CAPE TOWN'S DAY ZERO – LESSONS FOR NEW ZEALAND

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ABSTRACT

As Cape Town struggles to survive through the 3rd year of this 3 year drought, the Day Zero concept has captured the imagination of the world; but what has really happened in the lead up to a situation where taps could be switched off for the first time in a major City? As a water resources engineer that has been directly involved with Cape Town water supply issues, I would like to share some pertinent behind-the-scene technical interventions that have probably prevented a Day Zero from having already occurred. We will also discuss key lessons learned which are quite relevant to New Zealand's water supply systems.

From 1990 to 2000 Cape Town showed a rapidly growing water requirement on the back of population growth and strong economic development, prompting the initiation of a focused approach to identifying and prioritizing future supplementary water resources. In addition to detailed future water requirements and alternative water resources studies, Cape Town has (since the late 1990s) also been planning and implementing resilience measures into the management of its water resources.

Currently the City is almost entirely dependent on surface water resources that are usually replenished during the winter months by frontal rainfall systems. The use of water yield and planning tools in modelling Cape Town's complex water system for determining long-term system yield and reliability of yield has proved to be invaluable in managing the current situation and for evaluating possible future scenarios. This paper will highlight the use of these tools in assimilating system information to provide an efficient Decision Support System (DSS) for managing water resources and how this knowledge contributed to managing a serious drought period.

Pro-active water demand management (WDM) has also played an important role in curtailing the growing water demand of Cape Town. These WDM tools ranged from hard engineering options to public education drives specifically aimed at changing public perception regarding the value of water.

The effect of having planning tools as well as the implementation of WDM on managing water resources during this drought will be illustrated in this paper, along with relevant lessons learned to help prevent the occurrence of a Day Zero in New Zealand.

KEYWORDS

Cape Town, Day Zero, Yield model, Water Demand Management

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Wageed is a technical expert in waterway water quality, including the assessment of effects of pollution from both urban and rural environments. He has over 22 years' experience in performing and managing water quality assessments for water resource projects, hydrodynamic and water quality modelling studies as well as hydrological modelling studies. He has also been involved in computational fluid dynamics (CFD) analyses in support of detailed bulk infrastructure design. In addition to his experience in consulting, he spent 6 years in the academic environment lecturing at both undergraduate and postgraduate levels in the areas of biological wastewater treatment, environmental water quality modelling & environmental engineering.

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Clint serves as T+T's Water Sector Director, and a primary technical leader in stormwater pollution effects management. He has over 28 years of international and national experience across stormwater and wastewater projects – including networks and treatment. His experience includes many large project and programmes across the globe – ranging in scale from very large urban centres (e.g. London, Sydney, Chicago, San Francisco) to medium and small locations overseas and within New Zealand. His technical skills include water quality and quantity analytics – and monitoring/modelling/GIS tools used to facilitate development of corrective action programmes. Most recently Clint has been serving as a key technical advisor to New Zealand urban pollution policy forums such as MfE, Water NZ, Engineering NZ, and the Land & Water Forum. His inputs are being used to form strategies for influencing policy and regulation better formed to deliver New Zealand waterway outcomes.

1 INTRODUCTION

Cape Town is a coastal city situated on the south western coast in the Western Cape Province of South Africa. The City is situated in a winter rainfall area, historically characterized by wet winters (May – October) and dry summers (November – April). The major dams supplying the Western Cape Province and the City of Cape Town (CoCT) receives 90% of the annual runoff during winter, when only 30% of the annual demand is experienced (DWAF, 2007). Cape Town thus has a Mediterranean climate receiving most of its rain from cold fronts during winter.

During the summer months the demand for water increases significantly and approximately 50% of the total dams' storage is required during winter to supply the summer demand. The remaining 50% of the dams' storage is required as a carry over for periods of drought.

The CoCT has been completely dependent on surface water runoff to fill the major dams, but due to successive below average winter rainfall periods, the total water storage since the end of winter 2015 has decreased steadily from 75% to 40% at the end of winter 2017. This, of course, implied that the curtailment of demand was necessary since the 40% storage was insufficient to meet the summer demand of the City, with zero carry-over volume for any subsequent drought periods.

There was thus a real concern about the possibility that CoCT could become the first major city to run out of water even with the implementation of stringent water restrictions. Facing this real possibility, the CoCT coined the Day Zero concept as part of a public awareness campaign. Day Zero was essentially the date on which the combined water storage volume would reach 13.5 % and when the CoCT would abandon bulk water supply to homes, instead switching to centralized water distribution points. The Day Zero date was based on the outputs of a model and was originally scheduled for 21 April 2018, but then changed to 12 April, 11 May, 4 June, 27 August 2018 and is now postponed until 2019.

The rest of this paper will describe the behind-the–scenes resilience measures that were in place that actually prevented Cape Town from having experienced Day Zero earlier.

1.1 HISTORICAL PERSPECTIVE

Between 1990 and 2000 the economic growth for the CoCT averaged 2.6%, which was higher than the national average. This was accompanied by a representative increase in population and water demand. The historical water demand for the CoCT is shown in Figure 1a. From about 1954 the water demand increases exponentially to a maximum of 335 Mm^3/annum in 1999. Projections at that time showed that with unconstrained water demand, a maximum of 523 Mm^3/annum could be expected by 2014.

Also at that time, the 1:50 yield[1] was calculated to be 500 Mm^3, raising real concern that an additional water supply source would be required or that significant water demand management would have to be undertaken. This was even more concerning since the agricultural demand (about 100Mm^3/annum) also needed to be met from the 1:50 yield.

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[1] A 98% assurance of supply (1:50 year recurrence interval of failure) criterion is the standard across the South Africa

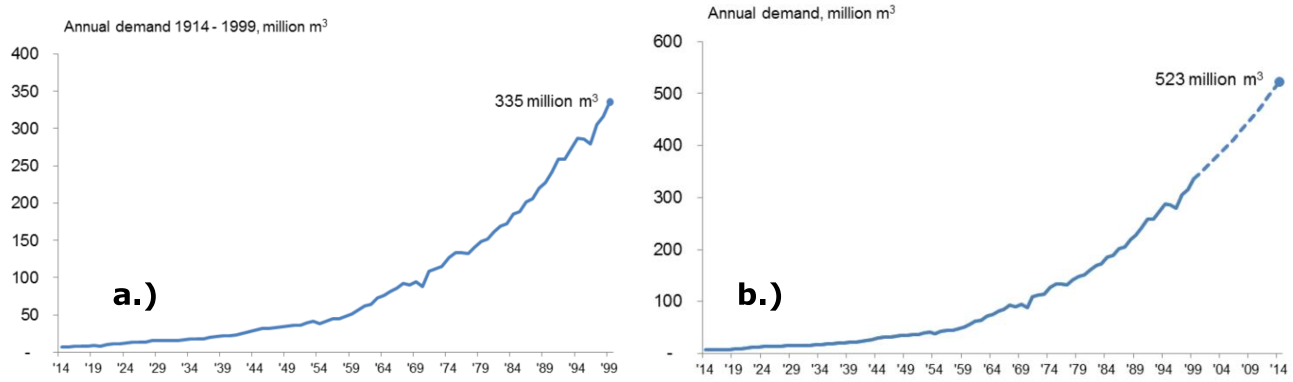

Figure 1: Cape Town's water demand a.) Pre-2000, b.) Unconstrained water demand between 2000 and 2014 (from Rhode, 2015)

Based on the actual historical urban and agricultural water demand on the Western Cape Water Supply System (WCWSS) (Figure 2), it can be seen that in 2000 the demand was already nearing the available system yield and a need for an additional water supply infrastructure was apparent. As early as 1995, however, the CoCT realized that the availability of water resources would be the limiting constraint to social upliftment and economic development and therefore committed itself to achieving a savings of 10% on the historical demand growth of 4 % per annum. A follow-up Integrated Water Resources Planning (IWRP) study in 2001 also identified that Water Conservation and Water Demand management (WC/WDM) would be the most feasible water augmentation options to meet the growing water demand (CoCT, 2007). This approach suited the Department of Water Affairs and Forestry (DWAF), since the capital expenditure for new water infrastructure could now be delayed. The major assumption of course was that annual runoff into the major supply dams would be close to the long term mean annual runoff (MAR) and that below average rainfall would not occur in three successive years.

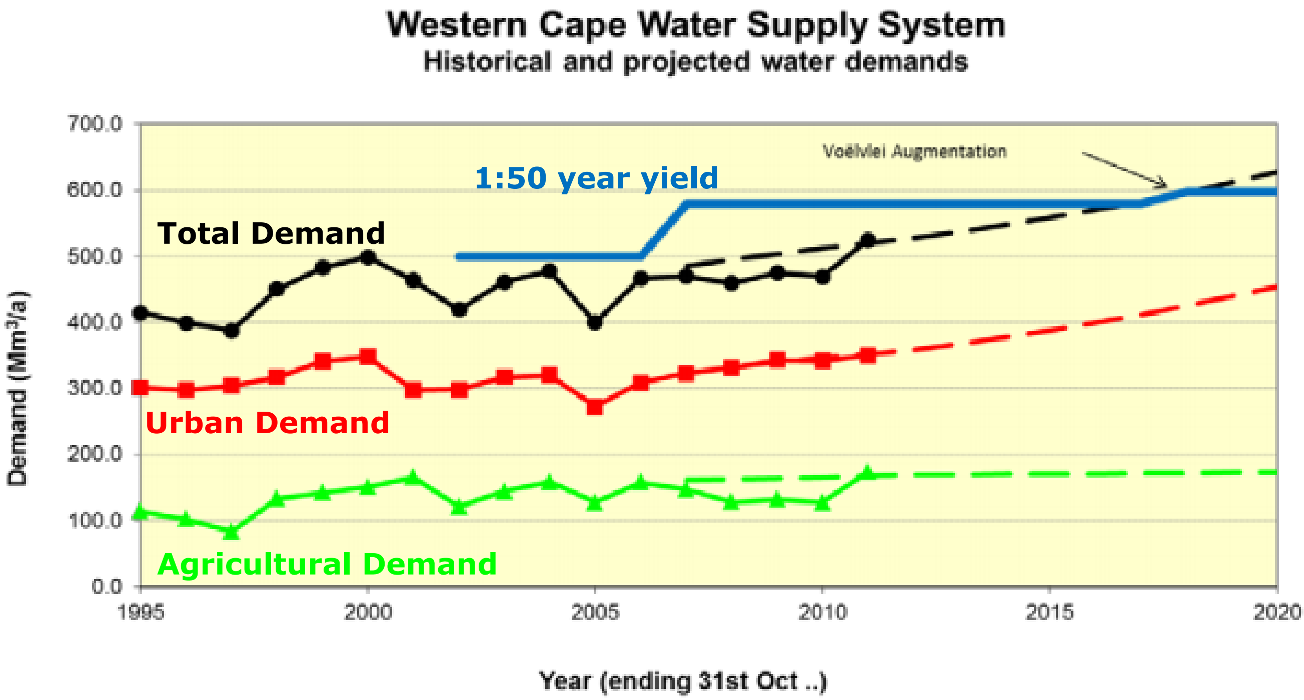

Figure 2: Demand vs. 1:50 year yield (DWAF, 2012)

2 CAPE TOWN WATER RESOURCES MANAGEMENT

2.1 WATER INFRASTRUCTURE

The major water supply dams for the Western Cape and CoCT are Theewaterskloof, Voëlvlei, Berg River, Wemmershoek and Steenbras dams. The capacities of these are listed in the table below.

Table 1: Capacity of major dams supplying the CoCT

Major Dam	Owner	Capacity (ML)
Berg Water Project	DWAF	130,010
Steenbras	CoCT	65,284
Theewaterskloof	DWAF	480,188
Voëlvlei	DWAF	164,095
Wemmershoek	CoCT	58,644
Total		**898,221**

Several smaller dams, mostly capturing runoff from Table Mountain also account for about 4,377 ML of storage in the system. The locations of the major dams as well as some of the other smaller dams are shown below.

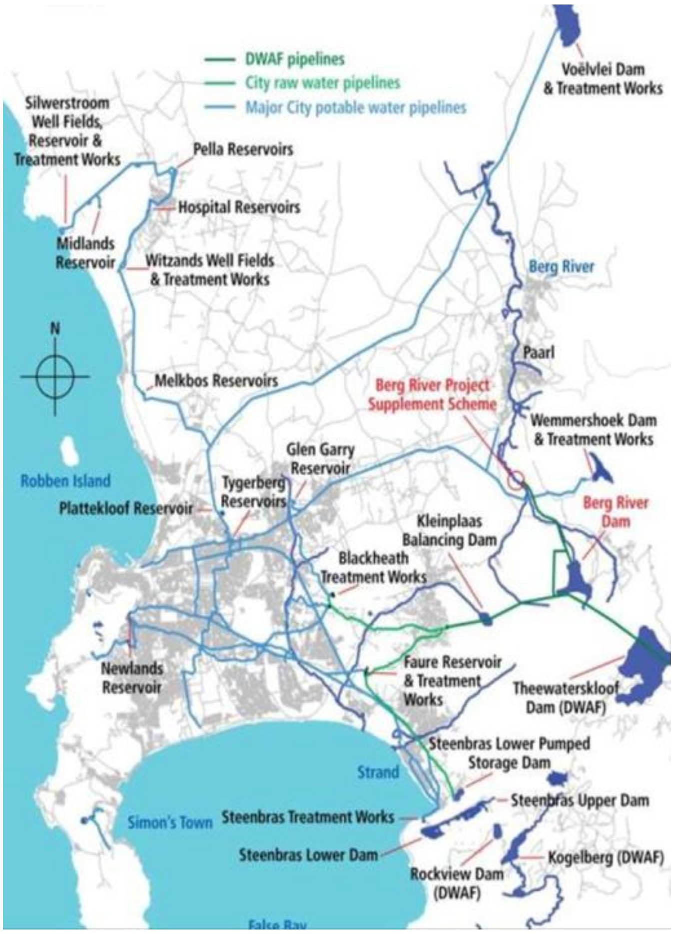

Figure 3: Location of dams supplying the CoCT (Basholo, 2016)

Other pertinent information related to the bulk water infrastructure and water supply system is listed in the table below.

Table 2: Pertinent characteristics of the CoCT water supply infrastructure

Infrastructure type	**Value in 2017**
Water treatment plants	15 • Production capacity 1650 ML/day • Capacity utilization 45 %
Bulk reservoirs	24 • Storage capacity 2740 ML • Avg. demand storage 3 days • Peak demand storage 2.5 days
Pipelines	655 km (bulk)

3 BUT…….THERE WERE SIGNS OF DROUGHT AROUND

Although the WCWSS seemed to always receive sufficient rainfall over the winter months to fill the major dams to capacity or near capacity, there were definitely signs that the rainfall patterns were changing and that more resilience measures in the water supply scheme were necessary.

The town of Beaufort West, situated about 500 km north east of Cape Town, has a population of about 53000 (2018) and receives most of its rainfall between January and May. The locality of the town relative to the CoCT is shown below.

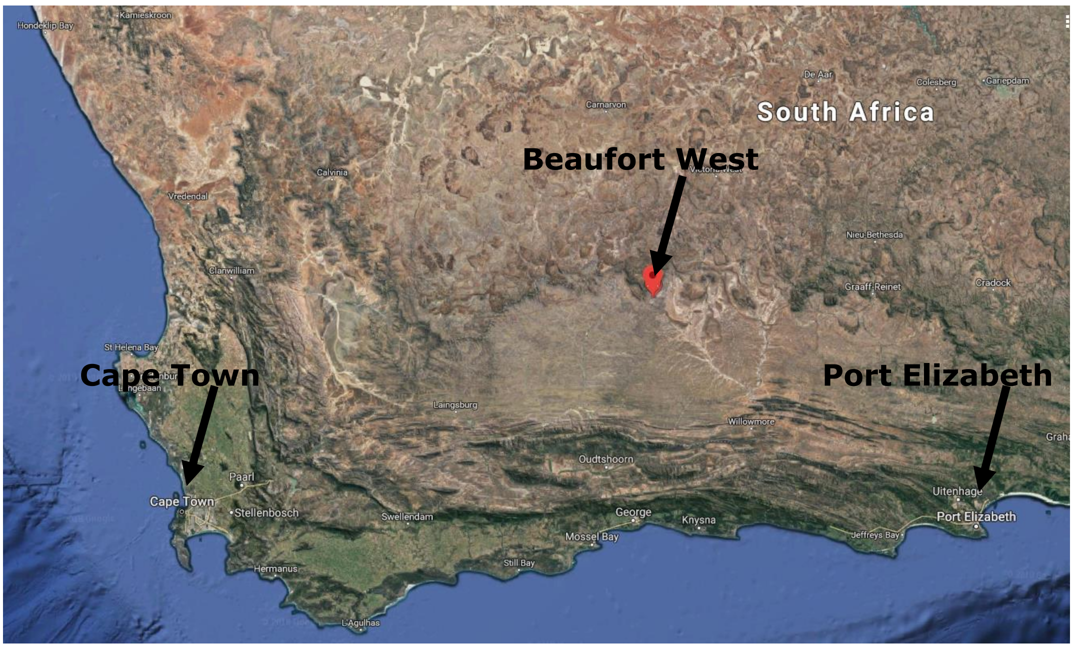

Figure 4: Location of Beaufort West and Port Elizabeth (Source: Google Maps)

Occasionally the town would also benefit from deep-penetrating cold fronts that bring rainfall to the entire country. However, in 2010 the town experienced it worst drought in 100 years. The surface water resources were entirely depleted and groundwater and trucks delivering additional potable water became the main sources of water supply. The severe water shortage prompted the design and construction of the first direct wastewater reclamation plant for drinking water production in South Africa. The construction of the direct wastewater reclamation plant was an emergency procedure and it was not the best circumstances under which to construct it. That being said, if there is no water available the "public perception barrier" to the use of reclaimed wastewater seems to disappear. A few voices at the time observed that this situation could become a reality for the CoCT as well and although this was a real possibility, it did not resonate as much as it should've since the storage percentage in the WCWSS dams were 99.4 % and 92 % at the beginning of November 2009 and November 2010, respectively. It is fair to say that the concern about drought is diminished when water is in abundance.

The then DWAF, Western Cape chief director did say that "*An increase in demand could have serious implications for the supply area (of Cape Town), as the next augmentation project may well have to be fast-tracked to ensure an adequate supply of water to every city, town and industry that gets its water from the Western Cape Water Supply System (WCWSS)*" (News 24, 2010).

A similar situation was playing out in the Eastern Cape around the city of Port Elizabeth, where insufficient rains were received during the rainy season resulting in the worst drought in 130 years. On 25 March 2010 the Nelson Mandela Bay area was declared a drought disaster zone. This declaration allowed access to national funding for emergency measures such as a desalination plant and the fast-tracking other surface water schemes (Water & Energy Conservation Systems, 2010).

Further away in the City of Perth (Australia) – with a climate similar to that of Cape Town – it has been observed (see Figure 5 below) that the runoff into their dams for the period 2008 to 2018 is now only 10 % of what it was during the first 70 years of the last century. This could be an indication of permanent climate change. Supplementation with groundwater started as early as the late 1960's and by the end of the 1970's nearly half of Perth's water supply was obtained from groundwater sources. Currently 46 % of Perth's water supply is obtained from groundwater sources, 47 % from desalination and the rest from reservoirs. The decline in inflows since the start of the 1970's indicate that building this resilience into the system was timeously done and represents the watershed moment for Perth's water supply management system (Morgan, 2018).

The past 3 years' hydrological drought in Cape Town could be the watershed moment and although the Day Zero event was staved off on this occasion, resilience in the system will have to be increased to avoid failure in the future.

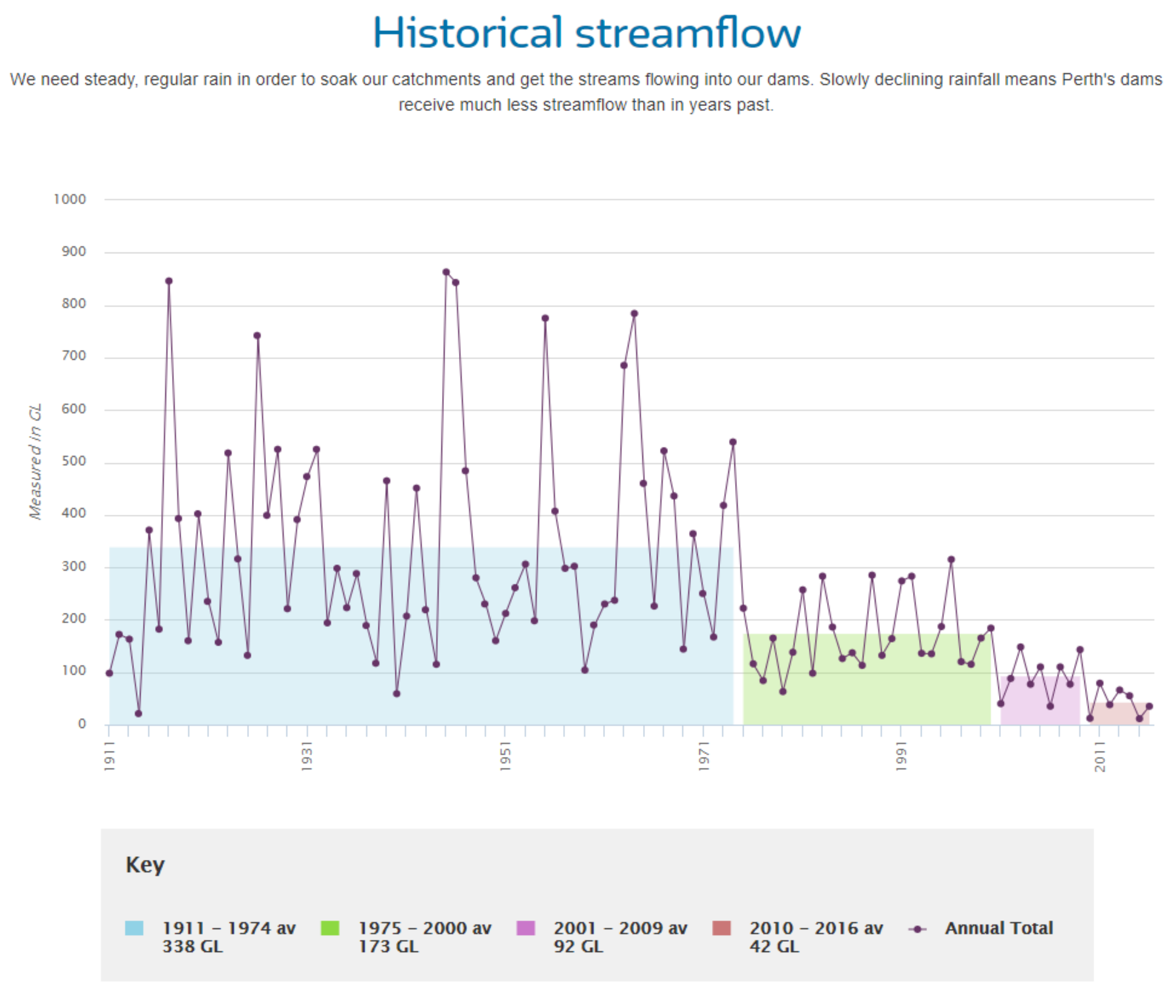

Figure 5: Historical inflow to Perth's dams (Water Corporation, 2018)

3.1 CHARACTERISTICS OF THE 2015 TO 2017 DROUGHT

Since the announcement of the initial Day Zero date the causes of the CoCT water crisis has been hotly contested - with reasons ranging from poor management, lack of planning political maneuvering, water demand growth, unreported agricultural use and lack of investment in infrastructure spending amongst others. Many people even subscribed to a conspiracy theory that the crisis is artificially generated with the sole purpose of creating justification for increasing water charges.

The aforementioned reasons have now largely been put to bed and consensus has been reached that the cause of the water crisis is the hydrological drought that has persisted between 2015 and 2017. The effect of this drought is best illustrated by the dam storage in the WCWSS as shown in the figure below.

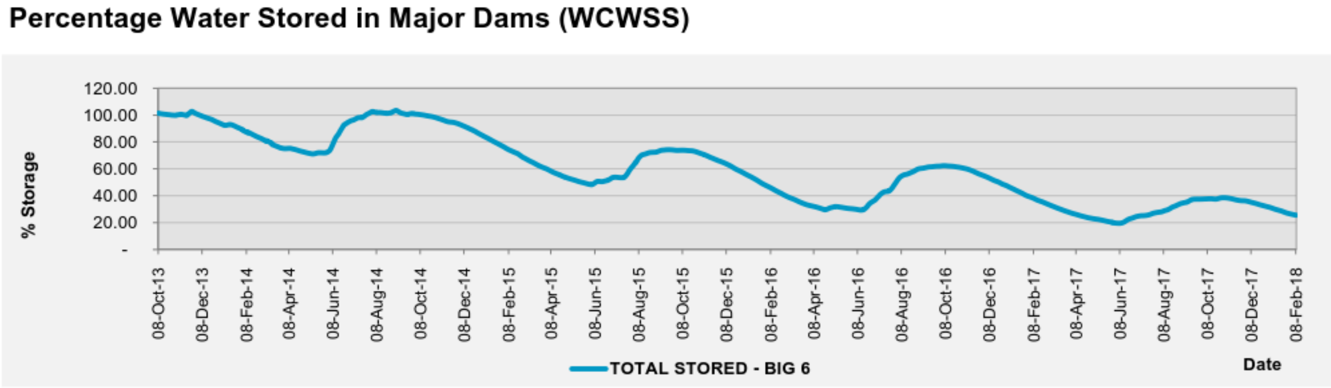

Figure 6: Storage volume trajectory in the CoCT's major dams

The figure shows that between October 2015 and 2017 the storage of the major dams gradually declined, with only about 40 % storage at the beginning of November 2017. This was a critical storage state since insufficient water was available to meet the summer demand. There was also zero carry-over capacity for future droughts.

A statistical analysis of the rainfall between 2015 and 2017 was undertaken to analyze the severity of the drought for a 1 to 3 year duration for the coastal rainfall gauges as well as those in the catchments of the major dams.

For the coastal catchments, neither the 2017 year nor the 2015 to 2017 years combined were the driest on record. These areas, however, are not where the runoff for the major dams are generated and are therefore not causal in the water crisis process. The rainfall stations in the catchments where the major dams are located told a different story entirely. In these catchments, statistical analyses for the year 2017 and the period 2015 to 2017 showed that these were the driest years on record since 1933, which translates to a drought return period of 1 in 84 years at least. Further statistical analysis showed that this type of drought more likely has a return period of 1 in 311 years with a 90% confidence that it falls between 105 and 1,280 years. Another interesting conclusion from the statistical analysis was that the rainfall at the gauges in the WCWSS dam region was actually declining at 17.1 mm/decade (see Figure 7), possibly indicating the effects of human-induced climate change (Wolski, 2018).

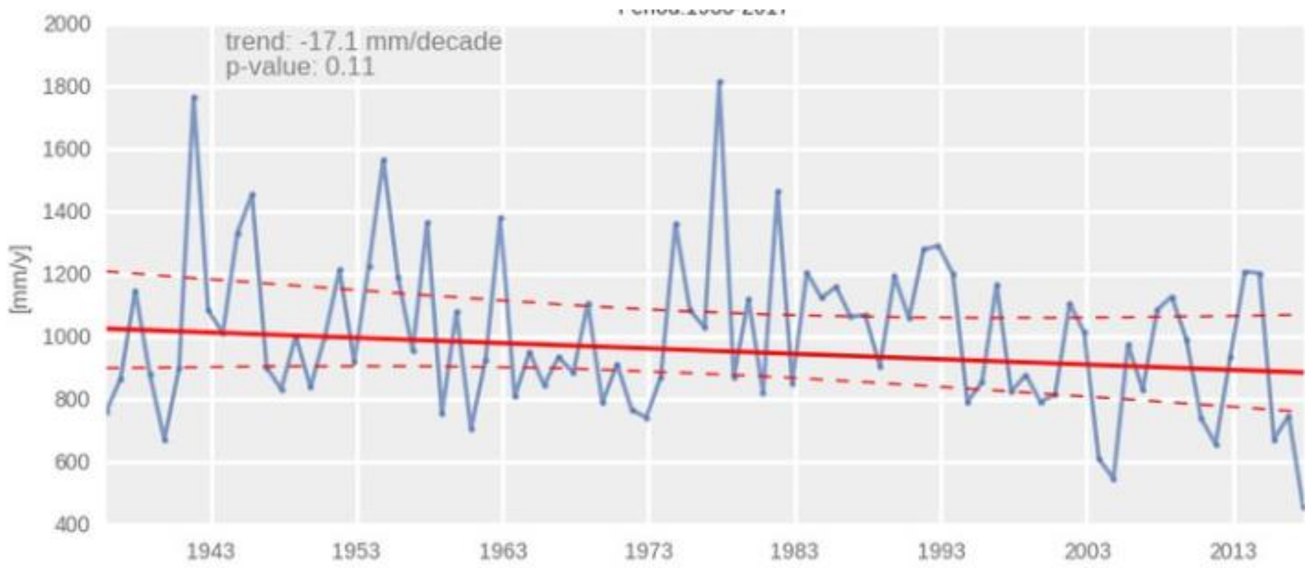

Figure 7: Rainfall trend as the mean of 3 stations in the WCWSS dam region (Wolski, 2018)

3.2 WHAT WAS DONE BEFORE THE DROUGHT

The water shortages experienced in the CoCT during the period 2015 – 2018 were certainly not the first time that this has happened since the turn of the century. During the summer of 2000 and 2004 actual demand approached the 1:50 year yield in the system (see Figure 2) and curtailment was implemented. During the summer of 2000, irrigation of gardens between 10am and 4pm was prohibited, while in 2004 irrigation of garden was even further curtailed with no irrigation allowed on specified days in designated areas. No restrictions were, however, placed on consumptive usage. In both cases the decisions to restrict or not were made at the end of October and the threshold for imposition of restrictions was 85 % storage at that time.

To better manage demand in the system the following water resilience/water conservation/water demand management tools were implemented.

3.2.1 HOUSEHOLD AND DISTRICT METERING

All the formal houses in the CoCT have a water meter and all customers pay for water according to their volumetric usage. In addition to this, the CoCT also installed meters for certain districts. Data from these meters allowed for volume balance calculations to be undertaken and for identifying areas where large volumes of water were potentially lost to leakage.

The meter reading programme was also accompanied by a programme to identify illegal and damaged meters that were subsequently replaced.

3.2.2 WATER RESOURCES MANAGEMENT TOOLS

In South Africa the Water Resources Yield Model (WRYM) is one of the main models that is used to balance the available water resources in the system with the water requirements and losses to which the system is subjected. The WRYM can be used in a yield analysis to assess the long and short term yield of a system at a fixed level of development. The yield could be determined based on a historical yield analysis (historical firm yield) or based on stochastic yield analysis where the risk of non-supply may be determined for a range of yields. This modelling approach provides a testing environment for assessing the systems behavior under selected scenarios before they are actually experienced (Nkwonta et al., 2017).

This approach is particularly useful in systems that have moved from a *run-of-river* approach for supply to a system consisting of multiple storages and channels. The basic components of the yield model are naturalized hydrology, rivers, reservoirs, weirs, diversions, losses, canals, pipelines, pumps and water requirements.

The operating rules for the system are defined via a set of penalties[2] that are interpreted according to relative size, which determine the priority for flow in the system. For the example in Figure 8, if the reservoir is in penalty zone 1000 (i.e. almost empty) only the urban demand of 0.5 m^3/s will be met, because the penalty for not meeting this is 1200 and is larger than the 1000 of the reservoir.

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[2] Dimensionless values assigned by the analyst to system components

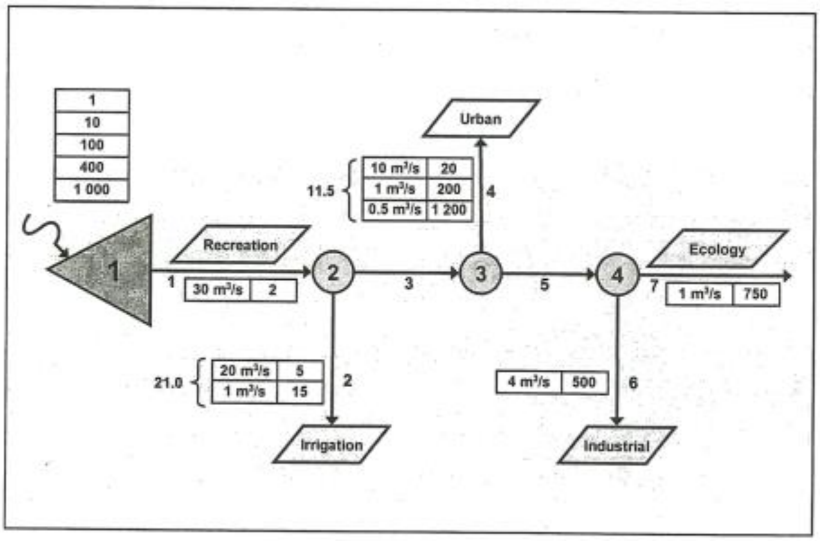

Figure 8: Example of a simple WRYM setup

These type of models have been set up for several water supply systems in South Africa, corresponding with areas of national economic significance and has been successfully used for determining realistic yields that can be obtained from these systems and for performing national water reconciliation studies.

The Water Resources Planning Model (WRPM) incorporates the same elements as used in the WRYM, but can accommodate a growing demand. Historically the WRPM was run on the decision date of 1 November to determine whether or not to impose restrictions for the subsequent summer.

The elements and data contained in the WRYM and WRPM models can even be used to determine when a system is likely to run out of water completely i.e. when day Day Zero is likely to occur.

The Day Zero model is a volume balance model and accounts for current dam levels, urban usage, agricultural usage, water donations, water augmentation projects and rainfall. Day Zero was calculated using a conservative approach whereby the average dam decline over the preceding three weeks were assumed to continue unchanged (CoCT, 2018).

3.2.3 PRESSURE REDUCTION PLANTS

Areas where pressure reduction plants could be implemented can only be identified if data is available to show the need for it, i.e. metering data should be available. The Khayelitsha and Mitchells Plain pressure management projects resulted in combined water savings of 11.4 Mm^3/a while another 13 projects added further savings of 8.44 Mm^3/a. An added advantage of pressure reduction was the reduced frequency of pipe bursts from 62/100km in 2010 to 24/100km in 2014 (Basholo, 2016).

3.2.4 ACTIVE LEAK DETECTION

An active leak detection programme was also initiated to replace/repair pipes/connections in areas known to have aged infrastructure (Basholo, 2016).

3.2.5 STUDIES ON INTERVENTION SCHEMES

Several detailed studies investigating the various augmentation schemes were undertaken by consultants to identify alternative water resources. These studies calculated the potential increase in yields that could be expected, cost of implementation as well as environmental implications. Some of the major studies, additional yields and estimated implementation dates are listed in the table below.

Table 3: Pertinent characteristics of the major augmentation studies undertaken

Augmentation scheme	**Additional yield (Mm^3/a)**	**Implementation date**
Voëlvlei Augmentation scheme (phase1)	35	2020
Water reclamation for potable use	40	2023
Sea water desalination	160	2030
Table Mountain Group Aquifer	40	2022

3.2.6 EFFECTIVENESS OF WATER DEMAND MANAGEMENT APPROACHES

Based on the implementation of the strategies above the CoCT was able to change the trajectory of its water demand significantly as is shown in figure below.

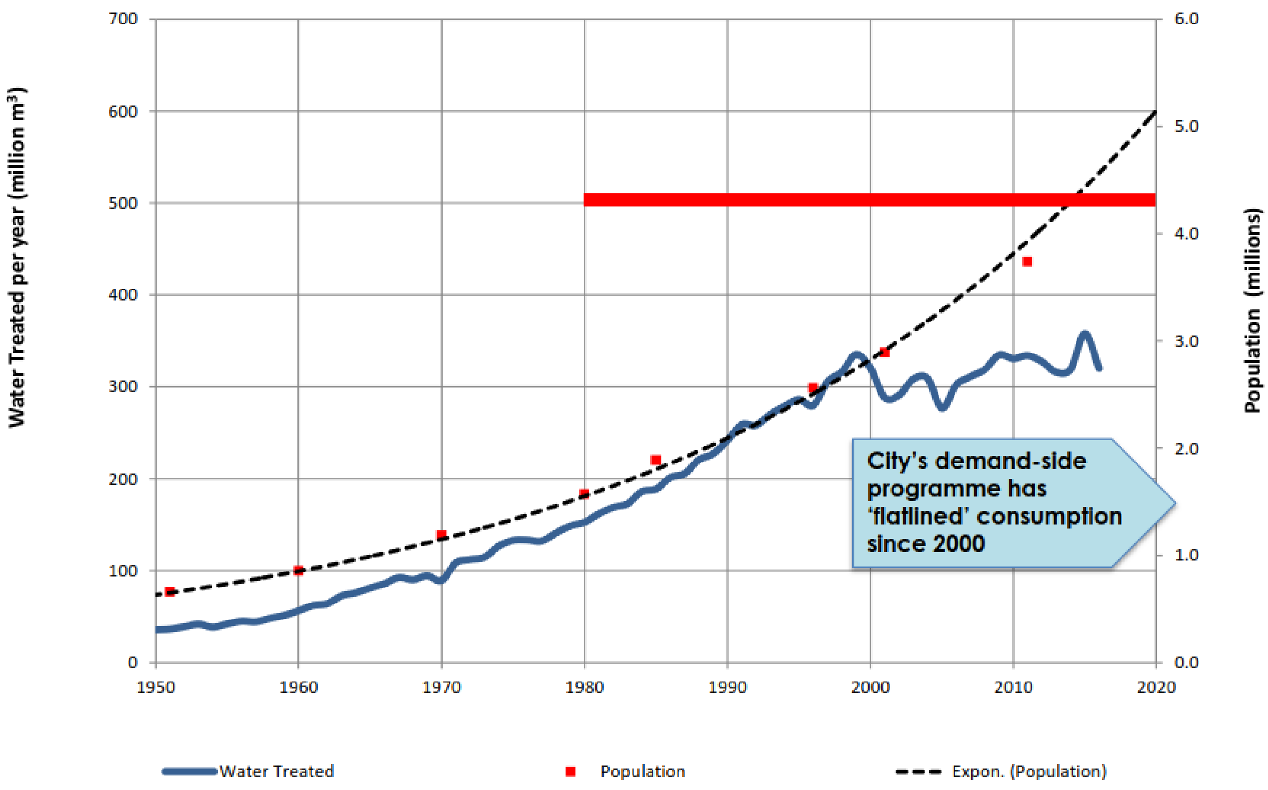

Figure 9: Historical water demands and population growth for the City of Cape Town (from Flower, 2017)

Unconstrained growth in water demand would have resulted in the available yield being exceeded in 2010 already, but the WDM interventions delayed this event sufficiently to allow for the implementation of the Berg River System that was completed in 2007; increasing the system yield to almost 600 Mm^3/annum. There is still an upward trend in water demand, albeit at a decreased annual rate.

The management team of the CoCT is now - more than ever - convinced that resilience is pivotal in keeping the city sustainable for its residents and have stated the following (Flower, 2017):

- *"The days of plentiful water supply have past. Good rainfall years should be considered anomalous as opposed to drought years,*
- *We must all adapt to water scarcity. This does not mean lower living standards or a diminished economy. The old 'water scarcity' must become 'enough water',*
- *The current situation presents an opportunity to build a new relationship with water. We must rethink our over-reliance on surface water and seek to build a Water Sensitive City,*
- *Now is the time to build resilience. It is our collective responsibility,*
- *We need to formulate a new relationship with risk as climate change adds significant uncertainty,*
- *Ultimately we need to make difficult choices for our future prosperity and seek a coalition of the best minds."*

3.3 WHAT HAPPENED DURING THE DROUGHT

Before and during the current drought several levels of restrictions were imposed on the residents of the CoCT. These ranged from Level 1 to Level 6B. The conditions of the level 6B restrictions that are currently in place are also listed below.

- Level 1 - Since 2005
- Level 2 – 1 January 2016
- Level 3 – 1 November 2016
- Level 3B – 1 February 2017
- Level 4 - 1 June 2017
- Level 4B – 1 July 2017
- Level 5 – 3 September 2017
- Level 6 – 1 January 2018
- Level 6B – 1 February 2018
    - A daily limit of 50 liters or less per person whether at home, work, or school;

- Outdoor usage of boreholes is strongly discouraged. Usage for irrigation purposes will be limited to a maximum of one hour only on Tuesdays and Saturdays before 9am and after 6pm;
- Borehole/well-point water use must be metered, records must be kept and be available for inspection;
- Permission from the national department of Water and Sanitation is needed to sell or buy borehole/well-point water;
- Agricultural users need to reduce usage by 60% compared with the corresponding period in 2015 (pre-drought);
- Commercial properties need to reduce usage by 45% compared with the corresponding period in 2015 (pre-drought);
- Residential units using excessive amounts of water will be fined or have water management devices installed;
- Hosing down of paved surfaces with municipal drinking water is illegal;
- Irrigation or watering with municipal drinking water is illegal;
- No use of portable play pools;
- Washing of vehicles, trailers or caravans with municipal water is illegal;
- Filling/topping up of private swimming pools with municipal water is illegal;
- Water features may not use municipal drinking water;
- Residents are encouraged to install water efficient parts to minimize water use at all taps, shower-heads and other plumbing mechanisms.

In addition to the restrictions, the names of the highest water consumers were also published in newspapers in an effort to apply social pressure in achieving compliance.

Initially the residents of the CoCT were slow to comply with the conditions of the water restriction level in force, but in the end the citizens of CoCT did respond extremely well and reduced daily consumption from 1200 Ml/d three years ago to 500 Ml/d during the week of 28 March 2018. University of Cape Town (UCT) academics have pointed out that no other city globally has managed that degree of reduction.

The water tariffs have also been amended upward to include for future funding of resilience measures. However, now that the dams are filling again the citizens of the CoCT are questioning why the tariffs need to remain high, which will require an awareness campaign to create understanding amongst consumers.

The reduction in water demand combined with water donations from farmers and the onset of the winter rainfall period has ensured that Day Zero has been postponed into 2019.

4 NEW ZEALAND PERSPECTIVE ON DROUGHT

Prolonged droughts are not currently a feature of the New Zealand climate, but with Climate Change this may change. The current approach to water supply in New Zealand seems to be based on a run-of-river approach, where there is an expectation that water will always be available when demanded.

When water resources become constrained, however, several sector could become vulnerable and resilience in the system is required. The questions that could be asked include:

- Are New Zealanders currently paying enough for their water?
- Is New Zealand prepared for drought?
- What resilience currently exists in the system?
- How will water be allocated during a drought situation?
- How will water demand be curtailed during a drought?

5 DISCUSSION

Based on the preceding sections the CoCT managed to avoid a Day Zero scenario earlier because:

- Water meters provided valuable information on water demand and are now considered to be a resilience instrument.
- Water resources yield models (WRYM) provides valuable insight on reconciling water demand with available supply and becomes a valuable management tool and source of information during times of drought.
- Water demand efforts delayed the need for augmentation and were crucial in preserving the remaining water supply during the critical drought period.
- The relationship of the citizens of the CoCT with water has now been changed and faster response to requests to reduce demand can now be expected.

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