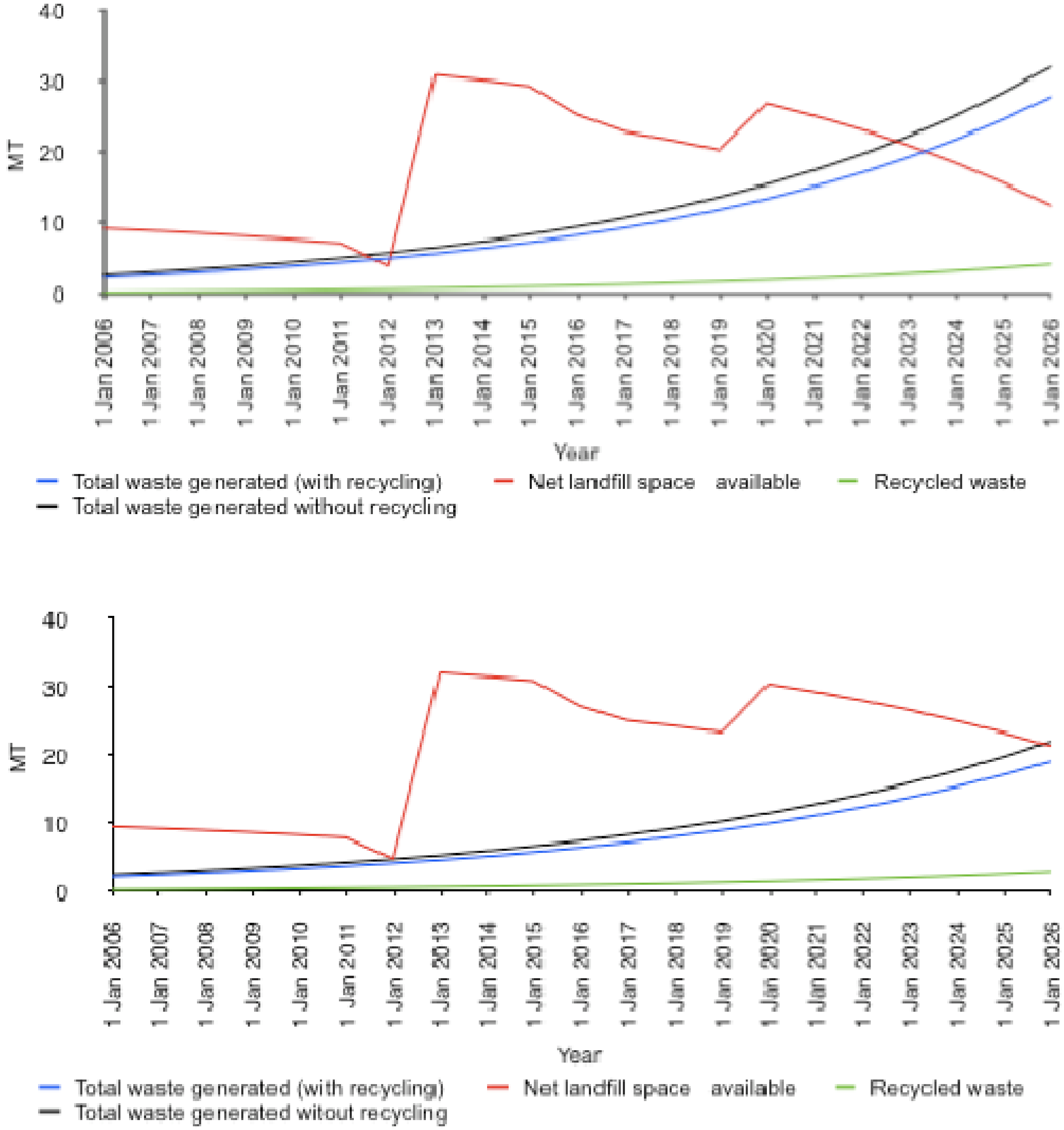
Simulations on solid waste management interventions

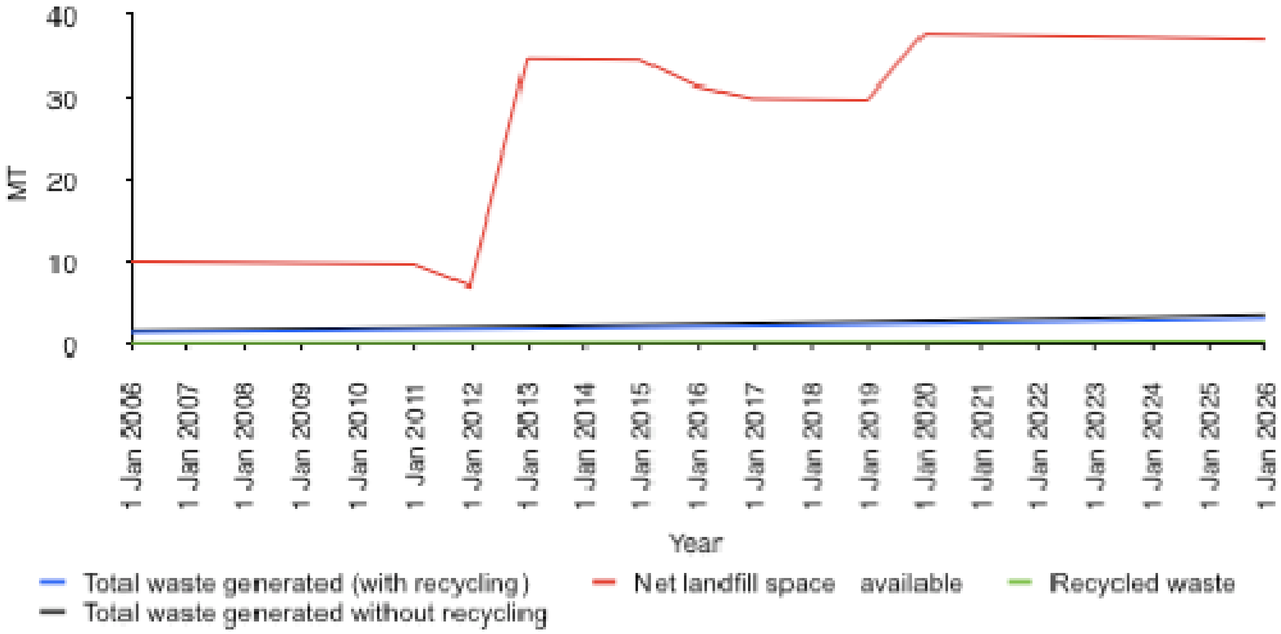
Three simulations were done, namely on compaction management, recycling and landfill densities.

Goal SWi: Increase compaction from a current factor of 1.1 to a factor of 1.2.

Increasing compaction will have a small overall impact on the net available landfill space and would not be sufficient to address landfill space shortages around 2011/2012 in the 2006 case. In the 2004-2006 case it may help to ease the pressure on the 2011/12 transition.

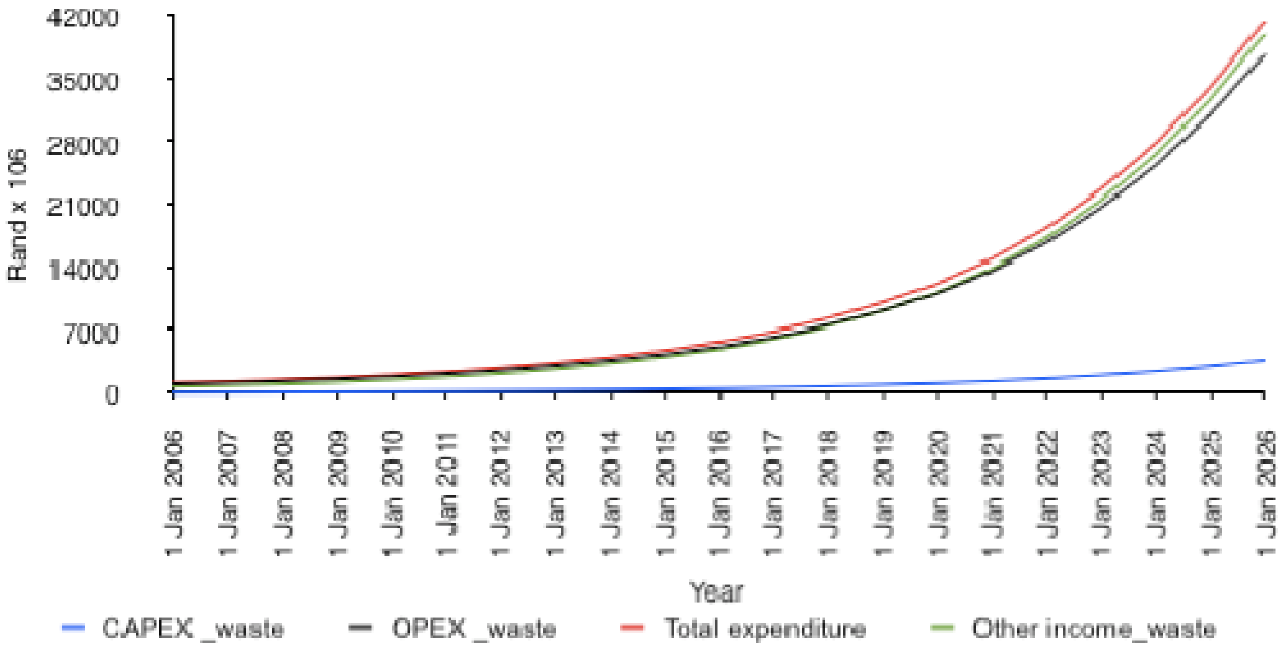
Figure 38: *Intervention simulations: Solid waste generated and landfill capacity: Increased compaction, City of Cape Town (Mt)*





Increase compaction does not directly address waste generation and it was modelled to have no impact on required expenditure.

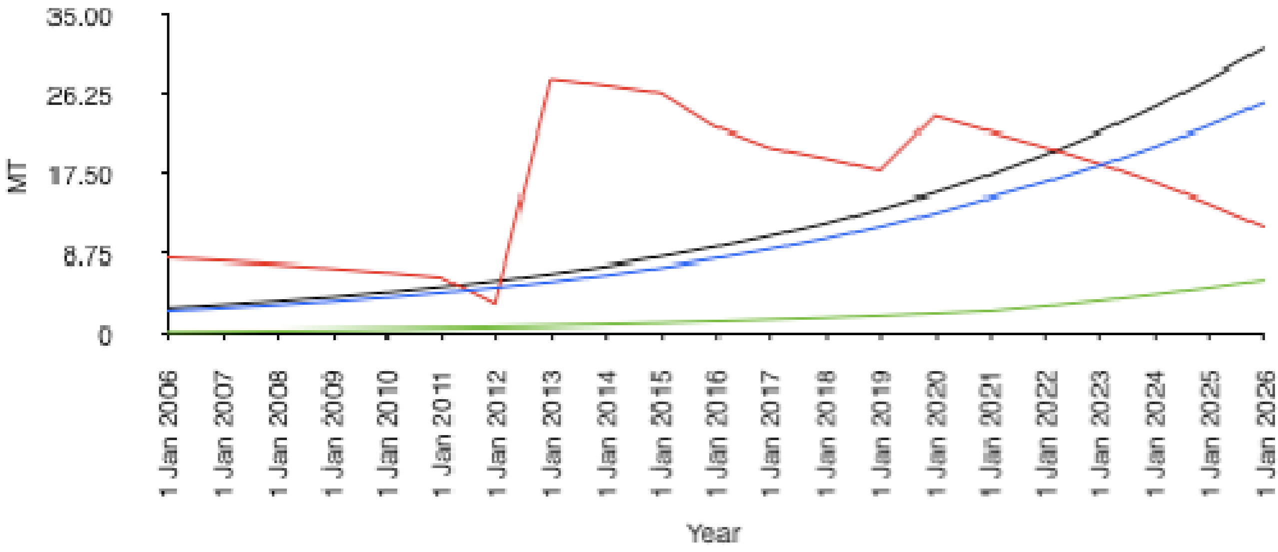
Figure 39: *Intervention simulations: Solid waste income and expenditure: Increased compaction, City of Cape Town (R million)*

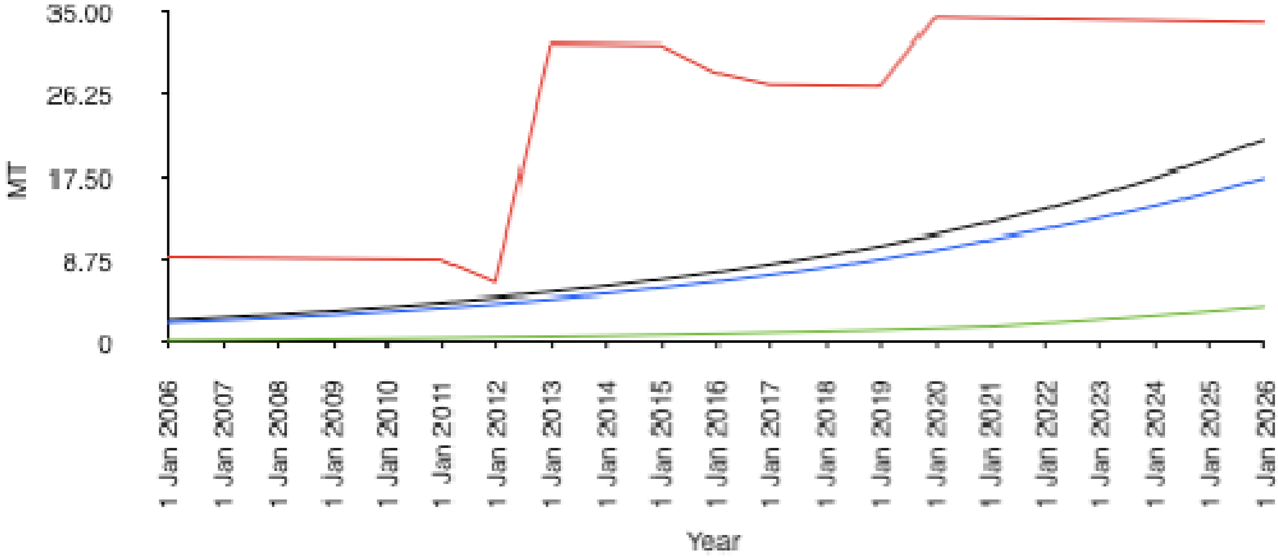


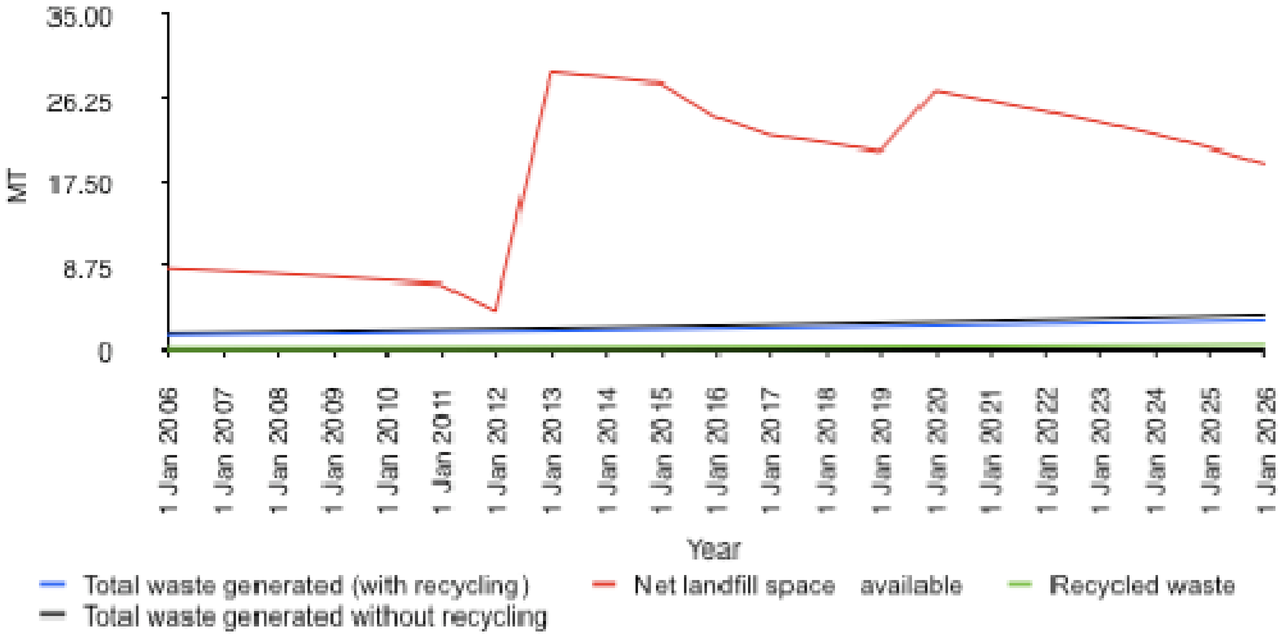
Goal SWii: Increase targeted recycling rate of 15% by 2010, 25% by 2020; and 30% by 2025.

It was assumed that the current target is to achieve a recycling rate close to the UK rate of 30%. To achieve this goal, the increase in the recycling is to occur in stages, that is 15% by 2010, 25% by 2020; and 30% by 2025. With an increase in the amount of the recycled waste, the total waste generated will decrease in all the cases as shown in Figure 40. In the 2006 case recycling will not be sufficient to mitigate against a shortfall in landfill capacity by 2011/12. With lower amounts of waste disposed, recycling is expected to lead to savings in expenditure and less pressure on income sources, but much higher rates are needed to make meaningful differences.

Figure 40: *Intervention simulations: Solid waste generated and landfill capacity: Increase recycling, City of Cape Town (Mt)*



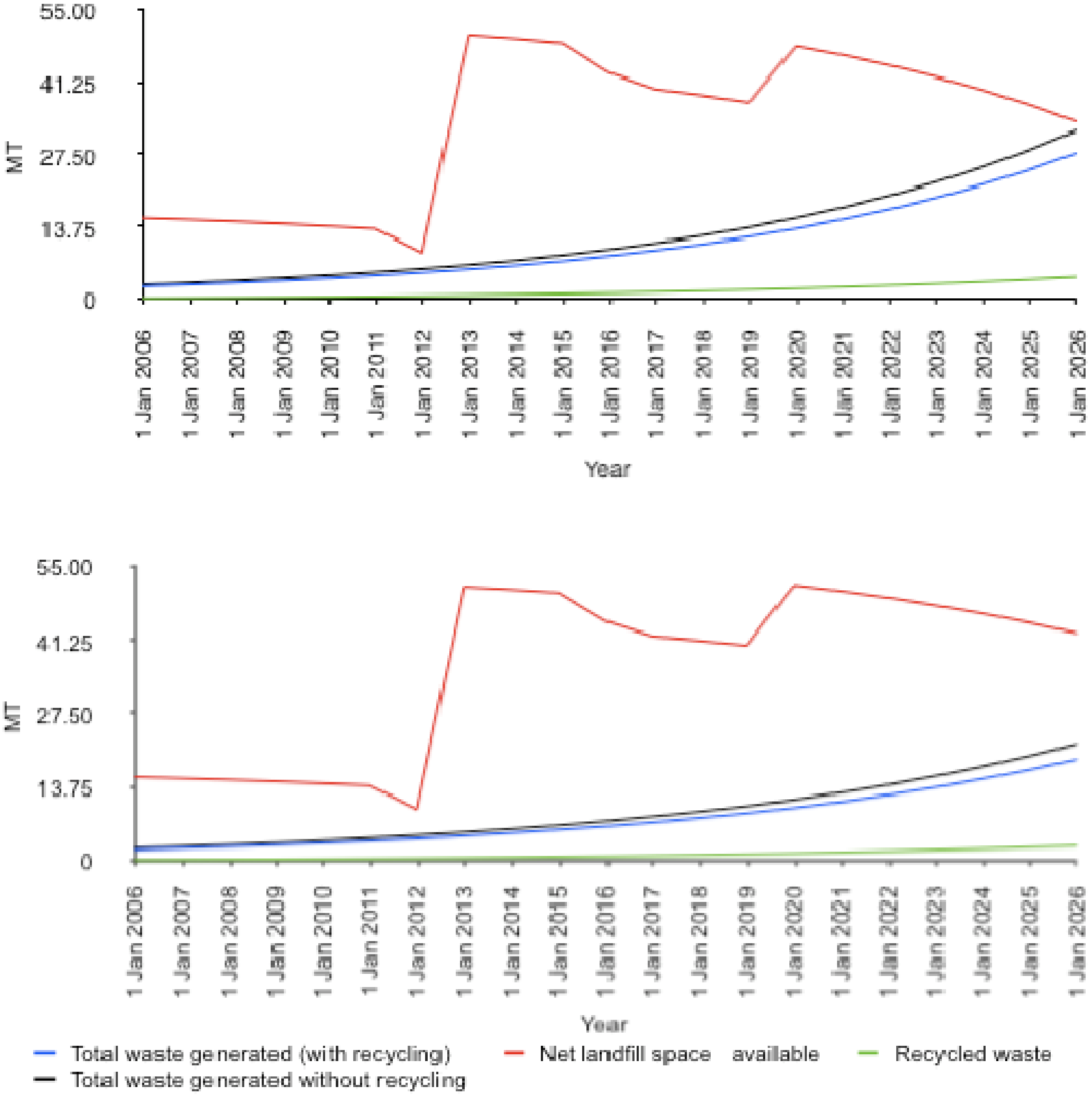


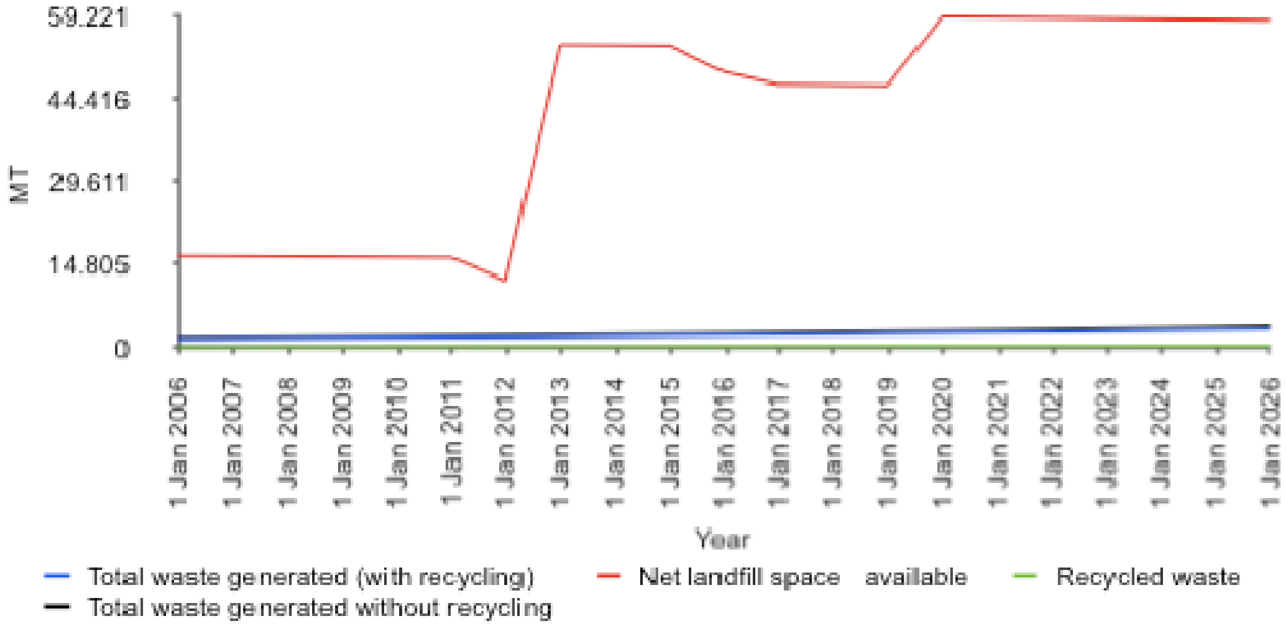


Goal SWiii: Increase landfill density from 0.45 to 0.7.

This option reflects a possible change in the composition of the waste stream. Increasing landfill density will in fact increase the net landfill capacity. In all cases this would be sufficient to manage the 2011/12 transition (Fig 41).

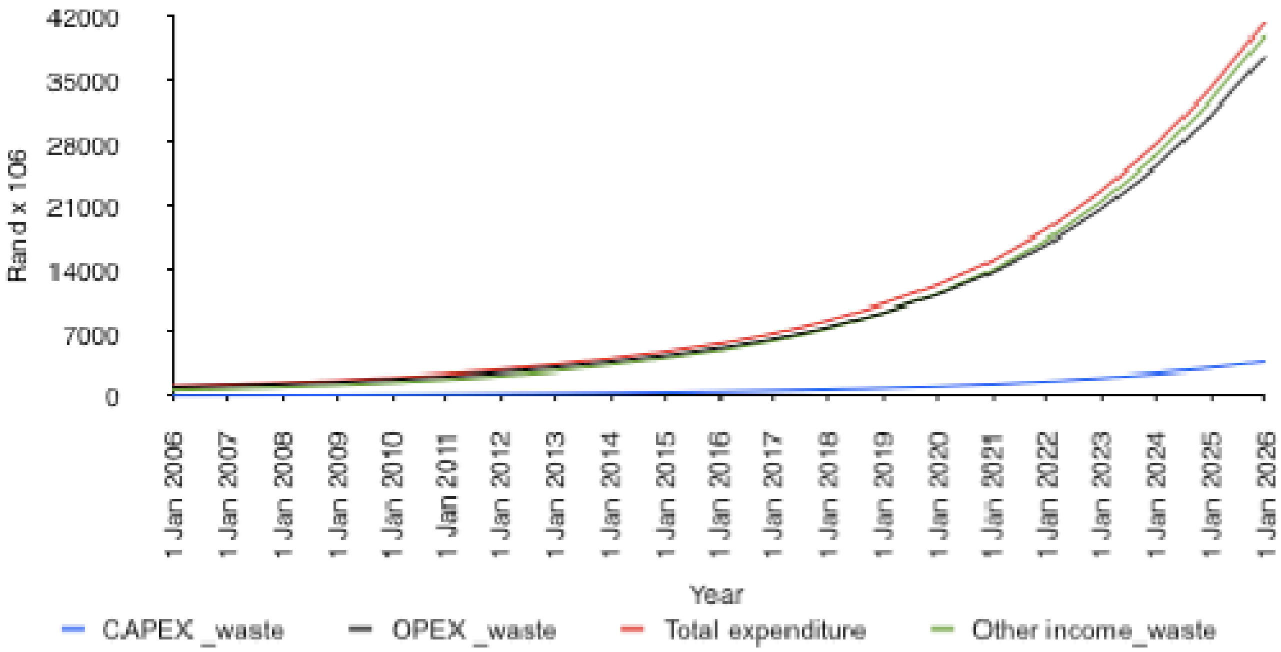
Figure 41: *Intervention simulations: Solid waste generated and landfill capacity: Increase landfill density, City of Cape Town (Mt)*





As total waste generated is not affected by increasing landfill density, no changes on required expenditure and income sources have been modelled (Fig 42).

Figure 42: *Intervention simulations: Solid waste income and expenditure: Increase landfill density, City of Cape Town (R million)*



Discussion of results

The purpose of the model was to better understand the following:

- The balance between projected growth for EWWS services and the physical ability to supply these services
- The income from service delivery and the expenditure required to maintain or improve EWWS services
- The effect of prices/tariffs on EWWS services
- The effect of supply and demand interventions on EWWS services

The model was set-up to gain insights on all of the above. Physical supply and demand simulations were based on actual historical use of municipal services and future simulations based on elasticities to growth in the economy and to growth in the population as well as to changes in tariffs. Required income and expenditure for future demand on services were calculated based on average budgets over the period 2005-2008. This is an important limitation of the model, as actual and budgeted amounts may differ substantially. Further work is required on an interpretation of final audited results for the City that are sufficiently disaggregated to measure operational and capital expenditure, as well as income from all EWWS services. The model can further benefit from better information on longer-term trends in the tariffs for services. Three interventions per EWWS service were modelled, mostly based on existing targets and plans by the City, but can certainly be extended to many other options. A next step would be to propose options that will respond to the key challenges emerging from this first round of modelling. Model results for each of the services are now discussed in more detail.

Water services

Two droughts within the space of half a decade left its mark on the water use and supply for the City of Cape Town. The year 2000 marked the end of a sustained growth in water use for the City. Per capita water use dropped from almost 320 liter per person per day to 270 liter per person per day and even lower in subsequent years. A key question is whether this discontinuity in the water use growth trend will be sustained or not.

In this project both high and low growth possibilities were simulated which illustrates the widely divergent futures that are possible. The model does reveal that in the case of above average growth in water use, as realised in the year 2005/6, existing water supply is expected to be sufficient only up to 2010/11. Neither the reduction of non-revenue water to acceptable norms, nor a target to minimise water wastage will change the outcome that demand for water will outstrip supply within the first half of the next decade. The most promising intervention is to increase tariffs, but even this option will only buy 1-2 years of time before supply will not be sufficient. The sustained water use growth scenario will have to be accompanied by rising expenditures as both costs increase with inflation and demand increases with economic and population growth. Such rising expenditures cannot be sustained by budgeted rises in water tariffs, which increases the dependency on other income sources, such as grants.

This is only one side of the water story. The other is a declining water use per capita, set in motion in the year 2000, first initiated by command and control style water restrictions and later with the introduction of a steep stepwise water tariff structure. In this scenario Cape Town has an oversupply of water, which in turn will place downward pressure of tariffs and an incentive to use more water. The simulations did not capture this dynamic feedback yet, but with an oversupply of water, it can be expected that owners of water schemes will try to at least cover their expenses. A long-term growth rate of around 0.4% pa will exhaust supplies by 2026. This compares to an average growth rate of 4.3% in 2006, an average of -1.3% over the period 2000-2006 and 1% over the longer period 1992-2006. Historically, growth rates in water use are far lower then the growth rates in the economy, but there are some notable exceptions. The modelling approach is a more realistic interpretation of how demand for services are likely to evolve in the future, but is also constraint by the lack of consistent elasticities over time in the case of water services provision. This does signal that other factors than income, population and prices influence demand for water, which is the case as supply and demand have been heavily restricted through droughts and drought management interventions in recent years. These historic sensitivities were used to simulate possible futures in this model explaining the large differences in simulations in the water sector. This is only a start and more research is needed on the underlying behaviour driving water use.

With an increased awareness of water scarcity, increased water tariffs as well as water restrictions, it remains to be seen whether longer-term growth in the demand demand for water will come close to the 3% used in the City's projections. The sheer volatility of water use, the absence of time series on water tariffs for different income groups, and a lack of understanding on the behavioural dynamics that dictate water use, however, precludes any binding conclusions yet. Another factor that need to be researched further is the economic costs that were incurred from such a reduction in demand.

Sanitation services

The sanitation and water systems are closely linked; when water use increases, demand for sanitation increases and when water use decreases demand for sanitation decreases. Despite being stable the this relationship is not fixed. The relationship does show some variation as the demand for sanitation as a percentage of water use tends to be higher in the water-constraint years and lower in the more water-abundant years. In other words, droughts do not affect sanitation per se, but do affect water use that are not returned towards water treatment plants.

As in the case of water, widely divergent futures were simulated, one with an increased amount of influent received over time (the 2006 case) and another with decreasing amounts of influent as demand for water decreases over time. In the 2006 case, it is simulated that the overall treatment capacity will be insufficient within 10 years. An increase in water tariffs will have the secondary benefit of prolonging the time wastewater treatment plants are expected to have sufficient capacity to treat influent received. In the case of an increase in water tariffs, the resulting reduction in water use will also reduce the demand for sanitation, and lead to savings on capital and operational costs. It is simulated that a 10% increase in water tariffs could lead to significant savings on sanitation expenditure.

What is important is that treatment capacity is not distributed according to the areas of growth and spatial disparities exist throughout the City. There is a critical shortage of treatment capacity in the areas experiencing rapid expansion (Pithey & Frame 2007) an aspect that could not be modelled, as the model is not spatially explicit.

Electricity services

The provision of electricity services was subject to nationwide disruptions in supply in recent years. As a result, the rate at which electricity use is changing in the City is declining, despite only small changes in the rate of economic growth and rate of changes in electricity tariffs. Elasticities to economic and population growth are declining as demand is suppressed through supply disruptions and the possible start of a more efficient use of electricity resources. With expected trend shifts on electricity use mainly due to supply disruptions, it is expected that elasticities to income and population will further decline over time. However, there is evidence that such a decline in use will not be absolute; electricity use per person is still increasing (as population growth slows down) with an estimated 2786 Kwh per person per annum in 2000 to 3090 Kwh per person per annum in 2006 - an average annual growth of 1.75% per annum.

In all simulated cases the chances of supply constraints are highest in in 2007/8, 2011 and after around 2016. Increases in prices and an increase in efficiency is expected to have a measurable impact on demand and more work is needed on the underlying behaviour driving electricity use.

At the projected 3% per annum at which electricity demand is expected to increase and an average budgeted implicit increase in tariffs of 3%, the provision of electricity services will become increasingly reliant on income sources other then tariff income. This simulation does not take account of the suggested increase of 35% in electricity tariffs in 2008 and high tariff increases in the next few years to counter the higher cost of electricity supplied by Eskom. Assuming that the 2006 estimated price elasticity of -0.27 will hold, which is low in comparison elasticities from earlier years, an increase of 35% does imply that a decrease of 9.5% in electricity use can be expected in 2008/9.

A further remaining question is whether a sustainable decoupling can be achieved at least cost to the City's economy. Supply disruptions and abrupt tariff increases suggests high and often unplanned costs of adaptation, especially in the earlier phases of such a situation. A more robust and sustainable decoupling of electricity use from growth would require more gradually evolving market signals on the real costs of electricity, coupled with institutional and technological options to adapt.

Solid waste services

The amount of solid waste generated has grown at double-digit rates from 2004 onwards. At an average of above 800 kg per person per annum in 2007, the City generates more then twice the amount of 300-350 kg per person per annum generated in the EU-10 member states and 1.5 times as much as the 570 kg per person per annum in the EU-15 (European Parliament 2008).

If the high growth in waste is sustained, landfill space is expected to run out by 2011/12. A very large new regional landfill site is planned for 2013. From a perspective of landfill space available and waste generated the important question is how to manage the transition around 2011-2013 in the short to medium term and the constraints between around 2020 and 2026 in the long term.

Elasticities to economic growth, population growth and solid waste tariffs were not used in the modelling due to absence of information on a reliable time series on solid waste tariffs. The information that was available signalled a very high elasticity to population and economic growth and a nominal *decrease* in solid waste tariffs, as calculated as the total tariff income over projected waste generated, over time. Historical rates of growth in waste generation was used instead. The model suggests that sustaining waste growth rates as measured from 2004 onwards would create a problem as early as 2011, while no landfill capacity problems are anticipated at growth rates as measured between 2000 and 2003.

Increasing compaction and recycling at current targets are not sufficient to address the landfill space deficit by 2011/12. Increasing the landfill space density factor (or a change in composition of waste) shows a promising impact, but the question is whether the waste stream will indeed change to a higher density over time and how this could be successfully affected by specific interventions.

The option to fast track bigger landfills or increase recycling rates to manage the 2011/12 transition is not only a question on physical possibility, but will increasingly be one of costs. Developing a greenfield regional site which is reliant on transporting waste from the City would have an impact on the capital and operational costs of solid waste management. The increase in costs and associated pressure on solid waste tariffs is expected to suppress the amount of solid waste generated, but it cannot be concluded to what extent yet. A key question is for solid waste management in the City is what the relative costs and benefits are of alternative landfill and increased recycling options are, and to what extent solid waste tariffs need to be adjusted in both cases to cover these costs. With evidence of low and decreasing costs, as well as increasing costs of other services such as electricity, it can be expected that there will be pressure to keep overall costs to the consumer down.

Conclusions and recommendations

The City of Cape Town experienced severe natural resource shocks in the form of droughts, electricity supply shocks and increased demand from rapid economic growth in a short space of time from 2000-2006. The municipal finance systems also underwent fundamental restructuring in the same period with an increased dependance on external grants. This was also the time in which service provision was rolled out to the indigent with an emphasis and supporting funding on electricity, water, waste and sanitation (EWWS) services to all households. Significant and rapidly growing housing backlogs, a backlog in bulk infrastructure to support service provision and remaining EWWS backlogs all add up to the pressure on municipalities to provide an increasing amount of services against the backdrop of supply constraints and changing composition of income sources.

Institutionally, the City is still adapting to these changing circumstances. Different EWWS service departments use different projections on future demand for services as based on parametric values, in turn often only partially based on different interpretations of economic and population growth. Demand-side adjustments are included as add-ons and not entrenched in projections through established methods such as the use of price elasticities of demand. A revision of the parameters driving the projected growth in demand for EWWS services in Medium Term Revenue and Expenditure Framework (MTREF) modelling is recommended.

Against this backdrop the participation process and the systems dynamics model focussed on gaining a better understanding on the relationship between the provision of EWWS services and municipal finances.

At least three themes on these relationships emerge from this work. First, the question arises whether the decoupling between increased economic activity and population growth in the water and electricity sectors are set to continue. There are promising signs, but in both these cases it has been associated with non-market related supply and demand disruptions. Second, there is a mismatch between budgeted tariff income, implicit tariffs and projected EWWS service demand in the City. Tariffs are budgeted to increase at levels far below inflation or, as in the case of solid waste, even decline in nominal terms. This is clearly unsustainable and will only increase dependency on other income sources such as grants, increase the need for borrowing, or both. It is strongly recommended that longer-term audited expenditures and income, disaggregated for EWWS services is used in the development of a full-scale management model. Third, current options to decrease demand for EWWS services do have only have a modest impact on simulated demand, but there are some promising signs from using tariffs to reach the desired effects.

Several observations based on the Cape Town modelling approach may have broader applications to other cities facing similar situations of inmigration of rural poor, natural resource constraints (e.g. water, landfill space) and environmental constraints (e.g. wastewater, carbon constraints on fossil-fuel based electricity).

First, there are questions on how to achieve a sustainable decoupling between economic and population growth and the demand for municipal services, and in turn, the natural resources and assimilative capacity of the environment on which it depends. The ability to adapt to natural resource shocks is impeded if their is very little flexibility in the system to adjust to a rapidly changing world. Municipalities should have the ability to gradually plan for and adapt to the scarcity of natural resources and environmental services and not only rely on abrupt and/or often costly mechanisms such as massive increases in electricity prices after years of declining real tariffs, or intrusive command-and-control style water restrictions.

Second, the demand for services are mostly projected on the basis of historical trends, a fundamental weakness in a transitionary context. City departments are advised to bring more robust scientific methods in planning for future demand, including a much better understanding on the actual behaviour of municipal service users. The opportunity for traditional supply options decreases and new supply options usually are more expensive. For example, viable sites for additional water supply schemes are becoming scarcer and greenfield landfill sites within cities are either not available or are not accepted anymore with concern about negative third-party impacts. Within a carbon constraint world, the price of fossil-fuel based power generation will eventually rise. These factors will increase the cost of supply, which in turn, will lead to a decrease in demand only if flexible institutions are in place.

Third, the apparent disconnect between planning for and managing municipal services and the budgetary planning process leads to a highly volatile planning environment. It may come as no surprise that city budgets generally are adjusted on the basis of parametric factors and often overrides requirements from municipal services departments. This leads to highly volatile budgets for especially capital expenditure which places pressure on implementation. Although more research is required on this, it is hypothesised that the heuristic rules followed by decision makers in the finance departments of cities in itself may be a source of emergent volatility in the overall system.

Fourth, the inability or unwillingness of municipalities to gradually adjust tariffs to better reflect scarcity sends the wrong signals to consumers. With artificially low tariffs there is little incentive for conservation of increasingly scarce resources. Low tariffs also increases dependencies on alternative income streams such as grants from other tiers of government. This situation creates uncertainty as every so many years a need is created for an overhaul of an, by then, outdated tariff system.

The following is recommended:

- Start a research programme on the behavioural drivers of especially water and electricity use to inform decisions on the effectiveness of tariffs as a management tool.
- Closely monitor whether the discontinuity in the water use growth trend will be sustained or not.

- Model the relative costs and benefits of alternative landfill and increased recycling options.
- Model to what extent solid waste tariffs need to be adjusted in both cases to cover these costs.
- Research how to finance rising expenditures on EWWS services in the context of insufficient tariff income and an increased dependency on other income sources, such as grants.
- Research the costs of a reduction in demand for water and electricity to the local economy and the role tariff adjustments can play in alleviating such costs in future.
- Research and model the supply, demand and financial aspects of EWWS services for different income groups.
- Research and model spatial sensitivities in the provision of EWWS services, most notably sanitation treatment capacity which is not distributed according to the areas of growth and the impacts of low quality effluent discharged on the local environment.
- Research and model how to achieve a sustainable decoupling of economic growth and resource use at least cost to the City’s economy.
- Modelling impacts of different categories of waste on landfill space density
- Research the merits of gradual versus abrupt transitions
- Research and model costs of alternative supply options (dams, treatment plants, renewable energy options)

Acknowledgements

We gratefully acknowledge funding from UNDP and DANIDA.

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