A review of the strategies adopted between 2015 and 2022 towards two South African local government water supply crises

Stephen Hosking and Marius van der Merwe

ERSA Working Paper 885

June 2023

A review of the strategies adopted between 2015 and 2022 towards two South African local government water supply crises

Stephen Hosking[1] and Marius van der Merwe
June 2023

Abstract

This paper reviews combined local and national government water service policies to manage two local short-run water supply crises and lessons learned from them. The respective water supply crises are those of the City of Cape Town (CoCT) 2015 to 2018 and the Nelson Mandela Bay (NMB) 2015 to 2022. It identifies the strategies that were used to address the respective crises and deduces that a trade-off exists between water demand suppression and water supply augmentation. It concludes that the efficient trade-off between these two strategies can only be determined through a proper costing analysis. It recommends that future such crises be addressed only after the respective costs of the two strategies have been evaluated and compared because only on that basis can an efficient mix of short-run strategies be determined.

Key words: Water supply crises, Municipalities, Cape Town, Nelson Mandela Bay

1. Introduction

It was international news that the City of Cape Town (CoCT) experienced a serious water supply crisis between 2015 and 2018. Less widely publicized, but of equal importance within South Africa, was that Nelson Mandela Bay (NMB) was also experiencing a water supply crisis over an even longer period of 2015 to 2022, and still was at the time of writing (end of 2022) in the grip of a water supply crisis.

This paper reviews combined local and national government water service spending programme (on water supply infrastructure) and policies to manage local short-run water supply crises, the lessons allegedly learned, the contexts for the crises and the instruments with which the CoCT and NMB set about reconciling their water supply with demand. It distinguishes between long-run supply, long-run demand suppression, short-run supply augmentation and short-run (escalated) water demand suppression strategies practiced by the two metropolitan municipalities.

---

[1] Lead author email address sghosking@gmail.com. His ORCID number is 0000- 0002-6409-0039. Marius van der Merwe email address is EM@cafpoa.co.za . The authors gratefully acknowledge Water Research Commission funding under the project numbered C2022/2023-00766, entitled AN ANALYSIS OF THE ECONOMIC EFFICIENCY OF MUNICIPAL SHORT-TERM RESPONSES TO WATER SUPPLY CRISES IN SOUTH AFRICA, as we do the members of the reference group and other project team members, Jugal Mahabir (project leader) and Isiah Magambo who provided useful comments, and the University of Johannesburg as the contractor for this project.

Its aim is to identify whether a trade-off exists between water supply augmentation and water demand suppression and if so, how the efficient mix of these strategies could be determined - to guide municipalities in their management of possible future water supply crises they may face. The paper is organised as follows: the respective water supply crises are described, selected international literature is considered on the nature and evolution of water supply crises, selected lessons allegedly learned from the CoCT crisis are reported, an overview is provided of the long-run and short-run management tools available to the CoCT and NMB for reconciling supply with demand, a recent history of bias toward demand suppression is sketched and a model is put forward by which the short-run and long-run reconciliation of water demand and supply are integrated.

2 The CoCT and NMB water supply crises of 2015-2022

2.1 The CoCT water supply crisis of 2015-2018

It is the guidance of Muller (2022) that any analysis of a local water supply crisis should begin with a relevant reconciliation study – of water demand with water supply. A water supply crisis is an event, or likelihood of the event, when annual demand exceeds annual supply. It is signaled by the depletion of the local government's bulk water reserve and or the sustained diminution of the sources of raw water that it treats and reticulates as a potable water service.

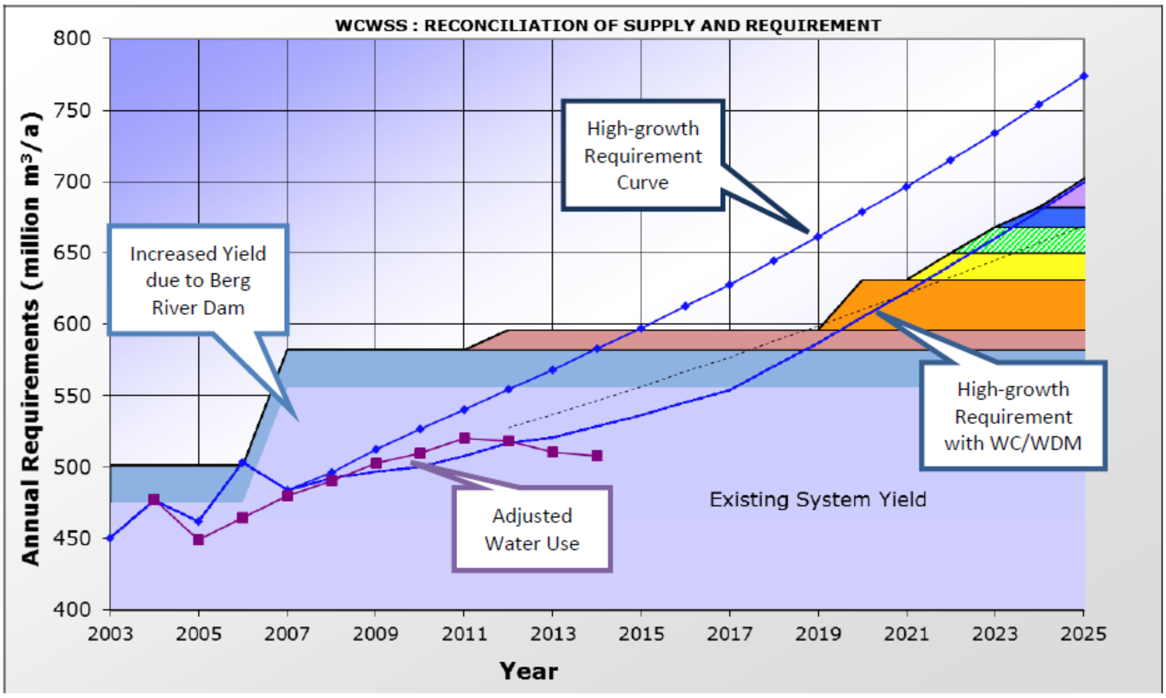
The relevant reconciliation for the CoCT with the Western Cape Water Supply System (WCWSS) was published by the Department of Water Affairs and Forestry (DWAF, 2007). In 2003 it was projected that water demand would exceed supply by 2012. The implementation of the Berg River-Voëlvlei Augmentation Scheme and the success of the CoCT program of comprehensive Water Demand Management (WDM), postponed this deadline to between 2015 and 2020 (DWS 2015; Sinclair-Smith and Winter 2018; Figure 1).

The microeconomic foundation for the DWS and CoCT water demand and supply reconciliation forecasts were a normal demand for a CoCT resident at 2007 price (cost/unit) levels at an average of 200 liters per person per day. Water demand per day depends on circumstances. It is higher during hot and dry periods and lower during cool and wet periods. The DWS (2015) argues that, thanks to the CoCT implementing water conservation (WC) and water demand management (WDM) controls, demand could be reduced and the sufficiency(security) of long-run water supply extended '*to at least 2020 before the next augmentation scheme needs to come online*' (DWS, 2015). One such scheme was optimising the yield abstracted from the Berg River.

The annual surface water yield for the WCWSS averages just less than 600 million kilolitres (Figure 1). The maximum possible annual yield (in terms of dam holding capacity) is about 900 million kilolitres. The City of Cape Town's annual water use license allocation from the WCWSS, including the additional yield of the Berg River scheme, is 398 million kilolitres or 398 000 megalitres (1 megalitre = 1 000 000 litres = 1000 kl) per annum (City of Cape Town, 2017). That allocation enables the CoCT to draw an average of about 1090 megalitres per day to satisfy water demand. Numerous other licenced holders also extract value out of the use of WCWSS water, e.g., those in the agricultural industry.

The obvious conclusion drawn from the WCWSS reconciliation study of Figure 1 was that the CoCT was vulnerable to a short-run (SR) water supply crisis from or after 2015 – 2020, unless it suppressed water demand to an adjusted water use profile and or timeously supplemented its WCWSS bulk water supply allocation. The long-run (LR) water supply plans of the CoCT municipality not only included the Berg River –Voëlvlei scheme, but also Table Mountain and other aquifer mining, wastewater recycling and desalination. The CoCT also had strategies in place to save water supply by smart adaption to climate change and increased alien vegetation clearing in strategic catchment areas.

Figure 1: The LR need for the CoCT water supply scheme supplementation after 2015 or 2020 (LR supplementation scheme yields shown in distinct colours from light blue)



Source: DWS (2015)

The catalyst for the CoCT water supply crisis was an exceptional drought that occurred in its strategic catchment areas during 2015-2018. On 28 February 2015, the water stored in the six dams of the WCWSS was 637,731 million kilolitres and the CoCT urban water service daily demand (after adjustment for WC/WDM water demand suppression) was 1 270 megalitres, i.e., above the allocated daily average. On the back of 3 years of below-normal rainfall, the CoCT annual water allocation from the WCWSS was cut for the 2018/19 year from 398 million kilolitres to 250 million kilolitres (City of Cape Town, 2019). The lower allocation allowed for an average supply of 684 megalitres per day - about half of the actual demand in February 2015.

Although by 30 April 2018, the CoCT water demand had been reduced to 555 megalitres per day, the water stored in the WCWSS dams had also been reduced - to a mere 191 million kilolitres (21,2% of capacity). Of this water stored, less than 70 million kilolitres were readily usable, and steadily declining. The CoCT share of the 70 million kilolitres WCWSS stored water reserve was less than 50 million kilolitres and subject to bulk water losses due to evaporation and supply system defects. On 30 April 2018, the CoCT calculated that, unless there was soon more normal rainfall, it would be unable to supply current water service demand beyond someday in June 2018, a day it referred to as ‘day zero’. That day was averted by the timeous arrival of sufficient rains during first half of the winter of 2018.

To summarise: the contexts for the 2018 City of Cape Town (CoCT) water supply crisis were:

- a reconciliation study projection of the insufficiency of long-run water supply capacity by 2015 relative to predicted water demand 2015-2018 (a government failure according to Muller, 2020; Bischoff- Mattson et al., 2020)
- a drought over the catchment of the dams that feed the Western Cape Water Supply System 2015–2017 (Otto et al., 2018; Fell and Carden, 2022; CoCT Weekly Water Dashboard, 2022).

2.2 The NMB water supply crisis of 2015-2022

The Gamtoos Irrigation Board, 1,1 million residents in the Nelson Mandela Bay Municipality (NMBM), more than 373 industries, the Coega Industrial Development Zone, and several smaller communities in the Kouga Municipal area all receive water from the Algoa Water Supply System (AWSS) (DWS, 2022). As far back as 2006 the NMB Metropolitan Municipality, as the Water Service Authority (WSA) for its area of jurisdiction, prepared and published a Water Services Development Plan (WSDP). It was required to do so under the provisions of the Water Services Act (Act 108 of 1997) (NMBM, 2006). The WSDP, which has a 5-year term validity horizon, states that a WSA has a duty to ensure efficient, affordable, economical, and sustainable access to water services, considering the need for regional efficiency, for achieving the benefit of scale and for incurring as low costs as feasible.

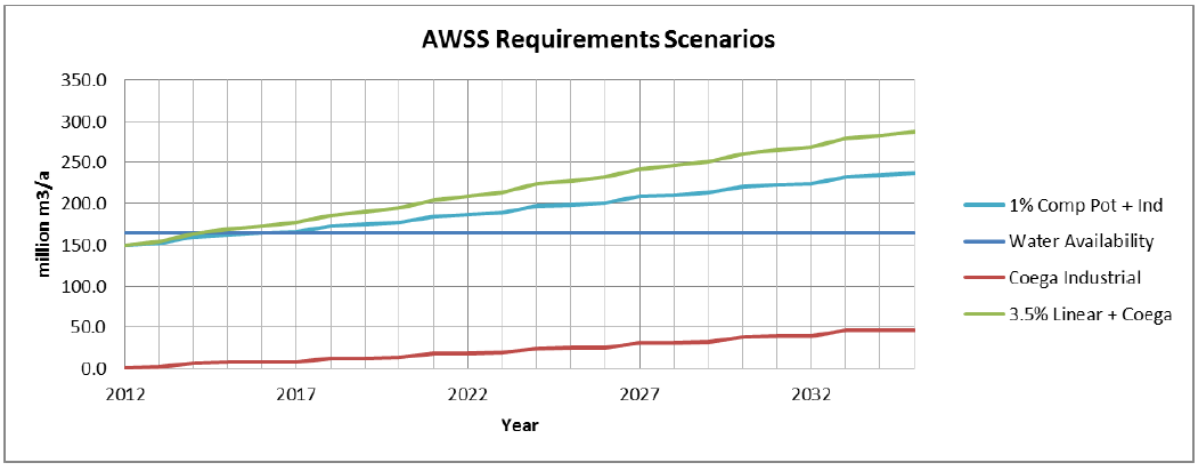
The WSDP objectives included a Supply Side Analysis versus a Demand Side Analysis to be done in conjunction with programmes of a 10-year housing development plan, a Spatial Development Framework (SDF), an Integrated Development Plan (IDP), a Water Services Development Plan (WSDP) and the NMBM Vision 2000 (but not a maintenance and replacement plan for ageing infrastructure) (NMBM, 2006). Included in this WSDP were historical studies done by the (then) Department of Water Affairs and Forestry (DWAF), namely the Algoa Water Resources System Analysis (AWRSA) in 1992, the Algoa Water Resources Stochastic Analysis (AWRSA) in 1995/96, and the Algoa Water Supply Pre-feasibility Study (AWSPS) in 1999/2000. These studies included and considered data on the previous drought for the period of 1987-1992 (NMBM, 2006).

The AWRSA study found a lack of, or ambiguity in, hydrological data records on water meter readings and impacts that were introduced in 1972 (NMBM, 2006). It concluded that a conservative estimation of future water demand and the timeous, albeit premature implementation of the Elandsjagt Scheme in 1985, would enable the continuation of supply during 2006, despite the severity of successive previous droughts. A prominent role was afforded the Water Demand Management Program (WDMP) in the AWSPS study, but it also highlighted some short-run water supply augmentation possibilities to be explored, such as saving 22Ml/day by curbing Mid-Night Flows (MNF) and on-site leakages (NMBM, 2006).

At the date of publication, the WDMP categorised SR augmentation supply as that required to make up for predicted savings in water demand that failed to materialise, and LR water supply schemes as those brought about through an increase in infrastructure capacity and an accelerated implementation of the WDMP (NMBM, 2006). Even before 2010 an important part of the LR water supply schemes for the NMB municipality was bulk fresh water drawn from the country's largest dam, the Gariep, via the Nooitgedacht Water Scheme to the Metro's western supply zones.

In 2011 the Department of Water and Sanitation released an updated water reconciliation study for the AWSS (DWS, 2011). It found that the combined average annual yield of the AWSS was 164,4 million m^3 (Figure 2). It projected water demand, adjusted for WC/WDM water demand suppression, would exceed water supply by the year 2015 (and sooner if the projected demand of the Coega industries were included in the calculation), unless supplementary (long-run) water supply schemes were implemented (Figure 2). By the year 2022 NMB municipal annual water demand was projected to be between about 180 and 210 million kilolitres (Figure 2).

Figure 2: The LR need for the NMB water supply scheme supplementation after 2015



Source: DWS (2011)

The LR water supply plans for the NMB included an increase in the quantity of Orange River Water transferred to the NMB municipality, various aquifer mining schemes, several wastewater recycling schemes and seawater desalination. The importance of increasing the quantity of Orange river water was re-emphasized by the AWSS Strategy Steering Committee. It issued the following media information report from its meeting dated 2: April 2012, with respect to the matter of the 'Sustainable water supply for NMB Municipality and surrounding areas'.

> *"Even with WC/WDM fully successful it is anticipated that the water requirement will increase in this economically active area with its growing population. NMBM is constructing the Nooitgedacht Low-Level Scheme as an extension to the existing High-Level Scheme that will treat Orange River water, delivered through the Orange-Fish-Sunday's system, to drinking water standard for supply into the NMBM water supply system. Some of the funding required for this project was obtained under the emergency drought funding and NMBM is still in the process to obtain the outstanding balance of the funds required to complete the scheme. Construction should be completed by October 2013, depending on the availability of funding."* (WC/WDM = Water Conservation/Water Demand Management).

The 'final' phase of the extended Nooitgedacht scheme was completed in May 2022. A year prior to that, by June 2021, virtually all the NMB municipality water reserve within the AWSS and NMB municipality dams had been depleted. A protracted drought from 2015 to 2022 was the catalyst for a series of short-run water supply crises in the NMB.

In May 2022, the NMB municipality and the DWS announced that the NMB municipality would cease piped potable water delivery to some customers and that the quality of the water it delivered was no longer of potable quality. Specifically, it was announced that 24 days from 19 May 2022 (i.e., 12 June 2022)

> "*107 suburbs, townships and areas in the metro will run out of water within a month, when access to the dams is lost. These areas include some of the metro's most densely populated areas — and besides the consequences for fresh water for household use, the impact on the sewage system will be catastrophic.*"

The two government entities conceded that:

> *"the metro* [is] *relying solely on water from the Gariep Dam. This scheme, known as Nooitgedacht, is a single, load shedding-dependent system with no reserves. The Gariep Dam, on the border between the Free State and the Eastern Cape, is presently overflowing.*"

and

> "*the Nelson Mandela Bay Metropolitan Municipality (NMBM), the Municipal Health Department, along with municipal Scientific Services found drinking water failures had occurred and issued a boil water notice to their water users"* [Minister Water and Sanitation, 21 April 2022 – reply to a parliamentary question].

In the long-run the NMB municipality enjoys lower cost of water supply options due to its established access to Orange River water, but the CoCT municipality enjoys higher social willingness to pay for increasing water supply capacity due to its higher per capita income generating capacity.

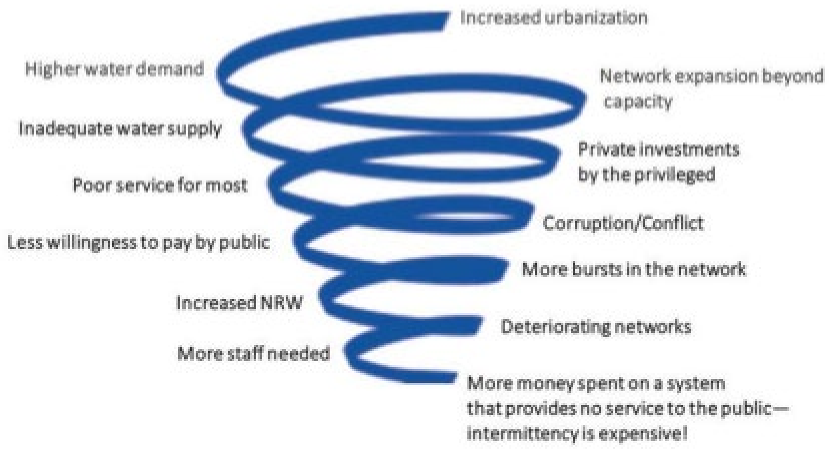
3 Selected international perspectives on how water supply crises come about

It was already clear in September 2000, when the member states of the United Nations (UN) proclaimed and endorsed the 21st-century Millennium Development Goals (MDG), that humans across the globe faced and would face serious developmental challenges. By 2010 an estimated 3% of the land surface was urbanised and more people lived in cities than in rural settings (Koester et al., 2010). One of the 21st Century global impacts of these global effects was the increased frequency of regional water shortages (Parks et al., 2019). By 2012 it was clear that, to satisfy ever-increasing demand, a determined effort across all global sectors and institutions to deliver sustainable water and sanitation services was required (Jacobsen et al., 2012).

The MDGs represented numerical time-bound goals for development, some of which related to urban water management by 2015 (Lai et al, 2008). Among the most significant failures to achieve MDG targets were those of a 50% reversal of the loss of environmental resources and a 23% reduction in the population number without access to potable water and proper sanitation (Ritchie and Roser, 2018).

Under these circumstances, it is almost inevitable that increased water supply crises will evolve in urban settings throughout the world. The evolution of water supply crises is a complex downward-spiralling process (Figure 3). Urban water systems incorporate ecological, social, and economic aspects. Within these systems, natural water resources and ecosystems interlink with infrastructure for water supply, collection and treatment of wastewater and flood protection (Jensen and Khalis, 2020). Urban water systems are a synergy of the technological, infrastructural and managerial elements of water supply in a city linked with varied bulk water resources, exposed to the unquantifiable impact of climate change and urbanisation (Florke et al., 2018).

Figure 3. The downward spiral of intermitted water supply Source: IWS.



Note: NRW is non-revenue water

As is the case globally, the water market in South Africa must cope with many challenges that can trigger the downward spiral to a water supply crisis, including severe regional droughts, poor water conservation, the use of outdated and inadequate water treatment infrastructure and unequal access to water among different sections of the population.

The challenges of water supply faced by the CoCT and the NMB municipalities during the 2015 – 2022 period were not unique when viewed from a global perspective. New York, Los Angeles, and Mexico City also face water supply challenges. Countries in the Horn of Africa and North Africa, viz. Ethiopia, Somalia, Kenya, and Morocco have recently experienced one of the worst droughts in 30-40 years (WHO, 2021; El-Khattabi, 2022).

No matter what way water supply shortfalls are addressed by local governments, there are always multidimensional hurdles to overcome and costs to consider (OECD, 2012), such as:

- In the allocation of duties and tasks,
- The alignment of hydrological and administrative goals,
- The asymmetry of information between central and local governments, as well as between utilities, local authorities, and customers
- The sufficiency of technical capacity, staff, time, knowledge, and infrastructure.
- The stability and sufficiency of funding for national, sub-national, and local municipal governments to acquire and operate water infrastructure
- The coordination between various ministries.
- The level of interaction with the public on the government response to the above challenges (Berg, 2016).

A public choice view toward political participation in water supply decision-making is to be found in the "group-centred" theories. This viewpoint holds that politics can be seen as a process of competition between various collections of people with overlapping private interests, looking to sway government policy, with the state serving as an 'impartial' agent for effecting wealth transfers between suppliers and between demanders (Bieker et al., 2010, Smith and Cartin, 2011, Rees, 1998). This view does not find such political activity inefficient, but a natural extension of competition from the market space into the public good distribution space.

The weight given to each interest group in public good distribution defines how effective it has been in influencing political decisions to the advantage of its members. In his classic work on collective action, Olson (1965) shows that selective incentives are necessary to transform a coalition of rational individuals into a 'privileged' interest group.

It follows logically that the greater the tendency for local government to treat water supply as a public good, the greater will be the effort invested in the politics of persuasion with respect to the distribution of that supply. It also follows logically that accomplishing urban water security necessitates an understanding of urban water systems within a collaborative stakeholder framework (Aboelnga et al 2019).

4 The lessons allegedly learned from the successes (and failures) of the CoCT management of its 2015-18 water supply crisis

During the first half of 2018, the CoCT was able to avert what it defined to be "Day Zero" through a combination of demand suppression and intensive supply management. The crisis ended when normal winter rainfall arrived in June 2018. The CoCT water supply crisis provided useful lessons and exposed the critical need for a water system rooted in principles of equity, sustainability, and water sensitivity (Fell and Carden, 2022).

In July 2022, the NMB municipality was still in a water supply crisis, so there had not yet passed enough time to enable reflection on lessons learned from its management of this crisis.

For the most part, many of these 'lessons' are tangential to the reconciliation task. As part of its Cities Support Programme, the South African National Treasury, identified 12 lessons for local government from the CoCT water supply crisis (National Treasury, 2022). The National Treasury did not specifically acknowledge the role played by escalated water demand management, but listed the lessons as:

- Building systems and relationships of mutual accountability for effective water management between spheres of government,
- Strengthening horizontal management between municipal departments and entities, strengthening leadership and capacity to enable flexible, adaptive decision-making
- Investing in partnerships beyond the City.
- Understanding the local water system
- Sharing information about the water situation to build public trust
- Actively seeking external expertise and experience
- Actively managing and integrating diverse parts of the water system
- Creating a robust networked system of water supply
- Recognising the limitations of the current financial model for water
- Strengthening leadership and the capacity to enable flexible, adaptive decision-making
- Developing a water-sensitive city vision
- Integrating climate change into water planning and demanding better climate information

The National Treasury recognised the merits and limitations of water supply augmentation. It placed emphasis on the management issues of improving relationships and balancing incomes and expenditures in public water supply accounts under drought-induced crises. With respect to the lesson of creating a robust networked system of water supply the National Treasury (2022: 4) noted that although:

> *"micro"-sources of alternative water are important during a crisis, they cannot replace the city-wide system.*

With respect to the lesson on the limitations of the current financial model, the National Treasury (2022: 5) noted that the CoCT:

> *'faced not only the fixed costs of service delivery associated with existing infrastructure and staff but also a rising expenditure requirement to introduce demand management measures (metering) and augment water supply (such as boreholes).'*

As solutions to the funding problem, the National Treasury proposed:

- tariff restructuring to explicitly fund fixed costs of the water system, providing this does not function as a regressive "tax" on poorer consumers
- self-financing long-term demand management interventions

- the use of borrowing instruments such as Green Bonds
- more discussion '*on the role of privatization and what is acceptable in the South African context*."

Recognition of the government relationship defects, the presence of legal and political impediments and uncertainty contributing to the CoCT water supply crisis are also found in other commentary (Ziervogel 2019). Clearly, the 'impediments' context needs to be considered in any analysis of the way the water supply crises were managed by the CoCT and NMB municipalities and or recommendation of the way future such crises should be managed.

5. The LR and SR management tools available to the two municipalities (CoCT and NMB) to reconcile their water supply with their customer's water demand

While the socio-legal-political context is an important determinant of the scope for averting and mitigating water supply crises, the actual management of such crises is through the application of several instruments (policies or strategies) aimed at equating municipal water supply with demand.

What is not apparent from any of the currently available commentaries on the way the CoCT and NMB municipalities applied their respective reconciliation instruments was whether their mix of water supply augmentation and water demand suppression strategies was efficient. It is almost obvious that both water supply augmentation and water demand suppression strategies could be effective in mitigating a water supply crisis, but virtually no lessons are reported learned on the efficient mix of these strategies. This defect arises as a consequence of the lack of an existing framework in South Africa by which the efficiency of the mix of strategies at the local government level could be assessed.

Four instruments by which to reconcile water demand with water supply are considered below.

5.1 Planning long-run water supply schemes

The first instrument the CoCT and NMB municipalities have applied to reconcile water demand with supply is the implementation of long-run water supply schemes. This entails prioritising budget and effort for bringing into operation planned new schemes to supplement the long-run water supply. Additions to long-run water supply capacity are referred to in this paper as long-run water supply supplementation.

The time scale of the long-run may be measured in years and even decades. It is based on the time required to engineer new water supply schemes (Muller 2022). The advantage of long-run supply supplementation is that it can be scaled up to meet any level of demand (at a government and taxpayer cost). The target of long-run government (municipal) planned water supply management/strategy is to achieve a water supply capacity to satisfy customers' normal water demand in any given year with a target level of assurance, e.g., 95% or 98%.

5.2 Augmenting water supply in the short-run

The obvious short-run response to a deficiency in the long-run (planned) water supply is to augment the supply with water from other sources. Additions to long-run water supply through schemes that can be implemented in the short-run are referred to in this paper as water supply augmentation. They may be planned for in the sense that there is a facilitation of the option and therefore an option purchase cost incurred in enabling this water supply.

5.3 Long-run water demand suppression

Increasingly popular since the 2000's is an alternative or complementary approach to the problem of reconciling water demand with supply within the CoCT and NMB municipalities, namely to suppress the long-run demand for water. This purpose is achieved by applying baseline market and or non-market regulatory instruments (policies). The advantage of long-run demand suppression is that it can scale down the long-run water supply requirement and the associated capital cost. The disadvantage is long-run customer welfare sacrifice and foregone economic growth cost.

Market regulatory instruments are ones affected by the price charged (tariff structure imposed) for water service. The effectiveness of market instruments is limited to the extent that water service is a traded good or commodity on a market. To the extent water is treated by the local government and the customer as a public good, non-market instruments are required to suppress demand.

The effect of market instruments is to ration the traded commodity of water service according to customer's willingness to pay (which is a function of customer water preferences, the attributes of the water service provided, customer income and the prices of substitutes and complements to the customer's water service). The fiscal advantage of increasing prices to suppress demand is that it increases the local government's water revenue raised per kilolitre of water service sold (but at a customer welfare cost and foregone economic growth cost).

5.4 Short-run (or escalated) water demand suppression

When the intensity with which market regulatory instruments is ratcheted up for the purpose of scaling back short-run water demand and non-market regulatory instruments (policies) are introduced this paper refers to short-run (or escalated) water demand suppression.

Non-market instruments are ones that change water demand other than through changes to the price charged for the water service. Examples of non-coercive non-market instruments to suppress water demand (behaviour) are moral suasion (persuading customers that demanding less water service is the morally right thing to do) and the issuing of moral appeals and or warnings to water using customers (broadcasting to customers the adverse consequences they will experience if the local government runs out of water supply reserve), together with media campaigns (Booysen, Visser and Burger 2018). Examples of coercive non-market instruments to suppress water demand are making illegal and introducing penalties for certain types of water demand (like watering plants or filling swimming pools) and or placing restrictive devices on the quantity of potable water a customer may demand (such as a regulator that limits demand to 500 litres per day).

The effect of applying non-market demand-suppressing instruments is to ration the public good element of water service according to public choice. The advantage of applying non-market instruments relative to market ones for water service demand suppression is that they may be effective with respect to the public good ('legal right' linked) element of water demand. The disadvantage of applying non-market instruments relative to market ones to suppress demand is that to be effective they may have high implementation costs and induce a high political pressure cost consequence.

When a non-market mechanism is applied, it may become politically relevant whose water demand will be suppressed. In its crisis the CoCT municipality, for instance, politically determined that if aggregate water demand exceeded aggregate water supply, it would suspend piped potable water service to most (if not all) residents and replace it with a rationing system that entailed the costs of customer queuing and physical collection. In its crisis, the NMB municipality did run out of water reserves to satisfy aggregate water service demand. The NMB municipality politically determined that, as a result, it was unable to supply piped water services to some residential areas (coincidently ones where poorer people resided). It suspended piped potable water service to these residents and replaced it with a rationing system that entailed the costs of queuing and physical collection.

6. The bias shown by South African municipalities and national government toward water demand management over water supply augmentation

Both escalated water demand suppression and water supply augmentation were actively implemented strategies by the CoCT and NMB municipalities during their respective water supply crises. The water demand suppression strategy was termed as water demand management (WDM) and or water conservation (WC) by the two municipalities. In South Africa, WDM and WC were initially motivated as long-run water reconciliation strategies.

The South African Department of Water Affairs and Forestry define WC as the:

> '*minimizing of loss or waste, the care and protection of water resources, and the efficient and effective use of water*' (DWAF, 2004)

and WDM as the:

> '*adaptation and implementation of a strategy by a water organisation or consumer to influence the demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services and political acceptability*' (DWAF, 2004).

Over time the measures associated with WC have come to be considered as ones addressing the problem of water scarcity and opportunity costs, and those associated with WDM as ones addressing the problem of suppressing demand to reconcile long-run water supply availability to water demand. The DWAF (2004) document acknowledges that, although there are differences between WC and WDM objectives, it is not practical to separate them from a policy practice point of view. The common thread linking them is their commitment to efficiency:

- in the supply of water services (including minimizing water losses)
- in the use made of water demanded and
- in the exploitation of all existing water resources.

Measures aimed at achieving the WC goal must consider the scarcity and opportunity cost of water resources. Measures aimed at achieving the WDM goal must devote resources to water supply (production) and to modifying water demand, so long as there is a positive marginal net social benefit from doing so.

Much of the literature on WDM has concentrated on the WDM objective – changing long-run customer behaviour in water use and policy development to support this change (Inman and Jeffrey, 2006). The bringing about of this change has entailed determining the factors underpinning residential water demand – the weather, rates, income, household composition, housing characteristics, billing frequency, the type of outdoor irrigation and so on (Grafton et al., 2010; Johnston et al., 2011). To the extent consumer beliefs and attitudes are drivers of water use, there is scope to modify water demand simply by investing to change these beliefs and attitudes (Adams et al., 2013; Marlow et al., 2012).

In underdeveloped nations, WDM policy practice has overlapped with water supply augmentation – such as reducing water leakage rates. In wealthy countries, WDM policy is often code for improving the efficiency of water supply (Sharma & Vairavamoorthy, 2009). It has been argued that Cape Town's water distribution system is well-managed, and its WDM program (Table 2) has similar elements to those adopted by many affluent nations (Ziervogel, 2019).

The experience with WDM has varied widely internationally. WDM requires a variety of instruments and objectives. The advantages can be significant. But to achieve them, adaptable strategies for every local circumstance are required. Users must become more engaged, and decision-makers must be made more conscious of the issues involved. A "cultural" shift is required. The highest levels of government must support WDM and provide a cogent strategic framework, coordinate the activity and follow-up, and show consistent long-term commitment to the framework (GWP, 2012; Sinclair-Smith and Winter, 2015). Good international examples of such frameworks are Israel's national plan to improve water efficiency and Tunisia's national irrigation water savings strategy (GWP, 2012; Sinclair-Smith and Winter, 2015).

In the middle of the 1990s, the idea of WDM gained popularity within the CoCT municipality (as concerns grew about satisfying the city's rapidly rising water demand). The CoCT did not view WDM as a short-run policy instrument but as a long-run one – which it sought to integrate into its water supply reconciliation planning – where water supply supplementation and augmentation are combined with water demand suppression in a planned way.

International experience of supply-side responses to water supply challenges often showed them to be inefficient. Repeatedly major investments have been made by cities around the world in desalination facilities in order to address what are essentially short-run water supply challenges, never to be used, i.e., a great expense incurred with little positive benefit impact (El-Khattabi, 2022). These experiences have given rise to thinking globally that water supply supplementation solutions to drought-induced water supply challenges may not be efficient. The benefit yield from the investment is often not realised and there are often significant unforeseen environmental costs of projects to increase water supply (El-Khattabi, 2022). It is against this backdrop that the potential of water demand management (WDM) and water conservation (WC) has been globally touted as (often) efficient. WDM offers the potential to reduce the need for or delay the purchase of costly water supply infrastructure (El-Khattabi, 2022).

These sentiments may have been reinforced by observation in international literature that in some regions (like California) the per capita urban usage has been declining for several years on the back of the progressive implementation of a variety of voluntary and mandatory conservation measures. Other explanations for the decline in per capita water usage in California are deindustrialization and trends in less water-intensive technological innovation (Maggioni, 2015)

In their examination of the impact of resource rationing of agricultural groundwater, Ryan and Sudarshan et al (2022) found it inefficient because it limited farmers' use of water inputs without regard to the costs and benefits of water sourcing and use. In their examination of the water utilities before and after the reform process brought on by a water supply crisis, Van Den Berg and Danilenko (2014) found that exogenous influences on their internal structure and functioning made reform of insignificant impact on how effectively they operated. In the view of Berg (2013), it is practically guaranteed that excessive political participation in utility operations will result in inefficiencies.

Internationally the most prevalent use of water demand management as a response to a severe drought has been as a short-run instrument in the form of water rationing (Lund & Reed 1995; Kimengsi & Amawa 2015; Zhao et al 2021). Under these circumstances, water rationing is frequently applied without an underpinning strategy, timetable, deadline, or prior notification to the customers (Kimengsi & Amawa 2015).

That was not the case during the summer of 2017–2018, when WDM was escalated by the CoCT. The CoCT municipality felt water supply augmentation would not be able to make a significant contribution in the short-run (Dickin, 2017) so escalated water demand suppression to reconcile short-run water demand with short-run water supply. The CoCT did not 'spring' the rationing on its customers – it already was applying water demand suppression as a long-run strategy. All the evidence points to its escalated rationing being well publicised, planned and implemented, not so much a short-run rationing strategy but an integrated long+short-run water rationing strategy. Under circumstances where the demand suppression strategy is integrated (seamlessly blended), such as it is the cases of the CoCT and NMB municipalities, it makes little sense analytically to distinguish them, because they are applied in an integrated way.

Notwithstanding the collaborative efforts well publicised communications of local government and community organisations, the relative calm in areas historically neglected in service supply and increases in the incidence of things such as the reporting of leaks and neighbours watering their lawns in the affluent areas, clear evidence exist of unhappiness over the integrated long and short run water demand suppression measures imposed on many of the customers of the CoCT (Ziervogel, 2019).

In a critique of the WDM approach taken by the CoCT municipality and the DWS to its water reconciliation task, Muller (2022) has observed that:

> '*Cape Town's plight reflects this. Its decision-makers were not telling lies when they claimed that they had permanently reduced water consumption through demand management. The mistake they made was to claim an easy victory for their focus on demand management, ignoring more obvious drivers such as weather and population growth, and options such as increasing supply.*'

In his critique of the scaled-up WDM approach taken by the NMB municipality and the DWS, Muller (2022) has observed that the obvious solution to the NMBM water supply crisis was simply to draw more water from the Orange River:

> '*How can it be that it has taken more than ten years to build a relatively simple pipeline and treatment works that, in engineering terms, could have been completed in three years?*'

The inescapable conclusions with respect to WDM are that it is not a costless solution to a water supply crisis and can be used as a cover for failures in long-run water supply supplementation. There are consequential welfare costs to WDM. There may also be a significant foregone economic growth cost (unrealised development potential). The evidence of customer discontent, despite the careful implementation of the escalated water demand suppression strategy, indicates the presence and effects of direct and indirect (welfare) costs associated with demand suppression. Both municipalities explored water supply augmentation but appeared to consider the scope for it too limited for the management of short-run water supply crises.

International evidence on the relative merits of WDM as against water supply augmentation is mixed. Studies on WDM are often related to brief time periods, a small number of water agencies and technical studies of the efficacy of specific conservation interventions on the behaviours of households, rather than their efficiency of the particular water demand intervention (Hughes, 2012). Studies on water supply augmentation schemes often indicate they provide only short-term respite but fail to address medium to long run supply problems (Madrigal et al 2022).

7 A model for integrating the long-run and short-run elements of water supply crises

It is universally accepted that the timescale distinction between the Long-Run and Short-Run varies per industrial sector (National Treasury, 2019). There are a number of different views in the literature on the distinction between the short-run and long-run with respect to water (reconciliation) management. One view is that the short-run and long-run can be differentiated according to predictable market entry into or exit from the water supply by profit-seeking firms (implementable supply time scales) under competitive circumstances (Table 1). Another is that short-run and long-run can be differentiated according to the price elasticity of water demand (Figure 4).

Under the implementable time scale model (Table 1) the short-run and long-run are differentiated by the variability of the factors of production. In the short-run some factors are fixed but in the long-run none are fixed. Short-run models work within a temporal scale of months and singular years versus long-run models which span multiple years - enough time to allow for the adjustment of investment in technology, infrastructure development and land-use change (Cutlac et al., 2006).

Table 1: Short-Run versus Long-Run involve different causes and implementable time scales (Cutlac et al., 2006)

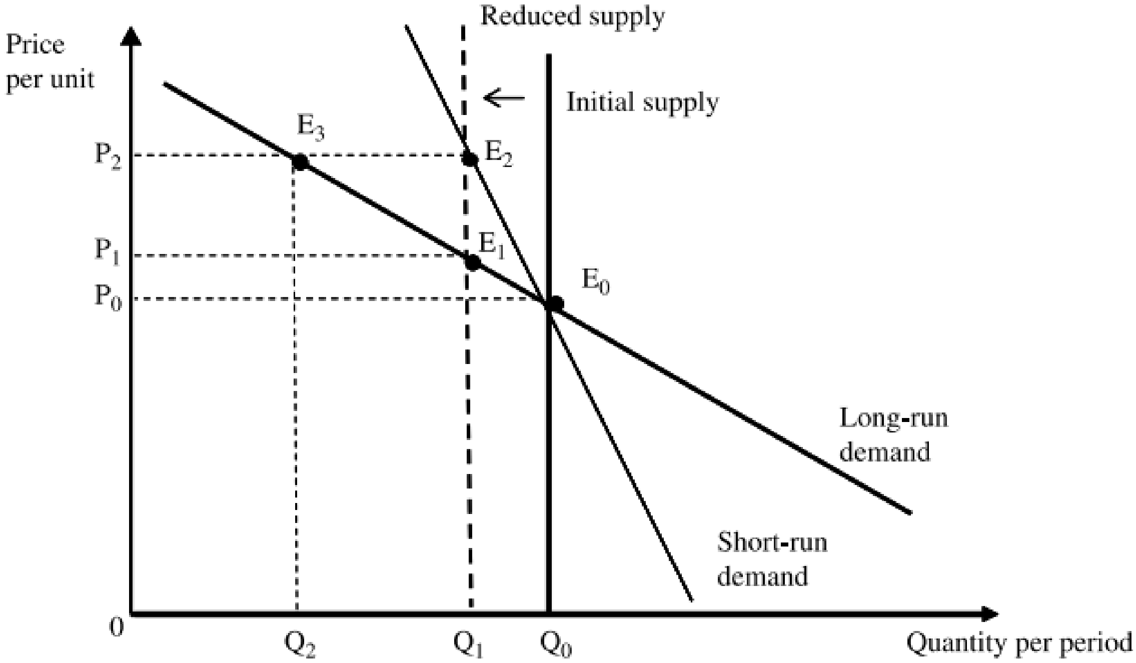
Short-Run	Long-run
• Fixed cost already paid = sunk costs	• No fixed costs
• Firms can shut down but not fully exit	• Can choose scale of production
• No of firms in market is fixed P≥AVC(min)	• Firms will enter if P>AVC(min) • Exit if P<ATC(min) • Or long run P=ATC(min)
• Firm will produce if profit can be positive, negative or Zero	• Profit = 0 if all firms identical

Notes:

P is price, AVC is average variable cost, ATC is average total cost

Under a model where the short-run and long-run are differentiated by the price elasticity of water demand (Figure 4), provision is made for a public choice-determined water supply (in both the short and long runs). When water supply is a public choice determined, it is perfectly inelastic with respect to price. It is an external factor that changes the water supply.

Figure 4: Differentiating short-run and long-run demand responses (Cutlac et al, 2006)



Drought may cause 'initial supply' to decline to 'reduced supply,' so water supply reduces from Q_0 to Q_1 (Figure 4). In the short-run this reduction of supply causes the price of water to increase from P_0 to P_2. In the long-run this increase in price causes the quantity of water demanded to decline further from Q_1 to Q_2, leading to a surplus water supply of Q_2Q_1. Market equilibrium, which is a balance between water demand and supply, is only re-established in the long-run (at E_1) when the price of water supplied is reduced to P_1.

In this model water management by local government is reduced to translating public choice into the water supply in both the short and long runs and setting the price of water with reference to short and long-run water demand. The setting of the price is an element of water supply management under this model (Figure 4). To be efficient the price must be set to recover the full economic cost of water supplied. The price set must consider the privately incurred costs incurred in supplying water and the imposed costs on others of water supply and use (externalities) (Danilenko, et al., 2014). The reality, though, is that very few operational water management models directly incorporate full economic costs, despite the improvements such incorporation can enable to the efficient allocation of water resources (Booker et al 2012; McKinney and Savitsky, 2003; Conradie and Hoag, 2004).

The weakness with both model distinctions between the short and long runs (Table 1 and Figure 4) is that they do not capture the circumstances appropriate to the decision-making on water supply for the CoCT and NMB. The distinction between fixed and variable costs is relevant, as is the price elasticity of water demand, but it is not competitive circumstances that regulate their price setting and the quantity supplied, nor is it the price elasticity of demand. The quantity of water supplied and the price on the market for this quantity are set under monopolistic circumstances. The municipalities have both long-run supply supplementation and short-run supply augmentation options, so it is incorrect to model supply as perfectly inelastic. There are economic implications for their municipality's gross geographic products of water supply decision-making, which are not reflected in these models.

To address these deficiencies, a different model is suggested by which to distinguish the short from the long run. It is a model appropriate to monopolistic circumstances where the potential is reflected for short-run private sector augmentation of local government's water supply (supply is not perfectly price inelastic) and a model that encompasses the implications for the municipality's levels and changes of gross geographic products.

It defines a short-run local government augmented water supply scheme as one to augment the long-run water supply, which is not part of the local government (or the DWS) long-run water system reconciliation plan. It is a capacity and facility that can be brought into operation within a brief time horizon. For this reason, it is suited to bridging a short-run shortfall of water supply (over that yielded from planned and implemented long-run water supply schemes) relative to water demand. Short-run water supply will be referred to in this paper as a water supply augmentation.

The short-run relates to production that can be brought into operation within say 3-6 months but is not part of the development of long-run supply capacity and operational cost. The short-run water supply capacity may be created:

- as a public good, by the decision of a local or provincial or national level of government to establish a water supply augmenting facility that can be started up within 3-6 months or
- as a traded good, by providing contractual incentives (contingent supply prices) to private local and international firms to develop a water supply augmenting facility that can be started up within 3-6 months.

In the literature on reconciliation of demand and supply, short-run water augmentation of supply is often trivialised as a 'minor' contribution (consideration). However, it was sufficiently important that the (National Treasury, 2022) saw fit to mention that it viewed a lesson learned from the CoCT water supply crisis as the benefit of the CoCT approach to the private farming sector to augment its water supply during the 2017-18 drought from water acquired from the Eikenhof dam. At some point, the costs associated with SR supply augmentation may be lower than those associated with water demand suppression. In this event, SR water supply augmentation can and should play a significant role in addressing water supply crises - greater than the literature has been inclined to acknowledge.

In its Water Outlook Report of 2022, the NMB municipality identified three mitigation interventions to apply over the short, medium, and long terms (NMB, 2022), but the municipality engineered itself into a position where it did not have medium- and long-term mitigation interventions they could apply to address their water supply crisis. It is almost impossible to build infrastructure fast enough to alleviate the acute effects of a drought-induced water supply crisis (NMB, 2022).

The NMB municipality's short-term interventions included both market and non-market driven water demand suppression (Water Restrictions and Punitive Tariffs; Household flow limiting devices; Public awareness and Consumer behaviour change campaigns) and water supply augmentation schemes (Pressure Reduction; Leak Repair Programmes; Clearing alien vegetation in catchment areas; Replacing faulty infrastructure; Basic water supply at collection points) (NMB, 2022).

It is suggested for the future there be three elements informing municipal water supply planning to satisfy water services demand:

- a long-run development plan for increasing the Gross Geographic Product (GGP) through the satisfaction of the public and private good demand for water services
- a long-run engineering plan for reconciling water demand and water supply and a short-run water supply capacity creating plan
- an economic plan for distributing the water supply so that it satisfies the public and private good demand for water services – in both the long- and short-runs.

These elements are modelled in Figures 5a, 5b and 5c. There is a public choice made for a target level of GGP in the short-run period t2. Three feasible targets may be considered by the municipality - GGP_A, GGP_B and GGP_C (Figure 6a). To achieve these respective GGP targets, a water supply must be employed of either Q_{ds} or Q_{as} or Q_{ss} (Figure 5a).

Figure 5a: A municipal development plan for GGP targeting through the satisfaction of the public and private good demand for water services

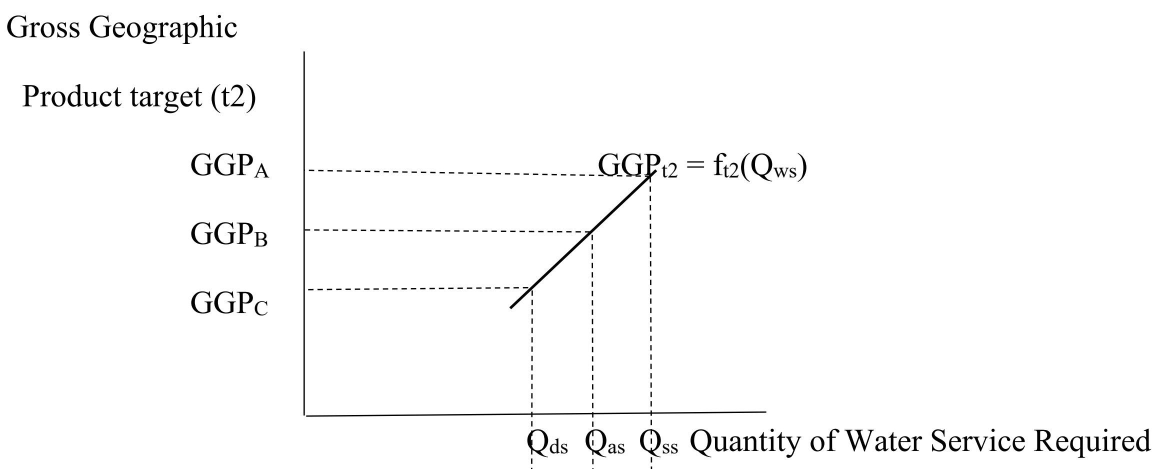


Figure 5b: The municipal engineering reconciliation plan for satisfying from accessible water resources public and private demand for water services

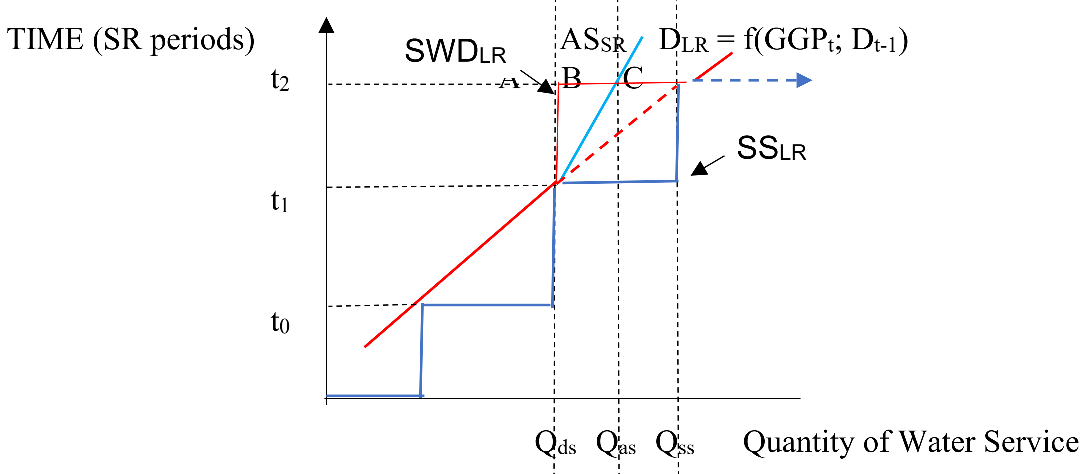
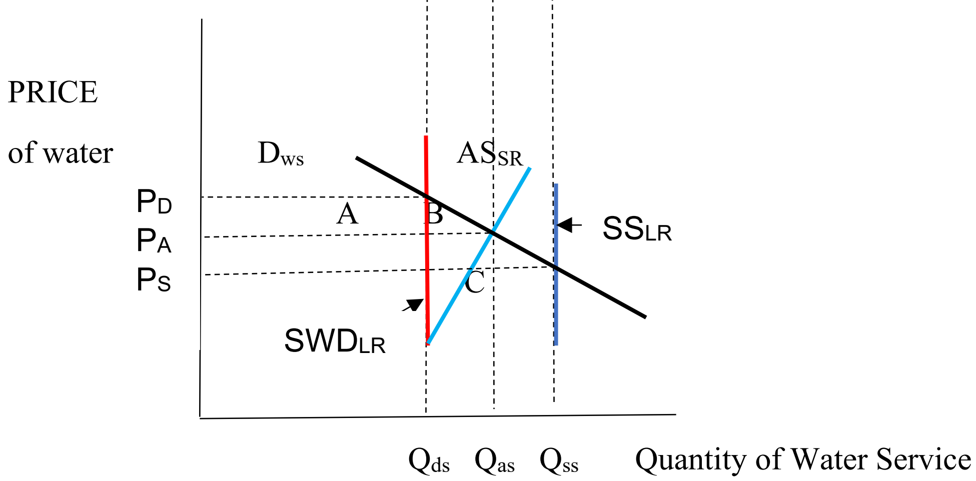


Figure 5c: A municipal economics plan for distributing the water supply so that it satisfies the public and private demand for water services in period t2



In the long-run public and private water (projected) demand (D_{LR}) is modelled as a projection of the ratio of past water demand to past GGP over trends (D_{t-1}:GGP_{t-1}) (Figure 5b). The long-run water supply plan relates to the municipal engineering proposals to satisfy long-run demand. The short-run water supply capacity creating plan is to encourage water supply increase from sources other than those engineered by the municipality. This option is referred to as water supply augmentation (AS_{SR} in Figure 5b).

The option of planning to suppress demand for municipal-supplied water service over any period (long-run or short-run) is referred to as water demand suppression (SWD_{LR} in Figure 5b). The option of planning a municipal water supply increase over time to assure satisfaction with a 98% probability (based on information on climate cycle yield variations) is referred to as water supply supplementation (SS_{LR} in Figure 5b). Within the short-run planning period defined as t_2, the alternative plans (options) put the municipality respectively at either point A or B or C and water supply at either Q_{ds} or Q_{as} or Q_{ss} (Figure 5b).

The economic plan for distributing the water supply (either Q_{ds} or Q_{as} or Q_{ss}) to satisfy the water demand (D_{ws}) during period t_2 through the planned three supply options (SWD_{LR}, AS_{SR} and SS_{LR}) is shown in Figure 5c. Escalated water demand suppression by market instruments requires a water price to be set of P_D. Water supply augmentation of will be encouraged at a market price of water of P_A and water supply supplementation requires a water price to be set for the water of P_S (to recover the costs).

In terms of the model put forward in figures 5b and 5c:

- any instruments aimed at achieving supply possibilities on the AS_{SR} curves (functions) are defined as short-run water supply augmentation strategies,
- any instruments aimed at varying the position of the SS_{LR} curves are defined as long-run water supply supplementation strategies
- any instruments aimed at achieving outcomes on the SDM_{LR} curve are defined as demand suppression (management) strategies.

The best choice of instruments applied and the outcome is in part defined by the underpinning objective, namely the GGP target, and in part by what is efficient under drought-induced circumstances.

8 Conclusion

The 2015-2022 water supply crises of the CoCT and NMB municipalities were predictable from reconciliation study information. There are many aspects that contributed to these water supply crises - government relationship defects, the presence of legal and political impediments and uncertainty, for instance.

There are two types (sets) of policy instruments and strategies by which water demand and water supply can be reconciled. It is useful to distinguish short-run from long-run strategies within these two sets – although there are overlaps and relationships between the short and long-runs. There are two basic types of short-runs (crisis management) strategies, represented by escalated water demand suppression and augmented water supply.

The water demand suppression strategy was successful to help mitigate both the CoCT and NMB water supply crises and make them more orderly – more so in the shorter enduring CoCT crisis than the longer enduring NMB crisis.

As far as water demand suppression is code for the application of the principle of efficiency, there can be no quibble as to its economic merit. The problem with water demand suppression arises when it is used as an alternative to water supply supplementation and augmentation because then a social welfare opportunity cost is incurred. There is no reason, *a priori*, to assume water demand suppression to be more efficient or welfare improving than water supply supplementation and augmentation as a strategy to reconcile water demand and supply.

The modelling of the short and long-run periods for reconciling water demand with supply suggests there is a potential trade-off between managing water supply crises through water demand suppression and water supply augmentation (or supplementation). For this reason, an efficient mix of these strategies can only be determined based on their costing of them.

This evaluation of the combined local and national government water service policies to manage local short-run water supply crises, indicates that, in the absence of such costing, the mixes of strategies that were adopted by CoCT and NMB to reconcile their respective water demand and supply were mere speculation in terms of their efficiency consequences. This paper recommends that such costing form part of future policy to reconcile local water demand with supply.

References

ABOELNGA HT, RIBBE L, FRECHEN FB and SAGHIR J (2019) Urban water security: definition and assessment framework. *Resources*, *8*(4) 178 - 196. https://doi.org/10.3390/resources8040178.

ADAMS DC, ALLEN D, BORISOVA T, BOELLSTORFF DE, SMOLEN, MD and MAHLER RL (2013) The influence of water attitudes, perceptions, and learning preferences on water-conserving actions. *Natural Sciences Education*, *42*(1) 114-122. https://doi.org/10.4195/nse.2012.0027.

BERG SV (2016) Seven elements affecting governance and performance in the water sector. *Utilities Policy*, *43*, 4-13. http://dx.doi.org/10.101016/j.jup.2016.04.013.

BIEKER S, CORNEL P and WAGNER M (2010) Semicentralised supply and treatment systems: integrated infrastructure solutions for fast growing urban areas. *Water Science and Technology*, *61*(11) 2905-2913. http://doi.org/10.2166/wst.2010.189.

BISCHOFF-MATTSON Z, MAREE G, VOGEL C, LYNCH A, OLIVIER D and TERBLANCHE D (2020) Shape of a water crisis: Practitioner perspectives on urban water scarcity and 'Day Zero' in South Africa. *Water Policy*, *22*(2) 193-210. http://doi.10.2166/wp.2020.233.

BOOKER JF, HOWITT RE, MICHELSEN AM and YOUNG RA (2012) Economics and the modeling of water resources and policies. *Natural Resource Modeling*, *25*(1) 168-218. https://doi.org/10.1111/j.1939-7445.2011.00105.x.

BOOYSEN MJ, VISSER M and BURGER R (2019) Temporal case study of household behavioural response to Cape Town's "Day Zero" using smart meter data. *Water Research*, *149*, 414-420. https://doi.org/10.1016/j.watres.2018.11.035

CITY OF CAPE TOWN (2015/16) Water and Sanitation: Water Demand Management and Strategy, https://resource.capetown.gov.za/documentcentre/Documents/City%20strategies,%20plans%20and%20frameworks/WCWDM_Strategy_doc.pdf.

CITY OF CAPE TOWN (2019) Our shared water future: Cape Town's water strategy. https://resource.capetown.gov.za/documentcentre/Documents/City%20strategies,%20plans%20and%20frameworks/Cape%20Town%20Water%20Strategy.pdf.

CITY OF CAPE TOWN (2022) Weekly Water Dashboard. https://resource.capetown.gov.za/documentcentre/Documents/City%20research%20reports%20and%20review/damlevels.pdf.

CONRADIE BI and HOAG DL (2004) A review of mathematical programming models of irrigation water values. *Water SA*, *30*(3) 287-292. http://www.wrc.org.za

CUTLAC IM, HE L. and HORBULYK TM (2006) Integrated modelling for river basin management: the influence of temporal and spatial scale in economic models of water allocation. *Water science and technology*, *53*(10) 55-63. http://doi:10.2166/wst.2006.297.

DANILENKO A, VAN DEN BERG C, MACHEVE B and MOFFITT LJ (2014) *The IBNET water supply and sanitation blue book 2014: The international benchmarking network for water and sanitation utilities databook*. World Bank Publications.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (2004) *National Water Resource Strategy, Department: Water Affairs and Forestry. Pretoria. First Edition. 271* pp.URL: https://cer.org.za/wp-content/uploads/2017/10/NWRS-2004.pdf.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (2007) *DWAF Annual Report 2006/2007. Department: Water Affairs and Forestry. Pretoria.* First Edition. 270 pp. URL: https://static.pmg.org.za/docs/080227dwafrep.pdf.

DEPARTMENT OF WATER AND SANITATION (2011) Reconciliation Strategy for the Algoa Water Supply System. URL: https://www.dws.gov.za/iwrp/Algoa/default.aspx. (Accessed 25 May 2022)

DEPARTMENT OF WATER AND SANITATION (2015) Reconciliation Strategy for the Western Cape Water Supply System. URL: https://www.dws.gov.za/iwrp/RS_WC_WSS/. (Accessed 25 May 2022)

DEPARTMENT OF WATER AND SANITATION (2020) 'Infrastructure Development', URL: https://www.dws.gov.za/Projects/sdg/Infrastructure%20development.aspx. (Accessed 17 September 2021)

DEPARTMENT OF WATER AND SANITATION (2022) Water and Sanitation on Algoa Water Supply System. URL: https://www.gov.za/speeches/water-and-sanitation-algoa-water-supply-system-26-jul-2022-0000.

DICKIN S, BISUNG E and SAVADOGO K (2017) Sanitation and the commons: The role of collective action in sanitation use. *Geoforum*, *86*, 118-126. https://doi.org/10.1016/j.geoforum.2017.09.009.

EL-KHATTABI AR (2022) The Neglected Side of the Water Management Equation: Demand Management. Policy Centre for the new South. URL: https://www.policycenter.ma/publications/neglected-side-water-management-equation-demand-management. (Accessed 20 October 2022).

FELL J and CARDEN K (2022) Lessons from the Cape Town water crisis and the need for a renewed technical agenda. Brookings Institution. URL: https://www.brookings.edu/blog/africa-in-focus/2022/03/30/lessons-from-the-cape-town-water-crisis-and-the-need-for-a-renewed-technical-agenda/. (Accessed 20 October 2022).

FLÖRKE M, SCHNEIDER C and MCDONALD RI (2018) Water competition between cities and agriculture driven by climate change and urban growth. *Nature Sustainability*, *1*(1) 51-58. https://www.nature.com/articles/s41893-017-0006-8.

GLOBAL WATER PARTNERSHIP (GWP) (2012) Water demand Management: The Mediterranean Experience. Ljungsbergs. https://www.gwp.org/globalassets/global/toolbox/publications/technical-focus-papers/01-water-demand-management---the-mediterranean-experience-2012-english.pdf.

GRAFTON J, LILLIS AM, and WIDENER SK (2010) The role of performance measurement and evaluation in building organizational capabilities and performance. *Accounting, Organizations and Society*, *35*(7) 689-706. https://doi.org/10.1016/j.aos.2010.07.004.

HUGHES DA, MOHOBANE T and MALLORY SJL (2012) *Implementing uncertainty analysis in water resources assessment and planning : report to the Water Research Commission*. URL: https://www.wrc.org.za/wp-content/uploads/mdocs/2056-1-14.pdf.

INMAN D and JEFFREY P (2006) A review of residential water conservation tool performance and influences on implementation effectiveness. *Urban Water Journal*, *3*(3), 127-143. https://doi.org/10.1080/15730620600961288.

JACOBSEN M, WEBSTER M and VAIRAVAMOORTHY K (eds) (2012). *The future of water in African cities: why waste water?* World Bank Publications. 177 pp. https://elibrary.worldbank.org/doi/abs/10.1596/978-0-8213-9721-3.

JENSEN O and KHALIS A (2020) Urban water systems: Development of micro-level indicators to support integrated policy. *PloS one*, *15*(2), p.e0228295. July 2020 http://dx.doi.org/10.1371/journal.pone.0228295.

JOHNSTON RJ, RAMACHANDRAN M, SCHULTZ ET, SEGERSON K and BESEDIN EY (2011) Willingness to pay hot spots and the distribution of ecosystem service values: implications for benefit transfer. In *Proceedings of Annual Meeting Agricultural and Applied Economics Association, Pittsburgh, PA, USA* (Vol. 2426). https://d1wqtxts1xzle7.cloudfront.net/30788830/J.

KIMENGSI JN and AMAWA SG (2015) Water rationing in the Buea municipality: patterns, effects, and coping strategies. *African Journal of Social Sciences Vol*, *6*(3). https://www.researchgate.net/publication/289184428.

KOESTER S, SIEKMANN M, STAUFER P, BEIER S and PINNEKAMP J (2010) Water oriented city planning as key driver for sustainable urban development. *Germany: Institute For Environmental Engineering Of RWTH Aachen University*. https://www.academia.edu/502113/Water_oriented_city_planning_as_key_impulse_for_sustainable_urban_development.

LAI E, LUNDIE S and ASHBOLT NJ (2008) Review of multi-criteria decision aid for integrated sustainability assessment of urban water systems. *Urban water journal*, *5*(4) 315-327. https://doi.org/10.1080/15730620802041038.

LUND JR and REED RU (1995) Drought water rationing and transferable rations. *Journal of Water Resources Planning and Management*, *121*(6) 429-437. https://doi.org/10.1061/ (asce) 0733-9496(1995)121:6(429)

MAGGIONI E (2015) Water demand management in times of drought: What matters for water conservation. *Water Resources Research*, *51*(1) 125-139. https://doi.org/10.1002/2014WR016301.

MARLOW DR, MOGLIA M, COOK S and BEALE DJ (2013). Towards sustainable urban water management: A critical reassessment. *Water research*, *47*(20) 7150-7161. https://doi.org/10.1016/j.watres.2013.07.046.

MCKINNEY DC and SAVITSKY AG (2006) Basic optimization models for water and energy management. *The University of Texas at Austin Technical Report.* Revision 8. https://www.caee.utexas.edu/prof/mckinney/ce385d/Lectures/McKinney_and_Savitsky.pdf.

MULLER M (2020) Money down the drain: Corruption in South Africa's water sector. *Johannesburg: Corruption Watch and the Water Integrity Network*. https://www.corruptionwatch.org.za/wp-content/uploads/2020/03/water-report_2020-single-pages-Final.pdf. (Accessed 12 October 2021).

MULLER M (2020) Some systems perspectives on demand management during Cape Town's 2015–2018 water crisis. *International Journal of Water Resources Development*, *36*(6) 1054-1072. https://doi.org/10.1073/pnas.1704665115

MULLER M (2022) Power Point presentation headed '*Decolonising Engineering'*, at Gqeberha, May 2022.

NATIONAL TREASURY (2016) Explanatory memorandum to the division of revenue. URL: http://www.treasury.gov.za/documents/national%20budget/2016/review/Annexure%20W1.pdf. Accessed 23 July 2022)

NATIONAL TREASURY (2022) '*What the Cape Town Drought taught us: 4 focus areas for local governments*', Cities Support Programme: Climate Resilience Briefing Note. URL: https://www.csag.uct.ac.za/wp-content/uploads/2018/12/CSP_climate_policy-brief_2018_11_26.pdf.

NELSON MANDELA BAY MUNICIPALITY (2006) *Water Master Plan 2005-2020*. URL: https://www.nelsonmandelabay.gov.za/datarepository/documents/water-master-plan-2005-2020.pdf.

NELSON MANDELA BAY MUNICIPALITY (2022) *Water Outlook Report 2022*. URL: https://nelsonmandelabay.gov.za/DataRepository/Documents/nmbm-2022-water-outlook-updated-feb-2022-rev-03_6xtve.pdf.

OLSON M (2009) *The logic of collective action* (Vol. 124). Harvard University Press. 198 pp.

ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (2016) *Water, Growth and Finance policy perspectives*. Organisation for Economic Cooperation and Development. URL: https://www.oecd.org/environment/resources/Water-Growth-and-Finance-policy-perspectives.pdf.

OTTO FE, WOLSKI P, LEHNER F, TEBALDI C, VAN OLDENBORGH GJ, HOGESTEEGER S, SINGH R., HOLDEN P, FUČKAR NS, ODOULAMI RC and NEW M (2018). Anthropogenic influence on the drivers of the Western Cape drought 2015–2017. *Environmental Research Letters*, *13*(12), 124010. https://doi.org/10.1088/1748-9326/aae9f9.

PARKS R., MCLAREN M., TOUMI R. and RIVETT U (2019). Experiences and lessons in managing water from Cape Town. *Grantham Institute Briefing Paper*, *29*. https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Experiences-and-lessons-in-managing-water.pdf.

REES JA (1998), May. Regulation and private participation in the water and sanitation sector. In *Natural Resources Forum* . Oxford. UK: Blackwell Publishing Ltd. Vol. 22, No. 2, 95-105 https://fr.ircwash.org/sites/default/files/Rees-1999-Regulation.pdf.

RITCHIE H and ROSER M (2018) Now it is possible to take stock–did the world achieve the Millennium Development Goals. *Our World in Data*, *22*. https://ourworldindata.org/millennium-development-goals.

RYAN N and SUDARSHAN A (2022) Rationing the commons. *Journal of Political Economy*, *130*(1) 210-257. https://www.journals.uchicago.edu/doi/epdf/10.1086/717045.

SHARMA SK, and VAIRAVAMOORTHY K (2009) Urban water demand management: prospects and challenges for the developing countries. *Water and Environment Journal*, *23*(3) 210-218. https://doi.org/10.1111/j.1747-6593.2008.00134.x

SINCLAIR-SMITH K and WINTER K (2018). *Climate Change and Urban Development: Lessons from Cape Town*. UCT Press. https://www.researchgate.net/publication/325626526.

SINCLAIR-SMITH K and WINTER K (2019). Water demand management in Cape Town: Managing water security in a changing climate. *Mainstreaming Climate Change in Urban Development. Juta, Cape Town*. 352 pp.

SMITH M and CARTIN M (2011) Water vision to action: catalyzing change through the IUCN Water & Nature Initiative: results report URL: https://policycommons.net/artifacts/1375106/water-vision-to-action/1989362/ (Accessed 23 Oct 2022).

VAN DEN BERG C and DANILENKO A (2017) Performance of water utilities in Africa. URL: https://openknowledge.worldbank.org/bitstream/handle/10986/26186/W17008.pdf?Sequence=7.

WHO & UNICEF (2021) Billions of people will lack access to safe water, sanitation, and hygiene in 2030 unless progress quadruples – warn WHO, and UNICEF. *Press Release*: 1–8. https://www.unicef.org/press-releases/billions-people-will-lack-access-safe-water-sanitation-and-hygiene-2030-unless.

ZHAO D, LIU J, SUN L, YE B, HUBACEK K, FENG K and VARIS O (2021) Quantifying economic-social-environmental trade-offs and synergies of water-supply constraints: An application to the capital region of China. *Water research*, *195*, p.116986. https://doi.org/10.1016/j.watres.2021.116986.

ZIERVOGEL G (2019) Unpacking the Cape Town drought: lessons learned. *Cities support programme| Climate resilience paper. African Centre for Cities, February 2019*. URL: https://www.blueeconomyfuture.org.za/gallery/ziervogel-2019-lessons-from-cape-town-drought_a.pdf.