Towards water wisdom in Cape Town

An exploration of potential water scarcity measures and required conditions

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Towards water wisdom in Cape Town

An analysis of potential water management measures and required governance conditions

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Theewaterskloof Dam taken by Greg Gordon in 2014 and 2018 (Gordon, 2018)

Summary

Cape Town suffered an extreme three year drought (2015-2018) resulting in a water scarcity crisis. 'Day zero', the day the city would have to turn off domestic taps, was averted due to strict water conservation and crisis augmentation measures. While the drought was extreme, the water crisis is also attributed to governance failings in media and academic research. Due to climate change, similar droughts are expected to occur more frequently in the future, reducing the accessible water supply to the City of Cape Town (CCT). Persistent increase in consumption and population growth will simultaneously continue to increase the CCT's demand for water. The CCT and the national Department of Water and Sanitation (DWS) have implemented various saving (e.g. regulating tariffs; consumption restrictions), buffering (e.g aquifers; reservoirs) and alternative-supply (e.g desalination; wastewater reuse) measures to reconcile supply and demand. Various institutional, physical, economic and equitability conditions need to be present to ensure that these measures are implemented effectively, fairly and sustainably.

Research presenting effective water management conditions or analysing possible measures to prevent droughts is prevalent, also for CCT specifically. However, an integral framework and method for connecting conditions and measures is lacking. This thesis aims to bridge this gap by: (1) summarizing the measures that can be taken to avoid water scarcity and (2) assessing the presence of the conditions necessary for these measures to work effectively in CCT. This is done with the ambition to recommend which measures could be implemented to effectively reduce the chance of water scarcity in CCT in the future. Data was collected through a literature review, expert interviews and using governmental, NGO and case-specific academic publications.

This study found that the CCT and DWS should focus on pressure management and the removal of non-native vegetation as cost-effective demand-oriented measures. Furthermore, the absence of financial capacity strongly influences the possibility of effectively implementing other supply- or demand-oriented measures. A 'rainless-day' fund could improve this condition and the chance of measures working more effectively.

Some measures require further research to be made more equitable. This includes the current means of revenue collection (which disproportionately burdens larger - and often poorer - households), the procedure for reallocation of water rights (which is slow and vulnerable to appeals processes), and the possibilities of aquifer recharge with treated wastewater (which would provide a sustainable solution for aquifer depletion and the acceptance of wastewater reuse).

Key concepts: Water scarcity; Water accessibility; Urban adaptation; Water demand management; Cape Town

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ANC	African National Congress
CBA	City Blueprint Approach (consisting of the TPF, CBF and GCF)
CCT	City of Cape Town (referring to the municipality)
CESCR	UN Committee on Economic, Social and Cultural Rights
CMA	Catchment Management Agency (oversees a WMA)
DA	Democratic Alliance
DWS	Department of Water and Sanitation (before 2009 DWAF: 'Water and Forestry')
GWP	Global Water Partnership
IB	Irrigation Board
IWRM	Integrated Water Resource Management
MAP	Municipal Adaptation Plan
MAR	Managed Aquifer Recharge
NWA	The National Water Act (1998)
SDGs	Sustainable Development Goals (or: Global Goals for Sustainable Development)
UN	United Nations
UNHRC	UN Human Rights Council
WC	Western Cape
WCG	Western Cape Government
WCWSS	Western Cape Water Supply System
WCRS	Western Cape Reconciliation Study
WHO	The World Health Organization
WMA	Water Management Area
WSA	Water Services Act (1997)
WSDP	Water Services Development plan
WUA	Water User Associations

I. Introduction

1.1 Drought in Cape Town

The Western Cape, in South Africa was plagued by a drought from 2015 to 2018; for three consecutive winters water reservoirs were not replenished sufficiently to fully cover the regular water use of the region. Multi-year droughts occur sporadically in the Western Cape, but no three-year period on record had ever been this dry. It only rained 221 mm in 2016 and 154 mm in 2017, both beating the previous record low of 229 mm in 1935 and far below the average of 619 mm a year (Olivier & Xu, 2018; Muller, 2018a). Cape Town, the largest city of the Western Cape, is home to a diverse population of about 4.1 million people that struggled with the effects of this multi-year drought. The City of Cape Town municipality (CCT) introduced the first voluntary restrictions on water use in 2016, attempting to cut back especially domestic use. Further restrictions were introduced throughout 2017, culminating to level 6b water restrictions - maximum 50 litres per person per day (p.p.p.d.) - in February 2018. Level 7 water restrictions were predicted to be necessary by March of the same year.

Level 7 restrictions would have involved the shut off of domestic water taps and the introduction of central pick up locations where inhabitants could get 25 litres of water p.p.p.d. The day these restrictions would be initiated was named 'Day zero'. Successful water conservation measures postponed day zero multiple times until it was called off indefinitely when autumn rains in 2018 replenished the large dams supplying Cape Town. Since September 2018 water restrictions have been brought down from level 6b and as of March 2019, level 3 restrictions are in effect, meaning that residents may use 105 litres p.p.p.d. (City of Cape Town, 2019a). In comparison, before the drought in 2015, Capetonians were using about 235 litres p.p.p.d. while European households were supplied about 114 litres p.p.p.d on average (EEA, 2018).

Figure 1 shows the change in the accumulated water levels of the six largest dams of the Western Cape between 2010 and 2018. The shaded area highlights a significant drop in 2015, when water use peaked due to the combination of a dry summer and no water restrictions. The reservoir level only partly restored each winter, to continue dropping in the following summer. The dotted line in 2018 shows the curve for the case in which water usage would have been the same in 2018 as in 2015 - demonstrating the impact of water restrictions on the system.

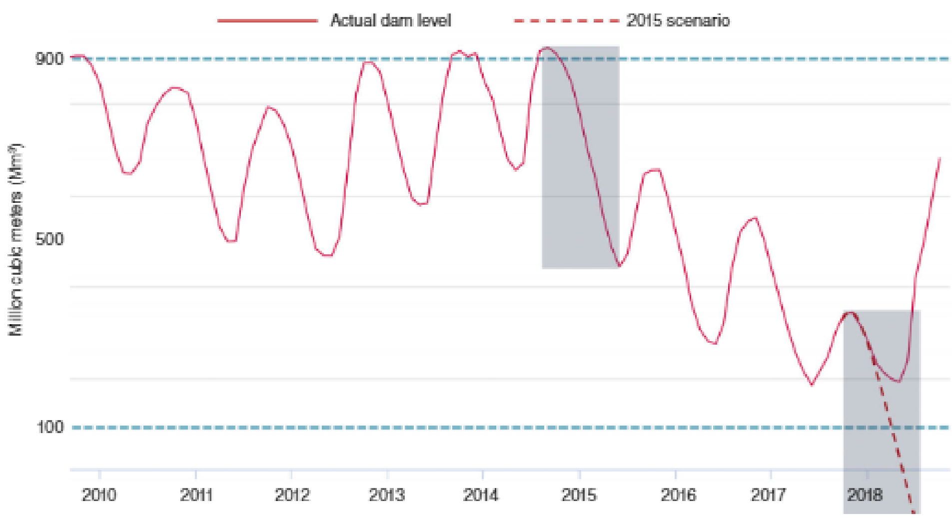

Figure 1: The accumulated water in the 6 largest dams surrounding Cape Town (Engvist & Ziervogel, 2019)

1.2 Defining Water Scarcity

During the past century the global increase in water use is estimated to be more than twice that of the increase in population (FAO, 2012). This has led to innumerable water-related issues around the world. Media, academic literature and public-policy arenas have used various water management concepts regularly, offhand and somewhat interchangeably to describe these developments. Water scarcity, shortage and stress - for example - are used with varying definitions and in reference to different situations. To understand their cruxes and nuances, it is important to pick specific definitions for this research.

Firstly, a *water shortage* occurs when the water supply is at a low level “at a given place and [...] time, relative to design supply levels” (FAO, 2012 p. 72). This shortage can be caused by an array of environmental or technical factors and is expressed as an absolute quantity. *Water scarcity*, on the other hand, is a relative concept that describes an excess of *water demand* over *available supply*. The demand is the aggregated demand of agricultural, institutional or domestic users. Available supply is the water present in the system that is *physically accessible*, but also *safe, affordable* and *acceptable*. Availability can therefore be reduced by a water shortage, but also by contamination, pricing, inadequate infrastructure or other external causes.

These attributes of available or accessible water are based on the UN Committee on Economic, Social and Cultural Rights (CESCR) 2002 comment: “The human right to water entitles everyone to sufficient[1], safe, acceptable, physically accessible and affordable water for personal and domestic uses” (CESCR, 2002). In 2010, the United Nations Human Rights Council (UNHRC) adopted ‘access to safe drinking water’ as a

[1] The World Health Organisation (WHO) proposes that at least 50 to 100 litres of water a day is needed for basic uses such as laundry, personal hygiene, drinking and preparing food.

universal human right, reiterating (and further defining) the CESCR variables (United Nations Human Rights Council, 2010):

- *Safe* water is free of hazardous chemicals, radiological substances or microorganisms (WHO, 2010). The WHO proposes guidelines which can be followed to assure safe drinking water.
- *Physically accessible* water is accessible to all, including children, elderly and disabled people. Collection should be possible within 1000 metres of home and should not take more than 30 minutes (WHO, 2010).
- *Affordability* is often omitted from the definition of 'accessible', but is taken into account in the CESCR general comment due to the impact of water use costs on poorer communities. In countries with large income gaps, water pricing is a complicated issue in which the worth of water as resource cannot be underestimated but the poor still need to be able to use it. According to the UNHRC, the cost of water and sanitation should not exceed 3% of a household's income.
- *Acceptable* water is a relatively vague concept compared to the other variables which have been operationalised distinctly. It refers, however, to the odour, colour and taste of water. Water and sanitation facilities need to be culturally appropriate and sensitive to gender, lifecycle and privacy requirements.

Therefore, water scarcity occurs when the aggregate demand cannot be met by a safe, physically accessible, affordable and acceptable water supply.
Finally, *water stress* refers to the broad term for the symptoms of water shortages or scarcity. These symptoms can be environmental (e.g. environmental degradation, declining groundwater, land subsidence) or social impacts (e.g. harvest failures and the resulting food insecurity, health risks, conflicts, political instability and economic costs in various sectors).

The water scarcity in Cape Town has been ascribed to both the extreme drought between 2015 and 2018 and governance failings, in the media and academic domain. In literature, water scarcity (and the resulting water stress) is suggested to be caused by either societal factors (e.g. population growth; a by-product of affluence), environmental elements (e.g. a drought; the effects of climate change), or a combination of the two. The dimensions of water scarcity vary based on their cause. The following three dimensions are a composition of the diverse types proposed in literature:

1. *Physical scarcity*: Physical scarcity is in principle a water shortage that has resulted in supply not being able to meet the aggregate demand (Seckler et al., 1998; World Bank, 2007).
2. *Economic water scarcity*: Due to a lack of technical, financial or human capacity, investments in infrastructure are inadequate resulting in economic water scarcity, or a lack of human capacity to satisfy the demand for water (Seckler et al., 1998; FAO, 2012).
3. *Institutional water scarcity*: Institutional (or organizational - as it is referred to by the World bank) scarcity refers to governments not "getting water to the right place at the right time" (World Bank, 2007). It is caused by institutional failure of governments to provide water to their constituents (FAO, 2012).

While the three dimensions are rooted in different causes, it is proposed in some literature that "most [causes] are capable of being remedied or alleviated" (UN-Water, 2006). One could therefore assert that even in the case of a physical scarcity there is some form of governance failing. This is supported by the Global Water Partnership (GWP) that has proposed that a water sector crisis is a governance crisis (GWP, 2000). It is, however, important to understand the differences between these dimensions to be able to tackle the scarcity effectively. All three dimensions of water scarcity are impacted by changes in the supply of and demand for water, but a change in either variable will not affect each dimension in the same manner. For example, an increase in supply could directly reduce physical scarcity, but in the case of economic scarcity, missing infrastructure could continue to hinder the accessibility to water. The water stress symptoms perceived by the inhabitants of a water scarce area are also somewhat dependent on the dimension of scarcity (FAO, 2012).

Figure 2 presents the relationship between these concepts. Socio-economic trends (population growth, economic fluctuations, cultural changes) impact the demand for water. Hydroclimatic trends (temporary droughts, long term climate change, varying seasons) and socio-economic trends impact the accessible supply. A decrease in water supply means an increase in scarcity, while a demand decrease reduces water scarcity. Finally, the three dimensions of scarcity lead to water stress (FAO, 2012).

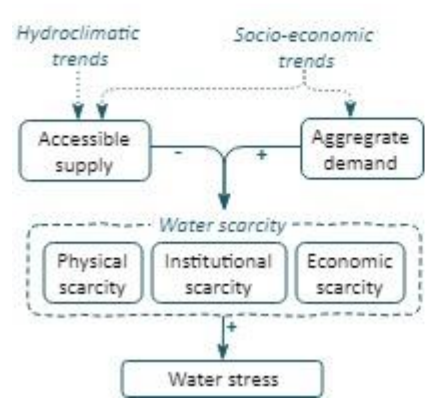

Figure 2: Water management concepts

1.3 Existing research

The drought and resulting water scarcity in Cape Town have received both local and international media and public attention. Newspaper articles, twitter feeds and public and political discussions have been dominated by possible causes, accrediting blame, tips for reduction of household water use and possible long term solutions. While there is ample (older) research on water management in general, this attention has only just started to translate to the South African case in the form of both evaluation of responsibility and justice issues, and proposed measures to prevent a future crisis.

Recently, Madonsela et al. (2019) used the City Blueprint Approach (CBA - developed by Schreurs, Koop & van Leeuwen, 2017) to assess the strengths and weaknesses of Cape Town's existing water management system. The CBA is a baseline assessment founded on three separate frameworks: (1) the Trends and Pressures Framework forms a social, financial and ecological context over which city managers have negligible influence, (2) the City Blueprint performance Framework highlights the strengths and weaknesses of the city's water management and (3) the Governance Capacities Framework provides an assessment of the city's capacity to deal with future uncertain threats (Koop & van Leeuwen, 2015; van Leeuwen et al., 2012; Koop et al., 2015). Looking further back, Mukheibir & Ziervogel (2007) proposed a basic framework by which a Municipal Adaptation Plan (MAP) could be developed for Cape Town. This framework proposes some conditions necessary for effective adaptive governance and highlights a few key vulnerabilities of the city. While both articles emphasize that they are a starting point - one that should be utilized as inspiration and as a tool for decision makers to further plan or evaluate their policies - the

MAP and CBA of Cape Town are the most comprehensive plan and evaluation of the city's water management to date.

Some articles also contemplate the influence of water governance research and assessment itself. For example, Mahlanza, Ziervogel and Scott (2016) published an article on environmental justice, water rights and poverty in Cape Town at the start of the crisis. They suggest that the 'adaptive governance' perspective of water management has generally neglected the issue of injustice and inequity surrounding water accessibility. Adding to this, Mukheibir (2010) compares and contrasts three prominent discourses surrounding water governance, namely the (1) Sustainable Development, (3) Integrated Water Resource Management (IWRM) and (3) Adaptation to Climate Change discourses. These articles provide a valuable review of water management research, but also key conditions that are necessary for water management to be effective, efficient and fair.

Finally, there are innumerable articles on specific water saving, buffering and harvesting measures. Most, however, are devoted to developing and/or evaluating one or two measures. A recent example is an article written by Olivier & Xu (2018) on effective use of groundwater "to avoid another water supply crisis in Cape Town".

So, Madonsela et al. (2019) and Mukheibir & Ziervogel (2007) formed a foundation on the key issues that need to be tackled by water governance in Cape Town. Some articles have also discussed which conditions make water governance effective and papers about specific water saving or harvesting measures are continuously published. A considerable gap in the literature concerns the comparison of possible measures and a set of conditions necessary for these measures to work. So far, this has not been studied. While the framework for a MAP in Cape Town by Mukheibir and Ziervogel, (2007) is a valuable start, it has not been further developed or, for that matter, updated in 12 years. Suggested measures in the MAP are only superficially compared to other options and the impact these measures have on water-equality is generally neglected. Additionally, the socio-economic and environmental conditions necessary for each measure to be (and stay) effective are not always explained, and hardly ever discussed at length.

1.4 Academic and Societal relevance

This topic is relevant to both the academic field and societal development. The academic relevance of this thesis lies in the knowledge gap presented above. There is a lack of comprehensive research on the possible measures that can be taken given the conditions relevant to the Cape Town case. This research addresses this knowledge gap and as such aims to provide a stronger foundation for an exhaustive water management plan for Cape Town.

As indicated, the scarcity in Cape Town has been caused by hydrological and institutional processes. The local hydrological processes supply a fluctuating amount of water depending on various climate mechanisms (including climate change). Institutions should implement measures that dampen these fluctuations and the impact they have on society. Water management measures can only be effective, however, if physical, institutional, economic and equitability conditions are adequate for that measure.

The societal relevance of this research lies in highlighting possible new measures or improvements to Cape Town´s existing water infrastructures and plans.

Safe water is a basic requirement for human health but is also a necessity for the large agriculture and tourism sectors that Western Cape drives on. The economic cost of the water crisis thus far is difficult to calculate due to the uncertainty of the indirect effects such as, for instance, reduced revenue from tourism, but is estimated to already be about 2.5 billion rand (€157 million) (Muller, 2018a). While day zero did not occur, the cost of time spent by a population of more than 3.5 million people waiting in line for water every day alone, is already unimaginable. The plausible outcomes of this (e.g. unequal waiting times as the rich can afford to have others pick up their water) would have inequitable impacts on an already uneven society.

1.5 Research Questions and Framework

This research aims to on the one hand, summarize the measures that can be taken to avoid water scarcity in Cape Town and on the other, assess the conditions necessary for these measures to work both effectively and fairly. Accordingly the research question will be:

To what extent are the institutional, physical, economic and equitability conditions - required for the implementation of measures to effectively reduce water shortages - present in Cape Town?

Figure 3 proposes a framework of the steps that need to be taken to answer this research question. First, existing literature on water scarcity and water governance will provide both the general conditions that need to be met for effective water governance and a list of possible water scarcity measures. Interviews and public reports will be combined with case-specific literature to evaluate whether the set conditions are present, which measures have already been taken in Cape Town and whether measure-specific conditions are also present. Finally, based on this analysis, recommendations will be made on which extra measures can be taken in Cape Town.

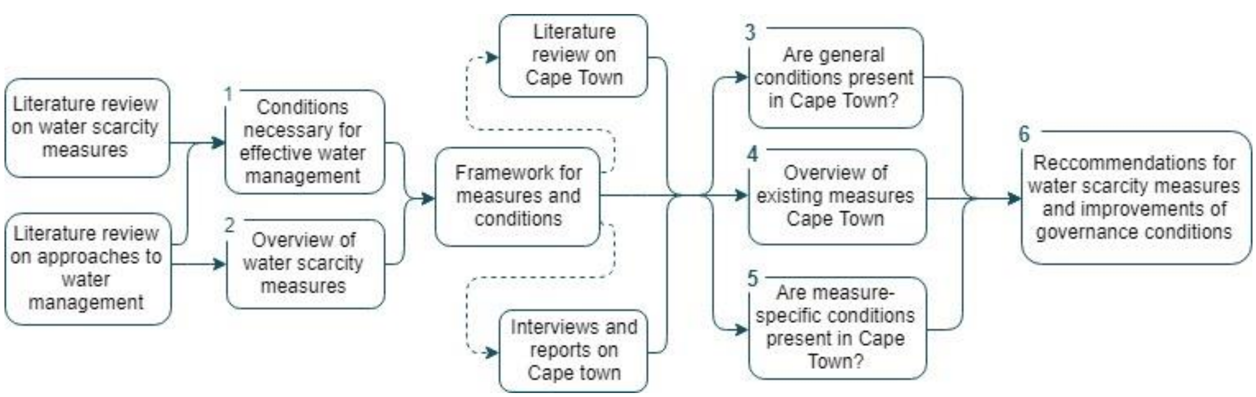

Figure 3: *Research framework*

The steps proposed by this research framework can also be presented as sub-questions, where the answer to each question forms a component:

1. What general conditions are required for effective water management?
2. Which measures to tackle water scarcity are proposed in literature?
3. Which general conditions are present in Cape Town?
4. What measures have been taken in Cape Town?
5. What measure specific conditions are present in Cape Town?
6. Which additional measures could be taken in Cape Town?

1.6 Outline of Research

The remainder of this research is set up to follow the research framework and sub questions. Chapter 2 presents the theoretical basis of the paper and answers subquestions 1 and 2. Chapter 3 proposes a methodology for answering questions 3, 4, 5 and 6. A broad view of the history of water management in Cape Town is given in chapter 4, before presenting an assessment on whether the general conditions are present (answering question 3). Chapters 5, 6 and 7 each tackle questions 4, 5 and 6 for a different type of measure. First, each of these chapters discusses which measures have already been taken in Cape Town (question 4) and considers to what extent measure-specific conditions are met (question 5). This is concluded with which additional measures could be taken (question 6). A general conclusion, discussion and recommendation is given in chapter 8.

II. Theoretical Framework: Conditions for Effective Water management and Scarcity Measures

2.1 Introduction

This chapter forms a theoretical and conceptual base for this research and answers the first two sub questions: (1) what general conditions are required for effective water management and (2) which measures to tackle water scarcity are proposed in literature? First, in section 2.2, three discourses surrounding water management are discussed in relation to their influence on the formation of conditions for effective effective water management. This is followed by a summary of the general conditions necessary for the effective implementation of water management measures. Section 2.3 presents a list of measures that may address scarcity, as proposed in literature. Finally, an analytical framework which with the following sub-questions can be answered is presented in section 2.4.

Both the water management measures and the conditions for effective implementation of these measures were found through an extensive literature review. The measures proposed in section 2.3 were found mostly in Mukheibir & Ziervogel (2007) and Olivier & Xu (2018). Each measure was then independently researched in Scopus, which provided a few more measures. Not all measures were chosen, as some were uniquely relevant to certain industries and did not provide a more general solution. Conditions were, in some cases, given in articles focused on specific measures. They were further examined by using search-terms provided by the water management discourses introduced in section 2.2.1 and formulated in terms of the three water scarcity dimensions (economic, physical and institutional). Two interviews were also done to add to this literature review. First, an interview with Daphina Miesijan[2] (2019) - on equitability and international laws surrounding water management - presented the set of 'equitability' conditions. These conditions were then further based on the rules and regulations set by the CESCR and the WHO (as discussed in section 1.2). A second interview with Albert Jansen[3] (2019), tested how these conditions would work in practice by discussing the issues surrounding the implementation of rainwater tanks in eastern Africa. This interview led to the addition of the condition *'material'* as this had proven to be an issue with the installation of his rainwater tanks.

2.2 Water management discourses and conditions

The effectiveness of water management is dependent on whether certain physical, institutional, economic and equitability conditions can be met when implementing water scarcity measures. For instance, without sufficient funding for maintenance (an economic condition), a reservoir could form a threat to surrounding communities. These conditions are (implicitly) mentioned throughout literature on specific water management measures and on theory surrounding water management approaches in general. This section first looks at three water management discourses, followed by a summary of general conditions for effective water management set in literature, answering the first subquestion: "What general conditions are required for effective water management?".

[2] Assistant professor Human rights and the environment at the Netherlands Institute of Human Rights

[3] CEO at Water Innovation Consulting, inventor of 'Hemelswater'

2.2.1 Water management discourses

An article by Pierre Mukheibir (2010) identified three main discourses addressing the issue of water management: the (1) 'sustainable development' (SD); (2) Integrated Water Resource Management (IWRM) and (3) climate change adaptation (CCA) discourses. Mukheibir (2010) examined these three discourses, identifying their various approaches, focus and institutional scales. An example mentioned earlier is the definition of accessibility to water. Both the CCA and IWRM discourses focus more on physical accessibility while the SD discourse centres more around the affordability and equitable cost of water. According to Mukheibir, the SD discourse centres around small-scale social and economic aspects of water shortages, while both CCA and IWRM have focused on top-down solutions to water scarcity based in the natural sciences. IWRM also uses resource economics while CCA looks into climate change impacts on water systems (Mukheibir, 2010). While the discourses still influence water management research and policy, they have developed and somewhat integrated since. The differences identified in 2010 are not as explicit and the conditions within each discourse have blended significantly. An example is the use of IWRM in a UN Sustainable Development Goal (SDG) 6 - Clean Water and Sanitation - target: "implement integrated water resources management [IWRM] at all levels, including through transboundary cooperation [...]" (UN GA, 2015). Both the use of IWRM and the focus on a larger scale (transboundary) insinuate a shift towards the IWRM discourse.

Due to this development and partial assimilation, the discourses play a smaller role in present research and are therefore not further discussed in this research. The concepts used in each discourse were used as search terms when looking for literature in Scopus. Examples for the Sustainable Development discourse are 'sustainable water management', 'water efficiency and waste', 'water accessibility' and 'affordability'. IWRM search terms included 'integrated water resource management', 'water scarcity', and 'resource economics' and the climate change adaptation discourse included 'water infrastructure', 'urban adaptation', climate induced droughts' and 'governance capacity'. Additionally, the principles on which the IWRM and the SD discourses are based on (The Dublin-Rio principles and the SDGs[4] respectively) are also used in the reasoning behind some conditions.

2.2.2 The conditions for effective water management

Table 1 provides an overview of conditions for effective water management, based on the water management discourses as described in §2.2.1 and on the dimensions of water scarcity as described in §1.2.

[4] SDGS (or the Global goals for Sustainable Development) were formed within the UN General Assembly in part to succeed the Millenium Development Goals (UN GA, 2015). The Sustainable development discourse identified by Mukheibir predates the SDGs but is neverless rooted in the same ideologies first highlighted in the Brundtland report published in 1987 (Brundtland, 1987).

Table 1: General *conditions for effective implementation of water management measures*

Condition	Explanation
	Physical
Space	Some measures need space to be carried out. This condition comes down to there being enough space to logically and efficiently implement a measure.
Water availability	Measures focusing (in part) on increasing the supply of water, need sufficient water to enter the system. This condition states that without well timed, sufficient amounts of water the measure will be ineffective.
	Economic
Material	Physical measures (as opposed to policy measures) require certain materials to be carried out. It is important that these materials are accessible and affordable to the institutions responsible for building and maintaining the measure. (Jansen, 2019)
Human resources	To be able to implement measures, people with sufficient skills and knowledge about the measures *and* enough time to implement the measures are needed. This includes engineers, construction workers, people for operations and maintenance, and researchers. (Jacobi et al., 2014)
Financial capacity	Financial capacity is a general condition in that it needs to always be met. For measures taken by institutions the capacity needs to cover initial investments *and* operations and maintenance. (Garrido et al., 2014)
	Institutional
Facilitating regulations	Certain regulations by national or local government can (unintentionally) constrain the implementation of a measure. All levels of government need to be checked whether they do not impede the implementation or possibly even facilitate it. *(Jacobi et al., 2014)*
Operation	A clear division of responsibilities and reliable cooperation between different layers of government and other institutions is required for the successful implementation and maintenance of the measures. (Willaarts et al., 2014)
Stakeholder engagement	The involvement of stakeholders in the implementation of water management measures is key to their success. To involve relevant stakeholders, they to be notified about the process *and* about their possibilities to participate in the management management. (IWA, 2019; Empinotti et. al. 2014)
	Equitability
Accessibility	The right to accessible and safe water needs to be preserved. This indicator is based on the standards set by the WHO and the CESCR as explained in §3.2. A measure either increases or decreases the safety and accessibility of water to groups in need. (Misiedjan, 2019)

2.2.3 Categorization of water management conditions

The conditions presented in Table 1 can be categorized in three ways: (1) by their dimension (as defined in §1.2), (2) whether they are elemental or effectual and (3) the applicability.

Following the dimensions of water scarcity discussed in §1.2, conditions can be classified as either physical, economic or institutional. The physical conditions are space and water. 'Space' indicates whether there is a suitable area to implement the measure (e.g. where can rainwater tanks or desalination plants be installed). The condition 'water' determines whether there is enough water for a specific measure. This is only relevant when looking at supply oriented measures (e.g. increasing the height of a dam is of no use if there is no extra rainfall or inconsistent rainfall reduces the effectiveness of rainwater tanks). Economic conditions include financial capacities (for both initial investment and monitoring), human capacities (both in terms of time and skill) and material investments. Institutional conditions include 'regulations' (that don't impede a measure), 'stakeholder involvement' and 'responsibilities'. An issue that is intertwined with each of these dimensions is that of ethics. This is why a fourth dimension is added to the conditions. For a measure to be *effective* it needs to be equitable and not serve certain groups while ignoring or even negatively impacting others. The equitibilty dimension is based on the terms set by the universal right to water, and the principles set by the Dublin-Rio act and in the SDGs.

The second categorization is the distinction between elementary or effectual conditions. Elementary conditions are required for the measure to be possible in the first place, while effectual conditions ensure that these measures become and - in the long run- *stay* effective. Neither category is more or less important but while elementary conditions are needed, effectual conditions are (in practice) sometimes forgotten or neglected - leading to possibly inequitable or unsustainable solutions.

An example of this could be the construction of a new dam. While primary conditions are present (available land and sufficient initial financial capital and input from the surrounding catchment area), it is possible certain secondary conditions are not met. The measure can become ineffective when stakeholders (ie inhabitants of flooded area or water users downstream) are not properly involved or compensated, if the financial burden is carried by those that cannot afford it or are not the end users, or if appropriate agreements haven't been made on the monitoring of the reservoir.

In the case of surface reservoirs, Di Baldassarre et al. (2018) have hypothesized two long-term effects that counter the initial positive effect of a new (or larger) dam: (1) the reservoir effect and (2) a supply-demand cycle. The reservoir effect (shown in pink in Figure 4) suggests that the increase in water supply from reservoirs deepens the public dependency on reservoirs, in turn furthering the vulnerability to reservoir-related failures. The second positive, reinforcing feedback is that of the supply-demand cycle (brown in Figure 4). This idea alleges that an increase in supply will lead to an increase in demand[5], therefore cancelling out the effect of the augmentation measure (Di Baldassarre et al., 2018). While both effects have not been proven yet, one can imagine that proper regulation could dampen both by, for example, monitoring dependency and possibly limiting use of the dams. By only taking into account primary

[5] Based on the economic terms Jevons paradox or rebound effect (Di Baldassarre, 2018)

conditions, policymakers could find the dam to be feasible, but not persé effective in the long run. The difference between elemental and effectual conditions also explains why certain measures have been taken, when conditions important to that measure have not been met. If the conditions in table 1 are not met, measures can sometimes still be implemented – but they could be less effective or possible exacerbate water scarcity in the long run.

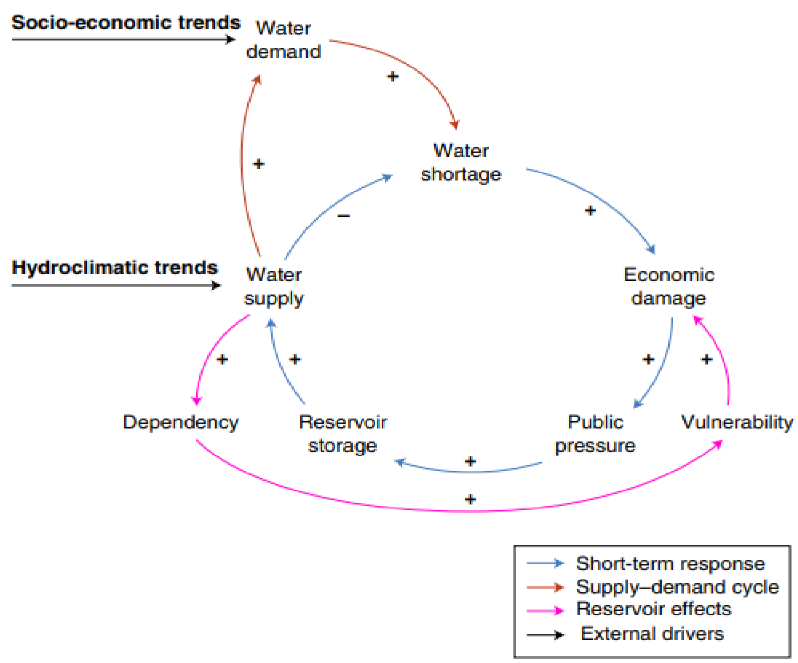

Figure 4: *Positive feedback displaying the reservoir effect and supply-demand cycle (Di Baldassarre et al., 2018).*

Finally, the third categorization is the relevance of a condition to various water scarcity measures. In some cases, conditions are only relevant to a few measures. For example, water availability only refers to buffering and alternative supply and not to water saving measures. Whether the right material is available is more relevant to hard measures (reducing leakages, new pumps to access an aquifer) than to soft measures (increasing water tariffs). In terms of relevance, there are three types of conditions:

1. Conditions that are somewhat **general**, including 'human resources', 'stakeholder involvement', 'financial capacity', 'cooperation' and 'accessibility'. These conditions can be met in a more general manner and are less dependent on specific measures and more on the institutions that implement them. While the findings for these conditions are somewhat constant, they can still be more relevant to certain measures than others.
2. Conditions that **measure specific**; they are only relevant to some measures and cannot be met on a general scale. The physical conditions 'water availability' and 'space' and the financial condition 'material' are not at all relevant to some measures and no general conclusion can be made whether they are met.

2.3 Water management measures

To be able to tackle water scarcity and the resulting water stress, water management is necessary to regulate either supply, demand or - ideally - both. This section will elaborate on the possible measures that have been proposed to either reduce water demand or increase the supply - answering subquestion 2: *"which measures to tackle water scarcity are proposed in literature*". These measures are presented in Table 2.

Table 2: Possible Measures to address Water Scarcity

Solutions	Explanation	Sources
	Buffering	
Surface reservoirs	Reservoirs are large scale, long term and public infrastructure.	Di Baldassarre et al., 2018; Muller, 2007; Dudley & Musgrave, 1988
Rainwater tanks	Household rainwater cistern or tanks are small private investments.	Muller, 2017; Assayed et al., 2013
Aquifers (MAR)	Groundwater aquifers provide large buffers. Through managed aquifer recharge can be governed sustainably.	Olivier & Xu, 2018
	Saving	
Reducing leakages	Leakages can be reduced through large scale infrastructural investments and by offering free plumbing.	Mukheibir & Ziervogel, 2007; Olivier & Xu, 2018; Tortajada et al., 2019
Pressure management	Reducing pressure on the water pipes cuts back use and leaks caused by overpressured taps.	Mukheibir & Ziervogel, 2007
Water rights Allocation	Prioritizing who or what gets water saves water for the most crucial needs (and reduces waste on secondary uses).	Muller, 2017; Olivier & Xu, 2018
Removing alien species	By removing non-native vegetation, more water reaches reservoirs and less is needed for parks and gardens.	Mukheibir & Ziervogel, 2007
Water restrictions	Water restrictions can be used as a crisis measure to reduce water use to the bare necessities when needed.	Booysen, Visser & Burger 2019; Tortajada et al., 2019
Regulating tariffs	Tariff incentives can be either positive (discounts for water efficiency) or negative (fines for overuse).	Mukheibir & Ziervogel, 2007; Tortajada et al., 2019
	Alternative-supply	
Reuse	Grey water reuse would alleviate pressures on a water scarce system.	Furlong et al., 2018; Mukheibir & Ziervogel, 2007
Desalination	The desalination of seawater provides a new source of freshwater for all uses.	Heck et al., 2018; Ben Brahim-Neji et al, 2019

Water management measures can be implemented on either private or public level. This depends on the involvement of public institutions and the scale at which a measure is implemented on. Measures can be taken at various (institutional) levels from singular households or companies to large scale measures implemented by the city, state or national governments. Many measures in table 2 can be implemented at a private (household, business, industrial) level, for instance installing a rainwater tank or water-saving appliances and can be scaled up for collective use (usually limited to a few participants). Larger measures, like reservoirs can also be built at personal or community level with minimal public involvement. This thesis will focus, however, on the side of measures that can be implemented directly by (or in coordination with) public institutions. When referring to a measure which is generally implemented on a private level, (e.g. rainwater tanks), the public policy regulating that measure is still relevant - and the measure will therefore be discussed from an institutional angle (as opposed to from a behavioural or private economic angle).

A second categorisation is whether a measure is a buffering, saving or alternative-supply approach. A buffering measure aims to stabilize water availability by holding water when it is in abundance (i.e. rainy seasons, wetter years) for when it is needed (i.e. droughts, dry periods). Buffers include aquifers, reservoirs, and rainwater tanks. The use and augmentation of naturally occurring buffers (i.e. aquifers) are included in this category. Water saving measures aim to abate the demand for water by reducing water loss, waste and use. These measures include infrastructural changes or new appliances, but can also refer to policies promoting the use of native species in gardening. The third category 'alternative-supply' refers to the use of previously deemed unsuitable water (i.e. waste or saltwater). This is done either by changing the water to make it suitable for all purposes - thereby increasing supply - or by only using it for specific purposes - decreasing demand (for 'suitable' water).

2.4 Analytical framework

As described in §1.2, accessible supply and aggregate demand are not only influenced by external hydroclimatic and socioeconomic trends, but also by the different types of water management measures. These measures will either reduce demand or increase the accessible supply, if certain conditions are met. For each measure, each condition proposed in Table 1 can be assessed as either present (+), partially present (*±)* or absent (-). An analysis will determine, for example, to what extent the condition 'financial capacity' is met for the measure 'water restrictions'. Whether a condition is present can be determined based on the rules set in Table 3.

Table 3: Analytical framework of conditions

	Physical Conditions
Space	Especially relevant to surface reservoirs, reuse and desalination: *+ There is enough regular rainfall to replenish the buffer* *± Buffer is replenished slowly or irregularly and cannot be used constantly* *- There is not enough water to replenish the buffer*
Water availability	Especially relevant to surface reservoirs, rainwater tanks, aquifers, reuse and desalination: *+ There is enough space to logically and efficiently implement measure* *± Space can be created to implement the measure* *- There is no logical place for the measure, making space is very difficult or costly*
	Economic Conditions
Material	Especially relevant to rainwater tanks, reuse, desalination and reducing leakages: *+ Material is readily available and affordable* *± Material is available but not always affordable* *- Material is inaccessible and unaffordable*
Human resources	*+ There is knowledge on the measure and enough skilled staff to correctly implement it* *± Knowledge and skills are present but not throughout the process or not enough* *- Either knowledge on the measure or the skills to implement it are missing*
Financial capacity	*+ There is sufficient financial capacity for initial investments and operations and maintenance.* *- There is no financial capacity for initial investments or for operations and maintenance*
	Institutional Conditions
Facilitating regulations	*+ Regulations do not constrain implementation, but facilitate it.* *± Regulations do not constrain the implementation* *- Regulations are unclear or even constrain the implementation of the measure*
Operation	*+ There is reliable cooperation and a clear division of responsibilities between institutions* *± Cooperation between institutions are inadequate OR responsibilities are not clearly divided* *- Both cooperation between institutions and division or responsibilities are inadequate*
Stakeholder engagement	*+ Relevant stakeholders are involved in the process of realizing the measures or sufficiently informed about possible involvement.* *± Some stakeholders are involved in the process but others are only informed about the outcomes* *- Many stakeholders are uninformed about the process or are ignored*
	Equitability Condition
Accessibility	*+ The accessibility of safe water is high and actively engaged* *± The accessibility of safe water is high but not consistent throughout the population* *- The accessibility of safe water is unintentionally low, negatively impacted or ignored*

As mentioned earlier, when presenting the conditions, not every condition is relevant to every measure. Whether this is the case is shown with a cross in Table 4 below.

Table 4: Relevance of conditions to each measure

	Measures	Physical conditions		Economic conditions			Institutional conditions			Equitability
		Space	Water availability	Material	Human resources	Financial capacity	Facilitating regulations	Operation	Stakeholder engagement	Accessibility
Buffering	Surface reservoirs	X	X		X	X	X	X	X	X
	Rainwater tanks		X	X	X	X	X	X	X	X
	Aquifers (MAR)	X	X		X	X	X	X	X	X
Saving	Reducing leakages			X	X	X	X	X	X	X
	Pressure management				X	X	X	X	X	X
	Water allocation				X	X	X	X	X	X
	Native vegetation				X	X	X	X	X	X
	Water restrictions				X	X	X	X	X	X
	Regulating tariffs				X	X	X	X	X	X
Alt. Use	Reuse		X	X	X	X	X	X	X	X
	Desalination	X	X	X	X	X	X	X	X	X

2.5 Conclusion

This chapter addressed both conditions for effective water management (answering sub-question 1) and water scarcity measures (sub-question 2). It also proposed an assessment framework in the form of identifying whether the indicators of conditions are present, partially present or absent. The following chapter will present a methodology for the remainder of this research, which will be used to assess whether the conditions suggested are present in the Western Cape.

III. Methodology

3.1 Introduction

The aim of this research is to answer the question: *To what extent are the governance, socio-economic and environmental conditions required for the implementation of measures to effectively reduce water shortages present in Cape Town?*

Sub-questions (1) 'What general conditions are required for effective water management?' and (2) 'Which measures to tackle water scarcity are proposed in literature?' have been answered in the previous chapters in Tables 1 and 2. These answers have resulted in the analytical framework proposed in Tables 3 and 4. This following chapter will elaborate on how this analytical framework will be applied in the case ofCape Town, answering subquestions: (3) *Which conditions are present in Cape Town?*; (4) *What measures have been taken in Cape Town?*; (5) *What measure specific conditions are present in Cape Town?* and; (6) *Which additional measures could be taken in Cape Town?*

Before elaborating on the application of the analytical framework, first an explanation of the (primary and secondary) data collection is presented in §3.2, followed by methods of data analysis in §3.3.

3.2 Sources and methods of data collection

To answer questions 3, 4 and 5, it is necessary to find which general and measure specific conditions are present and which measures have already been taken in Cape Town. This information can be found in publications by various governmental levels, NGOs and companies, but also through interviews with representatives of these three roles or with researchers. Figure 5 aims to create a clear view of all stakeholders involved in the water scarcity in Cape Town. There are three types of stakeholders: *key*, *primary* and *secondary* (DFID, 2003):

1. Key stakeholders have a large 'influence' in the process (i.e. national and local government)
2. Primary stakeholders are strongly affected by and thus have a large 'interest' in the process (ie. farmers and citizens)
3. Secondary stakeholders include other groups, institutions or individuals with an interest or influence that are not directly involved in the process (DFID, 2003)

A stakeholder is both 'key' and 'primary', if they are highly impacted by the process (*interest*) but also have a lot of power over it (*influence*). In Figure 5, a few stakeholders in the Cape Town water scarcity case are graded from 1 (low) to 5 (high) on their interest and influence as stakeholders. The stakeholders in grey are viewed as 'secondary'. This is a preliminary view on the stakeholders and their position within this case, but their own view of their interest and importance could differ.

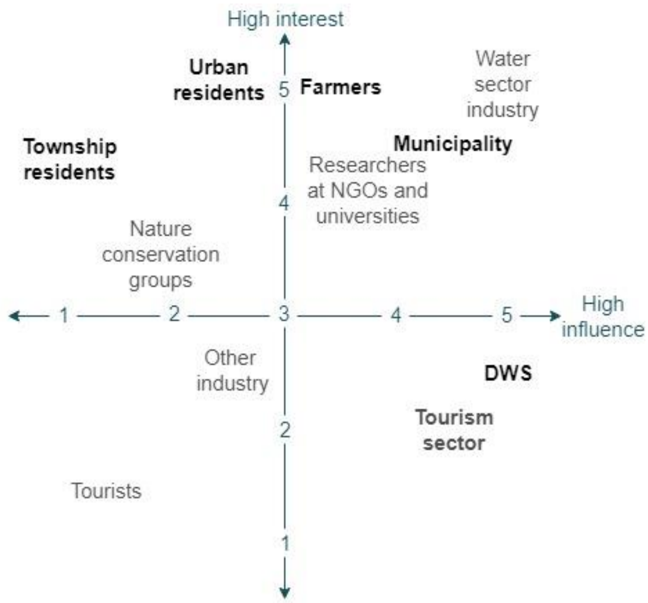

Figure 5: Cape Town's stakeholders

This figure illustrates the relevance of including stakeholders from (or representatives of) the municipality, the national Department of Water and Sanitation (DWS), farmers and the city's residents. Because of this, most effort has been put in contacting and including sources from these stakeholders in the data-collection process. To cover each of these stakeholder groups in the process of data collection, sources from each group were used. While interviews with government officials would have been beneficial, many did not have the time to meet. This was also the case for some researchers central to the reflection on how Cape Town dealt with the drought. To fill these gaps, second-hand data was used and new government publications were referenced. Table 5 provides an overview of each source, the topic this source provided or possible substitution if they were unavailable.

The interviews with respondents aimed to provide an understanding of the existing institutional structures in Cape Town, the roles of various parties and the relationships between the key institutions. The research used semi-structured interviews, as questions were adapted to a growing understanding of these structures, roles and relationships. This method also allowed for respondents to propose their own ideas on what the most important barriers or enablers for the different conditions and measures were, and in some cases come to an analysis themselves - as opposed to straightforward answers (Longhurst, 2010). The interviews could also venture into other research or possible respondents (if relevant) and most importantly, articles and publications by the municipality, Western cape government or DWS.

Table 5: Resources used to answer sub-questions 3, 4 and 5.

Source	Source type & Topic
Academic and private sector	
Boipelo Madonsela Researcher *Uni. of Cape Town*	**Interview (**12 March, 2019): About her article on CBA of Cape Town, Integrated Water Resource Management in the city, existing measures in and around Cape Town, about governance capacities and the general institutional conditions
Gina Ziervogel Researcher *Uni. of Cape Town*	**Articles**: No time for an interview, but substituted with her assessment of the Cape Town drought (Ziervogel, 2019), an article on climate adaptation and scarcity in South Africa (Ziervogel, 2018) and a brief history of water governance done together with Johan P. Enqvist (Enqvist & Ziervogel, 2019). These three recent articles provide an extensive summary of existing measures in Cape Town and the Western Cape and have provided information on whether conditions are present
Mike Muller Researcher *Wits University Johannesburg*	**Articles**: Was not able to interview, but emailed and discussed his articles on institutional failures leading to the drought (Muller, 2018a; Muller, 2017) and the role that experts and institutions take on in the process of water management (Muller, 2014; Muller, 2018b)
Megan McLaren Researcher *Uni. of Cape Town*	**Interview** (29 April, 2019) & **Articles:** DIscussed financial restrictions when implementing water management measures and research (done by her colleague Martine Visser) surrounding economic incentives, privacy vs naming and shaming and cooperation with municipality (Booysen et al., 2019; Brick, De Martino & Visser, 2017).
Amanda Gcanga Researcher *Stellenbosch University*	**Interview** (22 March, 2019): This interview provided a general understanding of the institutional and organisational structures (and weaknesses) surrounding the WCWSS
Maura Talbot Consultant *CES Environmental and Social Services*	**Interview** (28 March, 2019): Interview provided a perspective on governance of shared reservoirs, the development of small privatised measures, how the city deals with environmental and social impact of an intervention and about cooperation between rural water users and irrigation techniques.

Table 5 (continued): Resources used to answer sub-questions 3, 4 and 5.

Academic and private sector (continued)	
Various researchers and projects	**Articles**: The paper also references various articles that describe, assess and evaluate specific measures in Cape town, such as pressure management (WRP Engineering, 2002), tariff changes (Armitage, 2018), demand management (Jansen & Schulz, 2006), water management devices (Mahlanza, Ziervogel, & Scott, 2016), the use of groundwater (Olivier & Xu, 2018) and reallocation of water rights (Rawlins, 2019). Articles on the institutions surrounding water management in South Africa (and Cape Town specifically) were also used. This includes research about irrigation boards and water user associations (Faysse & Gumbo, 2004), the establishment of catchment management agencies (Meissner, Stuart-Hill & Nakhooda, 2017) and the process of decision making in urban adaptation (Taylor, 2017).
Government	
The City of Cape Town Municipality	**Publications:** Interviews with the municipality were not possible due to, among other reasons, strict regulations for municipality personnel. These were substituted by taking into account the municipal respondents quoted in Ziervogel's (2019) assessment of the drought. Additionally, the following municipal publications were used: publication explaining restrictions (CCT, 2019a), the new Cape Town Water strategy (CCT, 2019b), the various water outlooks during the drought (CCT DW&S, 2018a through e) and the city's Disaster Plan (CCT, 2017)
Western Cape Government Province	**Publications:** Publications by the Western Cape Government were used to form a socio-economic profile of the Cape and city specifically (WCG, 2017; WCG, 2018a)
Department of Water and Sanitation (DWS) (Part of) National ministry	**Publications**: A DWS report on water institutions in South Africa (DWS, 2013) and the strategy steering committee (officially under DWS) meeting minutes (DWS, n.d.) were referenced. Importantly, a reconciliation study and strategy done in cooperation with the CCT provided some history of measures and an extensive plan for future water demand management and augmentation measures (DWS, 2007)

Table 5 ***(continued):*** *Resources used to answer sub-questions 3, 4 and 5*

Government (continued)	
Catchment Management Agency (CMA)	While a CMA is supposed to be an integral part of the regional water management process in South Africa, the catchment surrounding Cape Town does not have a CMA. No publications could be used nor interviews done.
National legislation South African government	**Laws:** A few laws heavily influence water management policies in SOuth Africa and each was used to understand local regulations, the roles and responsibilities of institutions and how institutions should be organized; The Water Services Act (1997), the National Water Act (1998), the Municipal Structures Act (1998) and the Municipal Systems Act (2000) were all formed after the Constitution of the Republic of South Africa (1996). The older Water Act (1956) by the 'Union of South Africa' was also referenced.

3.3 Data analysis

3.3.1 Analysis of whether general conditions are present in Cape Town (Question 3)

The collected publications, articles and interview transcripts (respondents gave permission for the recording or notes were used) were uploaded into Nvivo. Nvivo is a programme that allows for analysis of qualitative data by organizing text into nodes (or topics) and subnodes. Statements made in interviews or publications can be coded under a specific node or subnode, grouping all statements (in all coded texts) about a topic together. The nodes used were 'measures' (e.g. reservoirs, tariffs or desalination) and 'general conditions' (e.g financial capacity or stakeholder engagement). The full list of nodes can be found in annex 1.

The statements under the node 'general conditions' in Nvivo are processed per condition type (ie. physical, institutional, economic and equitability). For each condition type the general characteristics are summarised, also for the conditions space and water availability - even though these are measure specific conditions. This is because some general statements were still made about (future) space and water availability in the Cape. The statements are then evaluated to provide an analysis on whether the general condition is generally present, partially present or absent (based on the analytical framework presented in Table 3).

3.3.2 Analysis method for taken measures & presence of measure-specific conditions (Ques. 4 & 5)

After the analysis of general conditions, the measure nodes were unpacked. While coding, a few nodes were added iteratively, as many sources mentioned these topics. For example, a node was created for all statements about 'awareness' (under the node 'saving measures'). Two subnodes ('public' and 'private') were also used to differentiate between the public and private use of aquifers.

The statements grouped under each measure were processed by first presenting what already exists in the Western Cape (a specific intervention or research into possibilities of a measure). Then based on the analytical framework in Table 3 and 4, statements describing measure-specific conditions were reviewed and summarised.

3.3.3 Analysis method for which additional measures could be taken in Cape Town (Question 6)

The final step in this research is to propose measures that Cape Town could still implement to minimise water scarcity in the future, answering the last research question. This was done by comparing possible measures (question 2) and their necessary conditions (q. 1) with measures already taken (q. 4) and the present conditions (q. 3 and 5).

3.4 Conclusion

The aim of this research is to find to what extent the physical, institutional, economic and equitability conditions required for the implementation of measures to effectively reduce water shortages are present in Cape Town. This was done by analysing government and project documents, academic papers and interviews with experts. The approach of selecting these sources and experts was based on a brief analysis of the stakeholder landscape in the WCWSS. The analysis of these resources was done using the coding programme Nvivo. Statements were coded and grouped to a specific 'condition' or 'measure' node. Chapter 4 will present the analysis done based on the statements coded to a general condition. Chapters 5, 6 and 7 will present the analysis based on the 'measure' nodes, per measure type (ie, buffer, saving or alternative-supply). These chapters will also conclude with a synthesis of each type of measure, proposing which additional measures are possible based on whether their conditions are present.

IV. The history and characteristics of Water Management in Cape Town

4.1 Introduction

This chapter will focus on answering research question 3 'which conditions are present in Cape Town' by first providing a brief history of the settlement in Cape Town and a history of Cape Town's water management and management during the drought. The following sections will describe characteristics of the city and its water management - each based on a set of conditions - namely the physical (section 4.3), institutional (4.4), economic (4.5) and equitability (4.6) characteristics. These characteristics represent the scope of this research on water management. Each section is concluded with an analysis of whether the physical, institutional, economic and equitability conditions are present. This is synthesized in 4.7.

4.2 Settlement and a history of water management in Cape Town

Before going into depth on the existing water management conditions and measures in Cape Town, this section will briefly explain the history of settlers and settlements of the Western Cape. The continuous power struggles and institutional transitions that took place, shaped the somewhat convoluted structures of present-day water management and are therefore important to understand.

The Cape was first occupied by KhoiSan groups, the nomadic San and the Khoikhoi. In 1652 the Dutch East India Company (VOC) decided to build a permanent settlement on the Cape, to protect the passing trading ships en route to Asia (Enqvist & Ziervogel, 2019). In order to provide for these ships, the VOC gave certain officials pieces of land to farm in 1657. These new farmers, later named Boers or Afrikaners, became autonomous from the Netherlands and started independent settlements. Many San and Khoikhoi were driven away by the Boers, as their nomadic lifestyle could not coexist with the farms. The farms used slaves brought in from other parts of Africa (the first coming in from Angola and Ghana) and from Asia (present day India and Indonesia). The British first occupied the Cape between 1795 and 1802, then giving it back to the Dutch. They returned in 1806, and the Cape colony became an official British colony in 1814. The Dutch language was banned and most Boers trekked further inland to escape British authority. In 1910 the 'union of South Africa' made the country a self-governing dominion within the British Empire. Enforcing the existing segregation between various ethnic groups in the country, only Afrikaners and British could run or vote for elections and Dutch[6] and English became the official languages of a united South Africa (SA History, 2016). This segregation was further legitimised through the policies of Apartheid, first introduced in 1948. Apartheid encompassed all laws that enforced the separate development of different racial groups. This included the registration of an individual's racial group, prohibition of mixed marriages, the physical removal and displacement of certain groups and later the formation of 'homelands' for each (non-white) racial group in which they could live (SA History, 2016). After continued criticism from the international community, including other Commonwealth countries, about Apartheid laws, South Africa left the Commonwealth and became an independent republic in 1961. Organised resistance in the form of

[6] Afrikaans, the language spoken by the Boers, was still viewed as a Dutch dialect and only recognized as one of the official languages of South Africa in later constitutions (1961 and 1983)

the Pan Africanist Congress (PAC) and the African National Congress (ANC) in combination with continued protests, riots and (international trade-) boycotts, brought about the end of apartheid when in 1993 the first democratic elections were declared. The newly elected government, led by Nelson Mandela and the ANC, presented a new South African Constitution in 1996.

Throughout these power changes, the population of the Cape continued to grow, and water management was necessary to keep water supplies clean and sufficient. VOC executives established the first laws protecting the rivers in the region from pollution by Dutch settlers. The first reservoir was built on Table Mountain under the British colonial rule in the 1840s. This was followed by the construction of other small dams in the Table Mountain range throughout the 19th century. Due to a population surge in the second half of the 20th century, larger water and sanitation infrastructure was needed. The Steenbras dam (1921), Voëlvlei dam (1952), Wemmershoek dam (1957), Upper Steenbras dam (1977) and the Theewaterskloof dam (1980) were built to continually augment the regular water supply to the Cape (Brown & Magoba, 2009). The more recent completion of the Berg River Dam in 2009 added to these five major dams.

During the apartheid regime, the City of Cape Town was divided into 25 self-governing municipalities, each responsible for the water management of their own district. Non-whites were forcibly removed from the inner city and moved to informal settlements on the Cape Flats causing a significant difference in tax base of each municipality. This resulted in a working system in some (white) municipalities, while infrastructure failed inhabitants in others. A drought in 1990 shed light on this extreme injustice as drought response failed to reach poorer settlements (Vogel & Olivier, 2018). This injustice could also be seen in the statistics on water accessibility. In 1994, 20% of the country had no access to piped water, but the range between municipalities was immense: from 1% with no access to 98% (Cole et al., 2018). After the installment of the democratic government, the new constitution (1996) established a universal right to water and sanitation for all. In 1997 the Water Services Act (WSA) provided specific guidelines and a regulatory framework and the 1998 National Water Act (NWA) continued to push for equitable services but also for water demand management. Merges of the 25 small municipalities in 1997 and 2000, ultimately formed the municipality City of Cape Town (CCT), redistributing the financial capacity for water infrastructure across the different neighbourhoods (Mills et al., 2019).

Around this period, a shift in focus on supply to demand management occurred in the operation of the water in South Africa. Especially the 1998 NWA moved away from increasing supply by building more reservoirs and focused more on demand management through the repair of leakages, price changes and awareness campaigns. As a result, water use declined between 2000 and 2005, after decades of relatively constant increase. In 2001, the Free Basic Water policy was passed with the aim to provide every South African with water - also if they could not afford it. This national mandate was implemented at municipal level, leaving each municipality to decide which groups ‘could not afford’ service costs and how much water was to be allocated (although 6000 liters per household was recommended in the act) (DWS, 2002).

The NWA also required the formation of a National Water Resource Strategy which would provide a framework for the protection and exploitation of water resources at catchment level, within Water Management Areas (WMAs). In 1999, 19 WMAs were identified across South Africa, based on catchment areas of major South African rivers. Cape Town was part of the Berg WMA. In 2004, these smaller WMAs were merged to form nine larger management areas in the National Water Resource Strategy. Berg WMA merged with Olifants Doorn to become Berg-Olifants WMA. As these boundaries are based on a physical characteristic (drainage regions), they do not correspond to legislative boundaries.

In 2005 a reconciliation study was initiated for the Western Cape Water Supply System (WCWSS) (Gcanga, 2019). The system, covering the previous Berg WMA (see Figure 6 below), supplies to various urban settlements and agricultural users. The system was under pressure due to a constant population growth, and the national Department of Water and Sanitation (DWS) and the City of Cape Town (CCT) set out to understand the trends in water use and plan for future augmentation schemes. A reconciliation strategy was published in 2007 identifying the possible future requirements, possibilities for the increase in water use efficiency and a few augmentation measures that would reconcile the future demand with the supply.

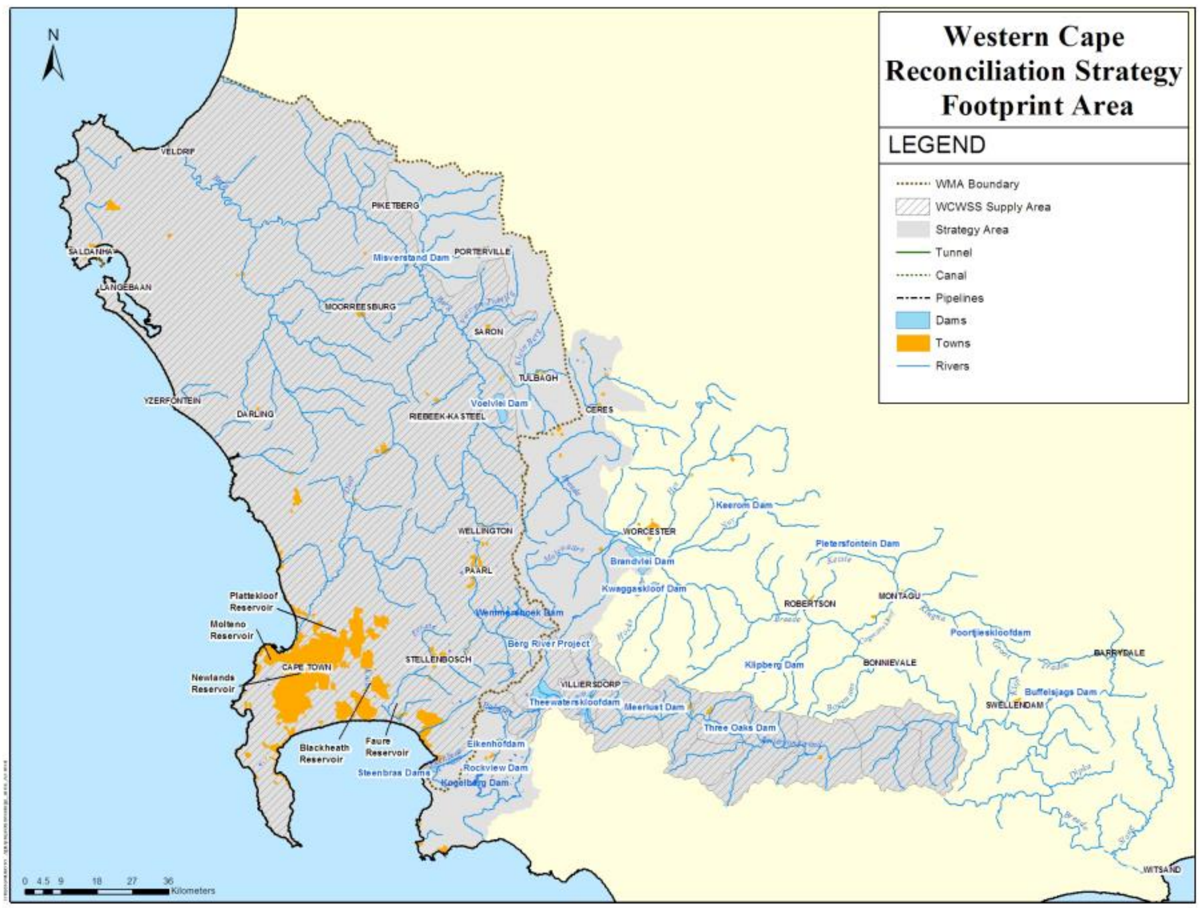

Figure 6: The Western Cape Water Supply System (taken from DWS, 2007, p. 3)

Finally, a water shortage caused by record low rainfall in the Cape occured between 2015 and 2018. The graphs in Figure 7, below, show the continued decline of water levels in the WCWSS dams, urban and agricultural water use and rainfall in this period. The water scarcity during these years highlighted limitations to the management of water in the WCWSS, and stressed interdependence between various parties responsible for the continued management of sources, infrastructure and use. The history of water management in Cape Town as described above establishes the background and foundation of the research problem. Further parts of the analysis will build on this history.

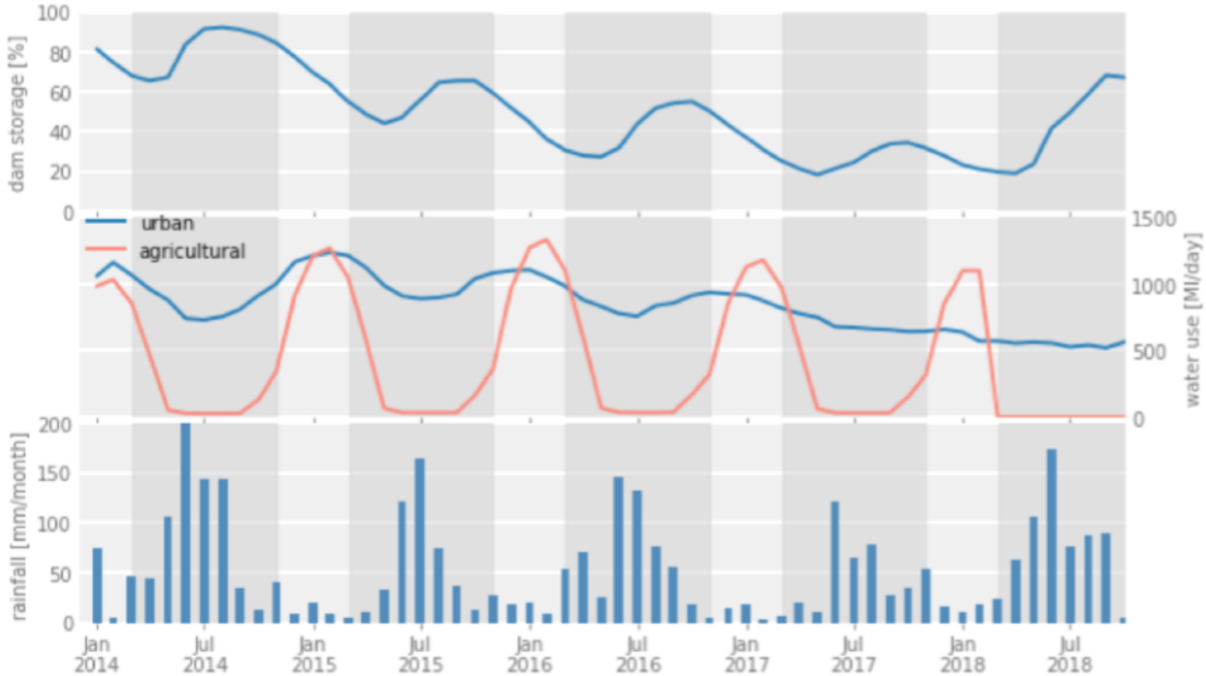

Figure 7: "Dam level, urban and agricultural use and rainfall in the Western Cape" (Ziervogel, 2019)

4.3 Physical characteristics and conditions

4.3.1 Physical Characteristics

The Western Cape - and Cape Town specifically - can be classified as a 'Mediterreanean-type' climate with dry summers and wet winters (Enqvist & Ziervogel, 2019)). Summer rainfall increases towards the east while aridity increases towards the northern parts of the province. The climate in Western Cape is strongly influenced by the Cape Fold belt (see Figure 8, below), a mountain range separating the arid and semi-arid 'Succulent Karoo Biome' and the coastal sand plains (Enqvist & Ziervogel, 2019). The Fynbos Biome can be found on the belt and adjacent coastal sand plains. Both biomes have high 'irreplaceability indexes' in terms of both flora and fauna and are therefore important to protect from the impacts of climate change and land use change (Driver et al., 2005). Impacts of climate change on the Western Cape are anticipated to include higher average temperatures, fewer cold days, an increased fire risk and possibility for flooding and storm surges along the coast, a decrease in average rainfall and finally, a heightening in the severity of droughts (Western Cape government; WCG, 2014).

Land use change is primarily driven by the expansion of agricultural land, urbanisation and invasive species (Rouget et al., 2003). These three drivers could, within 20 years, account for between 14% and 30% more land use change - mostly along the coast (WCG, 2014). The changing climate also influences these land-use change drivers as lower water availability in the future limits rain-fed agriculture and further urbanization, while alien species react differently to the changes in climate than local species.

Figure 8: The Cape Fold Belt is the L-shaped set of parallel mountain ranges in the Western Cape (Google Mymaps, 2019)

4.3.2 Presence of Physical Conditions: Water availability and Space

As indicated in §2.2.3, both physical conditions water availability and space are measure specific. Accordingly, no general conclusion can be made whether these conditions are present or not. Some general observations can be made, however as these physical characteristics strongly define the future possibilities for some water management measures within the WCWSS. Firstly, water is not supplied year-round and needs to be saved in the winter rainy season for the dry summers. This means that buffers need to be large enough to bridge months of water use without new input. Additionally, the likelihood of drought occurring has tripled due to climate change, and the water scarcity of the past few years could occur much more regularly (Otto et al, 2018). The availability of water supply is not constant, but will also become increasingly scarce and irregular, impacting all supply focused measures - and will therefore be further discussed for measures in chapters 5 and 7.

As for the condition space, the Karoo and Fynbos biomes surrounding the city are not only important to protect from land-use change, they also limit some forms of water management. New reservoirs are difficult to plan as their proximity to the biomes would limit the resources that flow to these ecosystems and additionally cannot be planned on these preserved areas. The physical conditions will be discussed further in chapter 5 (for reservoirs and aquifers) and 7 (for desalination plants).

4.4 Institutional characteristics and conditions

4.4.1 Institutional characteristics

The present institutional system surrounding water management in South Africa had not yet been formed when Cape Town was developing its water supply system. The complicated history of political change has also developed a mix of responsibilities and ownership concerning water management throughout the country. The first Dutch settlements, British colonial rule, the apartheid regime and the present-day democratic governments have each left a mark on the management of the Western Cape Water Supply System.

The Water Services Act (WSA) as presented in 1997 - and the earlier development of water management regionally - defines the responsibilities of various parties involved in water management in South Africa. The most important being the national Department of Water and Sanitation (and their regional offices), water boards, Water User Associations (and Irrigation Boards) and the Catchment Management Agencies. The responsibilities of different municipalities are defined in the WSA, Municipal Structures Act (1998) and Municipal Systems Act (2000). These institutions and their responsibilities are discussed below.

The Department of Water and Sanitation (DWS) and water boards

The Department of Water and Sanitation (DWS[7]) is part of the Ministry of Human Settlement, Water and Sanitation and is the main institutional body regulating management of water. It is primarily responsible for the equitable and sustainable use, protection, development, conservation, management and control of South Africa's water resources. It has overriding responsibility in terms of the provision of water services by municipalities and operates most water infrastructure. Some responsibilities have officially been delegated to regional institutions (CMAs and WUAs discussed below). The DWS is part of the central, African National Congress (ANC)-ledgovernment and is located in Pretoria (Gauteng province), but has a provincial department in Western Cape.

At catchment level, water boards (bodies of DWS) can be responsible for bulk water. In the case of Cape Town, which is part of the Western Cape Water Supply System, the DWS is primarily responsible. The DWS is also required to formulate and enforce restrictions for water users (when necessary) and for ensuring users receive the water allocated to them through water rights (Gcanga, 2019). These restrictions are determined in consultation with the Western Cape Order Supply Consulting Forum. This forum consists of municipal water managers and representatives from Irrigation Boards, Water User Associations and the department of agriculture. Advice from the forum is usually followed, but the DWS can make decisions without their approval (Gcanga, 2019).

Catchment Management Agencies (CMAs) and Water Management Areas (WMAs)

As mentioned in §4.2, 19 water management areas (WMAs) were identified in 1999, based on catchment areas of major South African rivers. In 2004, these were merged to form nine new WMAs, shown in Figure

[7] The DWS was until 2009, the Department of Water Affairs and Forestry (DWAF). In policy predating this institutional change the department is therefore referred to as DWAF. To avoid confusion, this paper only refers to the DWS - even when discussing articles or policy from before 2009.

9 below. These changes were made to "facilitate effective management of water resources" (DWS, 2004 p. E2). As the boundaries of these WMAs are based on a physical characteristic (drainage regions), they do not correspond to legislative boundaries. Cape Town (and the northern part of Western Cape) is situated in the Berg-Olifants WMA. Breede-Gouritz covers most of the rest of the province, and small parts of the northeast are within the Orange and MzImvubu-Tsitsikamma WMAs.

Each WMA should have its own Catchment Management Agency (CMA), with the purpose to delegate some responsibilities of water resource management from the DWS to a regional level. The CMA develops a catchment management strategy, advises on - and promotes community involvement in - the protection, development, management and control of resources within the WMA. Additionally the CMA is responsible for the coordination between various water management institutions. Presently, only two CMAs have actually been established in South Africa: the Breede-Gouritz (previously the Breede-Overberg CMA) and the Inkomati-Usuthu (previously the Inkomati CMA) (Meissner, Stuart-Hill & Nakhoba, 2017). The Berg-Olifants WMA does not have an operational CMA and almost all of the WCWSS is therefore located in an area without a management agency.

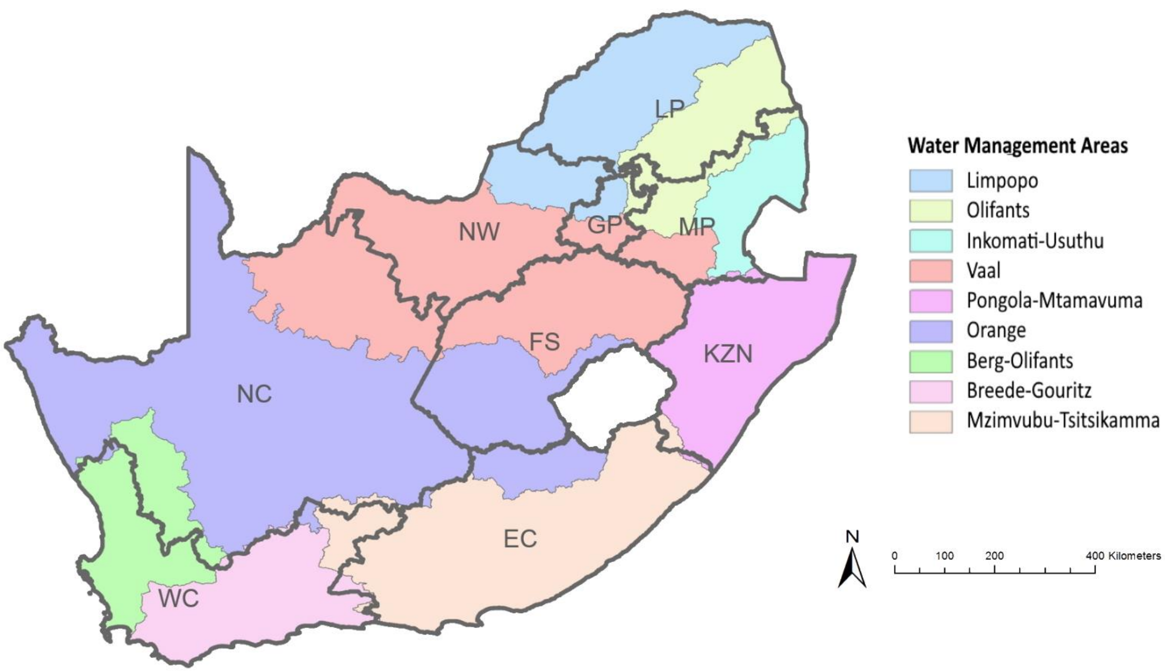

Figure 9: The nine Water Management Areas (adapted from Stats SA, 2017)

Water User Associations and Irrigation Boards

Historically, an Irrigation Board (IB) managed small scale collective water resources of mostly white, large scale, commercial farmers (Faysse & Gumbo, 2004). The DWS would release water to these IBs based on their collective water rights, and the board would then redistribute to their members. Farmers also built and managed their own dams as a collective (through their IB). The National Water Act (1998) called for the transition from IBs - which were operating based on the 1956 Water Act (Faysse & Gumbo, 2004) - to Water User Associations (WUA). WUAs would play the same role as IBs, as they focus on the localised management of water resources by individual water users. There are a few key differences, however, in how a WUA is managed as opposed to an IB.

Firstly, a WUA takes into account all people within a jurisdictional area, including those without water rights. This is meant to encourage the inclusion of Historically Disadvantaged Individuals (HDIs)[8] in decision making processes. Without enough HDIs on the board, an IB cannot transition to a WUA. A WUA is also a more political organisation, and farmers that are currently with an IB do not trust the possible influence that the national government will have when they transition into a WUA. Another example and result of distrust from IB-member towards the national government can be seen in the inclusion of emerging farmers to WUA's. The national government is attempting to allocate land and water rights to HDIs. If an IB transitions to a WUA, they would have to include these emerging farmers. IB members seem to be worried that these emerging farmers will infringe on their shared water rights, resulting in a weaker position of their farms (Gcanga, 2019). Some of the respondents also mention that even when an IB wants to transition, finding HDIs with land and willing to farm - so that they can reach the quota of HDIs needed for a WUA - is difficult (Talbot, 2019; Gcanga, 2019; Faysse & Gumbo, 2004). Finally, discrimination on the basis of race and gender is also identified as a barrier for including an HDI on a previously white, male board (Talbot, 2019; Gcanga, 2019).

Once a WUA has been formed, it can take up a few other responsibilities - aside from water allocation and localised infrastructural management. These responsibilities include possible catchment management functions, the assistance of historically disadvantaged farmers and supporting smallholders through joint investments or purchases (NWA, 1998).

The City of Cape Town municipality

The Water Services Act (WSA, 1997) identifies two roles that the city of Cape Town (CCT) has been assigned in various municipal acts: the Water Services Authority and the Water Services Provider. These two roles mean that the municipality is responsible for the access to water supply and sanitation services (ie. authority) and treats raw water and supplies potable water directly to consumers (ie. provider). The CCT is, in other words, responsible for delivery to the end users in Cape Town (CCT, n.d.a).

Before the drought, these tasks were the responsibility of the *municipal* Department of water and sanitation (completely independent from the national DWS discussed above). The various branches within this department tackled (among other tasks) stormwater flow, river management, water demand management, wastewater treatment, and reticulation (CCT, 2018). During the drought some roles were expanded, put on hold or moved to another department. When the DWS implements restrictions on use, the city is required to attempt to meet these limitations through demand management strategies (e.g. awareness campaigns, tariff changes, pressure management) (Ziervogel, 2019).

[8] An HDI was defined in the Preferential Policy Framework (2000) as a South African citizen that was either disenfranchised by Apartheid (a person of colour), is female or has a disability.

As the CCT historically already owned three dams in the WCWSS, they are also involved in the management and operation of these dams - although the DWS is still ultimately responsible for releases to the different users (Rawlins, 2019). In the 2007 reconciliation strategy (DWS, 2007), the focus of the CCT is placed mostly on reducing demand through water saving measures. The municipality was also assigned the further development of desalination and the use of aquifers, due to existing knowledge within the municipality on these two augmentation measures (Gcanga, 2019). This role is unique to Cape Town; in other metropolitan municipalities water boards take on these responsibilities.

4.4.2 Presence of Institutional Conditions for effective water management

The institutional conditions for effective water management (suggested in chapter 2) are cooperation, facilitating regulations and stakeholder engagement. Whether each condition is met, is discussed below.

Cooperation

Interviews and reports have provided a few key barriers in the present operations of the WCWSS. These include (1) political tensions between institutions, (2) uncertain division of responsibilities, (3) unclear communication between institutions, (4) the difficult transition from Irrigation Boards to Water User Associations and (5) power shifts within the municipality.

Firstly, political tensions between the CCT and the DWS were identified as a barrier for their collaboration. Cooperation between the national DWS and the CCT is key to effective water management of the WCWSS. The CCT is dependent on the DWS releases from reservoirs for their water supply and the DWS is dependent on the city's cutbacks in water use for the system to continue supplying. The reconciliation strategy published the various responsibilities of either party in further reconciliation of supply and demand for the future, but during the drought each institution blamed the other for mismanagement and the resulting drought in a very public "blame game"[9]. The most mentioned issue between the two main institutions, the DWS and the CCT, is the political tensions. Politics plays a large role in both the DWS and the CCT as both have two executive structures: the political council and the civil officials. The council has to approve plans written by city planners and engineers. The CCT and the Western Cape province are managed by the Democratic Alliance (DA) while the DWS, as part of the national government, is run by the African National Congress (ANC). These two parties are political opponents and were quick to blame each other during the crisis, but also did not work well together before 2015 (Gcanga, 2019). An example of this is the steering committee appointed to oversee the various studies and projects proposed in the 2007 reconciliation strategy. This committee consisted of representatives from both the DWS and the CCT and did not meet in the early phase of the drought according to municipal officials (Ziervogel, 2019). There are multiple gaps in their published minutes of meeting in earlier years as well, however (see DWS, n.d.). This has been attributed to both a frustrated cooperation within the committee and funding issues (which will be further discussed in 4.5.2) (Gcanga, 2019, Ziervogel 2019).

Secondly, the uncertain division of responsibilities was repeatedly mentioned as a barrier during the drought. Despite the CCT not having legal ownership of bulk water, it has taken on a lot of responsibility in the management of the WCWSS. In 2017 the city announced that they would solve the crisis instead of waiting for the DWS to act (Ziervogel, 2018). This has been viewed as an example of the "competition" between the ANC and the DA (Ziervogel 2019, p. 14)- but it also highlights the fact that the ownership of water management is unclear.

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[9] For example, see: (IOL, 2018)

A third barrier is the poor communication between institutions, within institutions and with the public. Various institutions interpreted data from the system (e.g. on water levels) differently and proceeded to communicate this data directly to the public, instead of cross-checking their conclusions (Booysen et al, 2019). This in part contributed to mistrust from water users towards the government. Poor communication on reasoning behind certain policy choices also led to apprehension between the DWS and the CCT. An example of this is the uncertainty within the municipality whether the DWS would implement and enforce water restrictions for agricultural use in 2018, as they had failed to do so in 2017. Aside from the communication between the institutions, collaboration between political representatives and technical specialists and other officials was strained (Ziervogel, 2019).

These first three barriers all centre around effective cooperation between different parties, understanding which information should be made public, when and how to communicate and how to deal with various interests. While not all these issues could be tackled by a Catchment Management Agency - especially the competing political interests of the DA and ANC are difficult to tackle- the Water Services Act introduced the CMAs as those responsible for the cooperation between all water management institutions at catchment level. The Berg Water Management Area (now the Berg-Olifants WMA) has never had a CMA, meaning the WCWSS does not have an institution responsible for the cooperation between these different parties. A CMA would make working across catchment boundaries, to transfer water from another catchment into the WCWSS, easier as well. Both the DWS and the CCT have been accused of not actively looking beyond their own institution for solutions and a CMA could support this (Ziervogel, 2019; Talbot, 2019). The DWS could also delegate other tasks to the CMA, lightening their load in this catchment and decentralizing some decisions. This could lead to more cooperation with local water users and a better understanding of their needs when forming policy (Talbot, 2019).

The fourth barrier that was mentioned frequently was that of the transition from Irrigation Boards to Water User Associations. As discussed in section 4.4, the National Water Act required all IBs to become WUAs. This still has not completely occurred, with the Western Cape having the highest percentage of IBs left: in 2013 there were still 113 IBs opposed to 38 WUAs (DWS, 2013). Government policy on the other hand, hardly mentions the existence of IBs, let alone properly assesses their role in water management. While the 2007 reconciliation strategy discusses ‘cooperative governance’ and the exchange of information with IBs as well as WUAs, Irrigation Boards are not required to follow the reconciliation strategy or to form a water management plan for themselves (while WUAs are). Additionally, various other policy ideas (to reduce water use among farmers and to redistribute water rights to meet the needs of new farmers and the ecological needs of the catchment) have reduced farmer’s already minimal trust in the national government (Talbot, 2019). This means that they have become less willing to transition to WUAs.

Finally, a few organisational changes were made within the municipality during the drought. A shift was made from the inward focus on water demand management within the city, to attempting to proactively engage in the management of the WCWSS as a whole. This was done in an attempt to ensure that restrictions in the agricultural sector were enforced, and to organize the transfer of water from reservoir meant for agriculture. In May, 2017, the CCT’s drought response moved from the municipal water department to the Chief Resilience Officer, but this was reversed later the same year (Ziervogel, 2019). This frustrated certain municipal officials as existing collaborations were disrupted and technical engineers who knew a lot about the system were suddenly not part of the process anymore. The move, ordered by the mayor, was attributed to the poor communication between officials and the mayor - but it also further exacerbated this relationship (Ziervogel, 2019).

Around this time the mayor also took on a more public and hands on approach to the crisis, organising daily meetings with NGOs, companies and city officials. Both the move and daily meetings were viewed by some as costly, ineffective and a distraction from other problems within city management (Ziervogel, 2019). It did lead to a broader approach to the issue, taking into account not only technical solutions but also how residents and businesses view water, the impact on the economy and ecology. Taking in external parties to brainstorm on possible tactics also resulted in the use of the word “day zero” in the city’s Critical Water Shortages Disaster Plan, published in October 2017 (CCT, 2017). The impact of the use of this word is disputed from panic inducing to giving the water shortage proper publicity and weight, but it definitely made an impact.

The above discussed five barriers indicate that both the cooperation between institutions and the division of responsibilities were unclear. While this is to some extent true, there are also key strengths to the WCWSS. The 2007 reconciliation strategy had proposed quite a few tasks to both the DWS and CCT, and while they disputed these later, this meant that the CCT had already done research into various saving and augmenting options when the drought hit. One respondent states that while they did not cooperate well, they each did what they had to do (Gcanga, 2019). The CCT council set up a Water Resilience Task Team and a Day Zero Disaster Committee and a Water Resilience Plan was developed in 2017, increasing interaction with public and civil society. The earlier mentioned Critical Water Shortage Disaster Plan did a lot for increasing the awareness on the extent of the possible impact of the drought.
Additionally, the regional DWS officials played a significant role in transferring 10 million cubic metres of water from the Eikenhof dam (a privately owned dam, previously reserved for the associations’ agricultural purposes) to the Steenbras Upper dam for Cape Town (Ziervogel, 2019). Their scientific knowledge and strong relationship with the farmers made this possible.

Despite these strengths (and improvements during the drought) reliable cooperation between the institutions is still a significant condition that has not been fully met in Cape Town. The division of responsibilities is somewhat clearer, but also disputed at some points.

Facilitating regulations

Regulations that are relevant to water management in South Africa are organized at different levels of government but are generally based on the National Water Act (1998) and the Water Services Act (1997). This condition is different for every measure though, so will be discussed more extensively per measure in the following chapters. There are two general observations, however, which both relate to the inflexibility of the government to react to water scarcity.

Firstly, one interviewee raised the unwillingness to invest in water trading schemes (Talbot, 2019). At the moment, legislation does not allow for trading of water rights. According to this respondent, the DWS are resistant to trading of rights because they think it would benefit the rich disproportionately. Trading could encourage users to save, and provide an opportunity for smaller users to earn by selling rights (Talbot, 2019). Further research would have to be done into how a trading scheme could occur at household, or business level in Cape Town - to be able to assess whether this is true.

A more important limitation that was mentioned repeatedly was the limited capability of the city and DWS to adapt legislation during the drought. There are various laws in place to protect the environment

(Environmental Impact Assessments necessary), waterways and water sources and to manage funds. These laws also prevented quick adaptable governance during the crisis, for instance, redirecting funds was difficult and slow (as mentioned above). This was due to restrictions and controls set in the Public Financial Management Act (1999) and the Municipal Financial Manag**em**ent Act (2002). These acts slowed down the process of redistributing funds within the municipality - but also made sure that redistribution did not occur unnecessarily. Additionally, when residents wanted to invest in alternative supply of water during the drought (such as their own borehole, use of rainwater or reusing of wastewater), legislation was unclear on which authorisations were required (Ziervogel). The CCT developed the Alternative Water Installation Guidelines to make the process more efficient for residents. This policy will need to be further developed for long term development of alternative-supply, also for non-critical situations.

In general, the limitations of existing legislation were often related to having to deal with emergency situations. meaning that they were not being flexible enough to accomodate alternatives quickly. This is however not relevant to long term water saving or augmenting measures, and it can therefore be assumed that broadly national and local regulations do not constrain the implementation of water measures.

Stakeholder engagement

The importance of stakeholder engagement varies strongly across each type of water management measure. Broadly, poor engagement of stakeholders is viewed as a weak point in the management of the WCWSS and of the drought in Cape Town.

Firstly, communication with the public on why measures were taken - especially during the drought- was poor. People did not know exactly why water restrictions were put in place or why tariffs changed during the drought (Ziervogel, 2019). This resulted in frustration, the belief that the CCT and the DWS had done nothing in the years preceding the drought, and that they now had to pay for the mismanagement of the WCWSS (Ziervogel, 2019; Kaiser & Macleod, 2018; Visser & Brühl, 2018). The public did not know about the augmentation schemes set up by DWS, the interbasin transfers that successfully delayed day zero, about the demand management research and measures taken by the city, or the continued research into alternative water sources (such as desalination and reuse; Lang, 2018). Citizens were under-represented in meetings and committees tackling the drought (Vogel & Olivier, 2018).

The earlier mentioned ineffective coordination between the city, province and national government led to different information reaching the public. This reduced the trust in this information (Booysen et al., 2019), with some citizens thinking day zero was a conspiracy. Communication did tend to improve throughout 2017, as it became central to the City's Disaster Plan (2017) and the mayor involved outside companies to help with communicating the CCT's and DWS's efforts in the drought (Ziervogel, 2019). Even at this point however, communication occurred mostly online and in English only - meaning it was still inaccessible to some Cape Town residents (Lang, 2018; Ziervogel, 2019). The lack of trust in the government stems in part from the historical "intentional neglect of coloured and black Capetonians' needs" and the failure to effectively tackle these injustices presently (Engvist & Ziervogel, 2019, p. 12). Processes need to be set up to build this trust in the long run.

Aside from effectively and clearly communicating with inhabitants, the DWS and CCT should also be working together with them and other stakeholders when looking for new solutions. This was hardly done and getting involved in the process of developing and implementing new measures is not made to be easy. It has been observed that a strong community (of inhabitants, businesses or NGOs) is necessary to make sure socio-economic impact assessments are taken seriously (and not just seen as a small part of the Environmental Impact Assessment) when implementing new measures (Talbot, 2019). This means that communities that have a weaker voice when it comes to these projects can be overlooked and tend to be more negatively affected by either new investments or by the lack of monitoring and maintenance.

Ensuring inclusive water management that does not just take into account various governmental institutions, but all stakeholders, is identified by various sources as Cape Town's largest challenge (Gcanga, 2019; Madonsela, 2019; Enqvist & Ziervogel, 2019; Talbot, 2019). This is due to both the significant differences in population groups, media that these groups use to communicate (both in form and language) and the ongoing (mutual) distrust between government officials and inhabitants. Communication about municipal policies and developments during the drought did improve, but it stayed somewhat on an informative level without room for discussion and dialogue. Stakeholder involvement is therefore considered to only be partially present, on a general level.

4.5 Economic characteristics and conditions

4.5.1 Economic characteristics

The Western Cape (WC) makes up 11.5% (6.621 million) of the South African population, of which about 4.1 million lived in the City of Cape Town (CCT) in 2018 (WCG, 2017; WCG 2018a). In-migration and natural population growth are both responsible for about half the population growth since 2006 (1.4 million in total) (Stats SA, 2018). WC is predicted to grow another 20% before 2030 (1.3 million), a much higher rate than the estimated national growth rate (11%) (WCG, 2018a). The city has a dependency ratio[10] of 48.4%. Both the population size and dependency ratio are expected to continue to grow in the near future, increasing the strain on public services.

Income inequality is an immense issue in South Africa, and while it is lower in Cape Town, it is still significant. The National Development Plan aims to reduce the national Gini-coefficient[11] to 0.6 by 2030 (from 0.7 in 2010) (NPC, 2012). According to the World Bank South Africa has the highest Gini coefficient globally at .63 in 2015 - although these values are difficult to compare as the years from which the global data originated differ from 1996to 2015 (Worldbank, 2019). In CCT the coefficient has wavered at about 0.61 (WCG, 2017). This inequality can also be seen in the growth of 'indigent households', or households that cannot afford basic services and therefore require municipal support in the form of Free Basic Services (FBS). The number of households that were approved for FBS grew by more than 30% between 2014 and

[10] A dependency ratio is the ratio of inhabitants of working age (15-65) to non-working (younger than 15 and older than 65)

[11] The Gini coefficient is a measure which describes the inequality of a population or the distribution of wealth among a country's individuals. A Gini-coefficient of 1 means high inequality (Only one person has all the income of a large group). A coefficient of 0 means a perfectly equitably society.

2015 (but stabilised between 2015 and 2016[12]). In combination with a growing population and dependency rate, indigent households will excessively strain the "already limited resources of [the] municipality" (WCG, 2017 p.14).

4.5.2 Presence of Economic Conditions for Water Management

This context of relative population growth, a growing dependency rate and the large income inequality in CCT is important to keep in mind when going deeper into economic conditions for water management, here focused on human resources and financial capacity.

Human resources

As described in section 4.4, and as further elaborated in this section, a number of institutions are involved in the management of water use and water sources in the Western Cape. Knowledge on water management issues, skills needed for the implementation of measures and staff necessary for both the accumulation of knowledge, the implementation and the monitoring of measures, are therefore provided by various institutions. Conditions like skill, knowledge or capacity are sometimes mentioned by sources in relation to the implementation of certain specific water management measures, but more often these conditions are general issues for any of the institutions involved in water management.

Irrigation boards and Water User Associations are supported in the management of their system by external engineering companies (Gcanga, 2019). The IBs and WUAs are usually run by members, which are farmers or other business owners. By hiring external parties to manage the engineering factors of their system, they ensure that the skills and knowledge needed are available.

The CCT municipality is generally in charge of providing users with potable water and demand management practices. The CCT has various departments involved in these processes, with the municipal department of water and sanitation at the centre (not to be confused with the national DWS, which is part of the Ministry of Human Settlement, Water and Sanitation). Each department, division or team has its own officials and focus. Aside from their own internal staff, the CCT has joined multiple international organizations centred around sharing of best-practices and knowledge on water management, like the 100 resilient Cities network and C40 Climate Leadership Group (Taylor, 2017). Additionally the CCT hired various engineering companies or NGOs to aid in the development of water management policy.

Many other CCT employees have also continued to contribute to the adaptation of Cape Town's water management through various other advisory bodies, such as the Water Resilience Authority (Enqvist & Ziervogel, 2019). As the water scarcity worsened, more and more civil servants were put on one of these teams to aid the drought relief efforts. Call centre employees were understaffed and did not know enough to properly answer the growing number of questions from civilians about water restrictions and day zero (Ziervogel 2019). By the end of 2018 a report published by Ziervogel (2019) found that many city officials had put in significant extra hours during the crisis and that the resulting psychological cost on many was high and has not yet been adequately dealt with (Ziervogel 2019). The continued work pressure on these

[12] It is unclear what caused this increase as it could be due to a sudden increase in poverty or due to the process of application for FBS. In 2016 30% of CCT's registered households were 'indigent'.

officials also led to a lack of space for creative solutions or proper reflection on policies that were being put in place.

The DWS is responsible for the management of bulk water and large-scale infrastructure. While the assumption is made that DWS has the capability to operate the Western Cape Water Supply System, respondents found that they did not have sufficient technical expertise or enough human resources to make informed and timely decisions (Ziervogel, 2019). CCT officials deemed DWS' reaction to the drought slow and insufficient, and it is suspected that financial restrictions have caused many engineers to leave the department (Gcanga, 2019, Ziervogel, Talbot, 2019). One source also expressed concern about the technical ability of DWS employees to manage dam releases, as it has been suggested that too much water was released to certain IBs and WUAs. The DWS does have a lot of sources of relevant information about the hydrological system within the WCWSS and staff that has worked in the department "for decades" which would strengthen the relationships, knowledge on organisational structures and communication (and information sharing) possibilities with various parties (ZIervogel, page 14).

For both the CCT and DWS there was not enough capacity to monitor water users and enforce the limitations, although this was somewhat improved during the drought when DWS officials from other regions were transferred to increase capacity (Ziervogel, 2019). Additionally, the people working within the political arena of both the DWS and CCT are critiqued for their non-technical, politically-entrenched attitudes. While some sources suggest a more technocratic decision making process in general, others expressed concern about the balance of heavily technocratic processes on the one hand and the too politically-motivated processes on the other (Talbot, 2019, Ziervogel, 2019). One source argued that political representatives are not equipped to make sensible and equitable decisions because they aren't educated in hydrological systems. Various interviewed CCT, Western Cape and DWS officials proposed that it was the communication between the technocratic officials and the political representatives that was muddled and inadequate (Ziervogel, 2019). The drought of the past few years has especially highlighted this misalignment.

Finally, the reconciliation strategy published in 2007 (DWS, 2007) initiated many preliminary, feasibility and scenario studies by both the DWS and the CCT. The report strongly influenced the level of knowledge available to either institution. This varied from information on cost and effectiveness to the implementation methods of various supply and demand measures. A significant limitation to the report - and the resulting planning for further augmentation and demand management studies - is that is only took into account economic and population growth as variables that would influence demand within the WCWSS. It failed to assess the impact climate change would have on water supply and demand, which some sources highlight as the reason for the water crisis, once the three year drought hit the area. Once the impending water scarcity became evident, however, CCT could implement alternative augmentation measures relatively quickly (compared to other municipalities) due to the existing research on for example, wastewater treatment, desalination and certain demand management techniques (Gcanga, 2019).

To conclude, there was a lot of research, knowledge and skill available in Cape Town before and during the drought, but it was not always effectively used. CCT and DWS have a long history of water management and both institutions are knowledgeable on augmentation and saving options. Both institutions did seem spread thin in terms of staff, which was highlighted during the drought. Communication between various institutions and civilians was inadequate, in part due to this stressed capacity of the staff. This condition was therefore assessed to be partially present.

The state of human resources, skills and related capacities presented above and the major impact it has had on the processes and developments in Cape Town, illustrates how critical the condition Human Resources is. The varying effects that this condition has on the possibility to implement certain measures will be further analysed in later chapters.

Financial Capacity

The financial resources of the different institutions are generally discussed less than their human capacity. An overarching theme however is that there is limited finances available for new investments, and even less for monitoring. An example is the brain drain of engineers that took place at DWS as the department could not afford to retain the staff. It is also suggested that the DWS representatives in the steering committee overseeing the reconciliation strategy of the WCWSS could not join board meetings in Cape Town due to budget cuts for their flights (Gcanga, 2019).

It is also unclear where the resources for new measures in CCT will come from within the municipal budget (Gcanga, 2019). This is in large part due to the system of revenue collection (McLaren, 2019). The CCT is in charge of collecting revenue and paying the DWS for their water use. Aside from the indigent households receiving free basic services, water bills are paid at household level in block-tariffs (CCT DW&S, 2018a). Households are charged based on within which range (predetermined blocks) their water consumption is. The first block (under 6 kilolitres per month per household) if free, but the price per litre increases for each following block. This means that large users pay more *per litre* than small users. This will be discussed further when assessing the measure tariffs. There were three factors that reduced the revenue collection before, but especially during the drought which strained the municipal budget.

Firstly, some respondents mentioned the immense difference in income across the municipality and the fact that even with these block-tariffs, water is relatively cheap for the rich and expensive for poorer communities (Talbot, 2019). High bills for households that cannot afford them has led to a drop in willingness to pay them, meaning the city was having a growing problem with collecting revenue (Gcanga, 2019). Once the drought hit, the willingness to pay decreased further due to price increases, but also because people did not want to pay for what they thought was a mismanaged system (Ziervogel, 2019; Gcanga, 2019).

A second problem with revenue collection is that 40% of Cape Town's population does not pay for their water services. This includes the previously mentioned indigent households (about 1.5 million people) and those living in informal settlements (Ziervogel, 2019). The cost of the supply to indigent households should be covered by a national operation grant (instead of the municipality), but either way it is a strain on their budgets.

The strategy behind revenue collection is as follows; the revenue from middle user groups was planned to cover their own use and that of those using water for free, while the revenue from the largest consumers was allocated to new augmentation investments (Smith, 2004). This designation has however led to a third issue with the municipalities water management budget during the drought. The richer high-end consumers - who had previously paid more per litre for their water - started cutting back during the drought and finding themselves in lower user-blocks and therefore paying less per litre. The drought increased the need for funding to implement demand management and supply-end measures, but the municipality's income from water bills drastically dropped due to these factors. Various sources emphasized that the present revenues are not enough for maintenance or replacement of old infrastructure, let alone the implementation of new measures (Ziervogel, 2019).

Some emergency funds were made available during the drought by reprioritizing spending within the CCT's Integrated Development Plan and by freezing other posts. Some sources suggest the freezing of other posts happened too quickly, as they were unfrozen when it turned out that the funds were not immediately necessary. The process was also labeled as slow and bureaucratic - but this also protected the system from overreacting and readjusting the municipal budget too much (Ziervogel 2019).

To conclude, the condition financial capacity is assessed to be absent. Strained financial resources limited the DWS's ability to actively participate in the reconciliation strategy steering committee or to enforce water restrictions when necessary. In the CCT, funding was difficult to reallocate to augmentation projects and the municipality's revenue scheme is too dependent on high water consumption, meaning saving by businesses and households during the drought drastically reduced the city's budget.

4.6 Equitability and accessibility

4.6.1 Equitability in Cape Town

In the aftermath of the Apartheid regime, the new government of South Africa has had to tackle a lot of inequality in terms of quality of life among various groups of South Africans. In Cape Town this inequality becomes obvious when looking at differences in income (as shown by the high Gini coefficient for Cape Town of 0.61), safety, education but also in the accessibility of water.

Cape Town was built on segregated communities, each with their own municipality (up until 2000) and each with their own water and sanitation infrastructure. Non-white communities have been displaced by force (e.g. from District 6), but people have also been displaced at large due to a lack of possibilities in their hometowns and provinces. This does not only include black South Africans from a multitude of ethnic and cultural backgrounds (among others the Zulu, Xhosa, Sotho, Tswana and Pedi) but also large foreign-born minorities (from Zimbabwe, Mozambique, Lesotho, Malawi and Swaziland) (Stats SA, 2016). These displaced groups settle in mostly informal dwellings in the Townships surrounding Cape Town. In the Western Cape, about 16.6% of the population lives in informal dwellings (as opposed to 13% nation-wide) (Stats SA, 2016). The access to water is strongly linked to living situation as those living in informal dwellings have to retrieve water from taps in public areas or from neighbours.

4.6.2 Presence of the equitability condition for water management: Accessibility

Each measure has specific financial and social costs that impact whether they can be viewed as equitable based on the allocation of these costs and the affordability of water as a result of these costs. It is difficult, however, to assess a measure as inequitable in itself, as it is only one part of a management process that includes a multitude of measures. A measure could overwhelmingly benefit a specific group - making it inequitable - but if another measure compensates this, the management strategy could still be defined as fair.

This section will highlight the issues that affect the equitability of water management in Cape Town in general and only three measures will further explore this condition: tariffs, restrictions and very briefly the re-use of water in chapter 5. Tariffs and restriction measures can disproportionately affect certain groups and therefore increase (or strongly decrease) the possibility of an equitable water management system.

As defined in chapters 1 and 2, accessibility refers to the physical accessibility of affordable and safe water.

Physical accessibility:

When asked what the leading challenge facing their municipality seemed to be, households across South Africa answered the "lack of safe and reliable water supply" (Stats SA, 2016: p. 56). Interestingly, water supply does not make the top 5 challenges when only looking at households in the Western Cape (Stats SA, 2016). This is most likely due to the fact that the Western Cape is the "most equal province in terms of water access" (Engvist & Ziervogel, 2019: p. 9; Cole et al., 2018). While the Cape leads in most access to piped water indoors and safe drinking water and has the least households with no access to piped water, the province is quite diverse and accessibility is a large problem for certain informal settlements (Enqvist & Ziervogel, 2019).

A majority of residents of the Western Cape receive piped water inside their house (76.9%) or within their yard (11.6%) and only 1% (almost 20 000 households) has no access to piped water (Stats SA, 2016). The remaining 10.4% of households retrieves their water from a source outside their yard. This is problematic because, while these taps are within a 1000 metres and 30 minutes, they are not always safe to reach. Many of the households that do not have piped water within their house or yard are located in the poorest areas of the Townships in the Cape Flats. Leaving your house to retrieve water at night, is therefore very dangerous. This group of people has physical access to water, but not continuously. Additionally, the 1% of households that do not have access at all are somewhat clustered in these poor parts of Townships. 10% of households in Khayelitsha do not have access to running water or toilets (Pengelly et al., 2017; Beck et al., 2016).

Safety:

Aside from physical accessibility of running water, the safety of water is also not a given. Only 93.2% of the Western Cape population have access to safe drinking water (Stats SA, 2016). During the drought the reduced pressure on the system and restricted consumption, limited the flow through the system. The water coming from taps was trusted less due to this. Capetonians resorted to bottled water, but towards the height of the crisis in 2018, bottled water was scarce and people travelled far to buy it.

Affordability:

According to the human right to water, affordable water costs less than 3% of a household's disposable income. The municipality provides free water to households that are eligible for Free Basic Services (FBS) because they cannot afford the service bills. Additionally, free water can be retrieved from the public taps in some townships. The remaining Capetonians pay for their water use, as they are not eligible for FBS or have not applied for it. It is unclear whether the water bills of this latter group cover more than 3% of the disposable incomes of these households; no research has been done on this topic and government publications do not report on it. Higher costs during the drought have led to a low willingness to pay, but the possible reasons vary from being unsatisfied with the supply to not being able to afford the new prices.

Finally, the frenzy surrounding Day zero was criticized for not acknowledging that Day zero had, in fact, always been reality for thousands of households. Retrieving water from public points is the norm for 1 in 10 people in the Western Cape (Stats SA, 2016).

To conclude, the majority of Cape Town has physical accessibility to affordable and safe water, but this is not consistent throughout the population. Vulnerable groups need to retrieve water from central locations, that are not always safe to access, while 6.8% of the population does not have sufficient access to safe drinking water. It is also unclear whether water is affordable to the poorer communities in Cape Town.

4.7 Presence of conditions for effective water management

The physical, institutional, economic and equitability characteristics of the city and the management of the WCWSS have been described in section 4.6. These characteristics give an indication whether and to what extent the conditions identified in section 2.3 are present. For some conditions, the assessment of their presence is dependent on specific measures - while for other conditions more general conclusion can be made on their presence (i.e. independently of the measure).

Thus, there are two sets of conclusions that can be drawn from these subsections:

1. **Measure specific conditions:** It cannot be determined in general terms whether this type of condition is present because the relevance of the condition is highly dependent on the measure. Specific conclusions can therefore only be made when discussing the relevant measures, which will be done in chapters 5, 6 and 7. This is the case for the physical conditions *'water availability'* and *'space'* and the financial condition *'material'*.
2. **General conditions**: conditions (assets and barriers) that are, at varying levels, relevant for all measures. It can, in general terms, be determined whether this type of conditions is present for all measures. This is the case for all other conditions.

Table 6: Summary of conclusions per condition for effective water management

	Physical Conditions
Water availability	Water is only supplied to the system in the winter and supply is irregular. Climate change is expected to increase chances of drought, increase irregularity of rainfall and decrease the amount of rainfall. This is a measure specific condition, only relevant to reservoirs, rainwater tanks and aquifers.
Space	Space for new measures is limited by other land uses, such as increased agricultural land and growing cities. This is a measure specific condition, especially relevant to surface reservoirs, but also to reuse and desalination plants.
	Institutional Conditions
Cooperation	Five key issues are raised in relation to cooperation between institutions: (1) political tensions between the CCT and the DWS, (2) an uncertain division of responsibilities, (3) unclear communication between institutions, (4) the limited transition from Irrigation Boards to Water User Associations and finally (5) various power shifts within the municipality. Despite certain strengths (eg. responsibilities assigned in the reconciliation strategy), the condition cannot be fully met (yet) when implementing measures. This is due to the continued strained relationship between CCT and DWS, as political rivals DA and ANC are their largest parties. *+ There is reliable cooperation and a clear division of responsibilities between institutions* ***± Cooperation between institutions are inadequate OR responsibilities are not clearly divided*** *- Both cooperation between institutions and division or responsibilities are inadequate*
Facilitating regulations	Regulations do not generally impede measures (aside from a possible water trading schemes), but the processes that are meant to protect institutions from mismanagement and protect the environment or people from unintended consequences - do slow down the process of implementing new measures. This was especially an issue during the drought, and while it should not be a problem when measures are implemented in normal, non-critical situations, more flexible regulations would be beneficial for a system that is expected to find itself in critical situations more frequently (due to climate change and an increasing demand for water). *+ Regulations do not constrain implementation, but facilitate it.* ***± Regulations do not constrain the implementation*** *- Regulations are unclear or even constrain the implementation of the measure*
Stakeholder engagement	Stakeholder engagement is more important to some measures than others, but the process of informing and involving stakeholders is - broadly - not sufficient. Communication towards the public has always been minimal, which led to a continued mistrust towards the government - especially when drastic measures needed to be taken during the drought. Meetings are organized to involve the public, but these are not properly attended. Communication about measures or the possibility to get involved

Table 6 (continued): Summary of conclusions per condition for effective water management

Stakeholder engagement	with the implementation of new measures does not reach a large enough audience due to technological or language barriers. *+ Relevant stakeholders are involved in the process of realizing the measures or sufficiently informed about possible involvement.* ***± Some stakeholders are involved in the process but others are only informed about the outcomes*** *- Many stakeholders are uninformed about the process or are ignored*
	Economic Conditions
Human resources	There was skill, research and knowledge available at both the CCT and the DWS, but the capacity of both institutions is limited. The DWS has lost people due to budget cuts and tends to focus more on technical knowledge - missing a broader perspective on resource management. During the drought CCT officials were overworked and various teams were understaffed. During the drought the CCT also started using external engineering or planning consultants to aid in the drought relief efforts. Broadly speaking, while there is enough knowledge within the WCWSS, there is not enough capacity to properly use it, work together or communicate to outside parties. *+ There is knowledge on the measure and enough skilled staff to correctly implement it* ***± Knowledge and skills are present but not throughout the process or not enough*** *- Either knowledge on the measure or the skills to implement it are missing*
Financial capacity	Financial capacity is specific to each measure, but come conclusions can be made based on the assessment in this chapter. Financial resources have been tight at the DWS for a longer time, limiting their ability to actively participate in the reconciliation strategy steering committee and to enforce water restrictions when necessary. The funding in the city were difficult to reallocate when needed in the crisis, but this also prevented an overreaction and overinvestment in inefficient augmentation measures. The city's revenue scheme is dependent on high water use, so saving by businesses and households during the drought drastically reduced the city's budget. + There is sufficient financial capacity for initial investments and operations and maintenance. ± There is sufficient financial capacity for investments, but income is not stable or the buffer for unforeseen circumstances is minimal. **- *There is no financial capacity for initial investments or for operations and maintenance***
Materials	Whether material for measures are present is completely specific to the measure. This is only relevant to all buffering (surface reservoirs, rainwater tanks, aquifers) and alternative-supply (reuse, desalination) measures.

Table 6 (continued): *Summary of conclusions per condition for effective water management*

	Equitability
Accessibility	The majority of Cape Town has physical accessibility to affordable and safe water. For communities in informal settlements and townships this is not a certainty. 1% of Western Cape (WC) has no access to piped water and another 10.4% retrieve their water from a source outside their yard. These public taps are not always safe to drink from and not always safe to access (at night). 93.2% of the WC population usually have access to safe drinking water (Stats SA, 2016). It is unclear whether water is affordable in the WC, but it can be assumed it is not for all consumers as willingness to pay service bills is low. This is a general conclusion for this measure, but it is especially relevant to regulating tariffs and restrictions. *+ The accessibility of safe water is high and actively engaged* ***± The accessibility of safe water is high but not consistent throughout the population*** *- The accessibility of safe water is unintentionally low, negatively impacted or ignored*

4.8 Conclusion

This chapter provided an analysis of whether the general institutional, economic and equitability conditions were present (+), partially present (*±)* or absent (-) and some limitations and strengths were given for the measure specific physical conditions water availability and space. This analysis answered the third sub-question ('which conditions are present in Cape Town') by summarizing the conclusions made in subsections 4.3 through 4.6, in Table 6 (section 4.7).

V. The Potential for Additional Buffering Measures

5.1 Introduction

This chapter will discuss to what extent each buffering measure has been implemented already and whether the conditions necessary for their effective implementation have been met. As mentioned in the previous chapters, buffering measures include surface reservoirs, aquifers and rainwater tanks. All three aim to augment the water supply.

Table 7, below provides an assessment per measure of whether each condition for effective water management is present (+), partially present (*±)* or absent (-). This is founded on the assessment done on the general conditions in chapter 4 and presented in table 6. A further evaluation of each measure separately, provides some adjustments to these general conclusions (when necessary). Additionally, the measure specific conditions space, water availability and material are also discussed and valued. Sections 5.2, 5.3 and 5.4 will first elaborate on in what way each measure has (or has not) been implemented, why these values were assigned to each condition and what is further possible for the measure.

Table 7: The presence of conditions for the effective implementation of buffering measures

	Physical conditions		Institutional conditions			Economic conditions			Equitability
Measures	Space	Water availability	Facilitating regulations	Operation	Stakeholder engagement	Material	Human resources	Financial capacity	Accessibility
Surface reservoirs	-	±	±	±	±		±	-	±
Rainwater tanks		-	±	±	±	±	±	±	±
Aquifers (MAR)	+	±	-	±	±		±	-	±

5.2 Surface reservoirs

5.2.1 The use of surface reservoirs in Cape Town

The Western Cape Water Supply System (WCWSS) is at present, supplied mostly by surface reservoirs, specifically the 6 major dams mentioned earlier: The Wemmershoek dam, Upper Steenbras dam and Lower Steenbras dam operated and owned by the City of Cape Town (CCT) and the Voëlvlei dam, Berg River dam and Theewaterskloof dam owned and operated by the national department of water and Sanitation (DWS) (Gcanga, 2019; DWS, 2007). These six dams make up 96.4% of the water supply in the WCWSS and are therefore the focus of a lot of policy formation surrounding the system. Dams on Table Mountain made the first sewage system in Cape Town possible introducing the area to modern sanitation and drainage in the 1890s which further pushed the population growth in the 20th century (Brown & Magoba, 2009; Wilkinson, 2000). The dams are filled in the Western Cape's wet winters (between May and October), when 90% of the yearly runoff occurs. About 70% of the yearly demand for water is used in the dry summer months, resulting in the need for large storage capacity to bridge this period. In the 2007 reconciliation strategy it was estimated that about half of the storage capacity is used within the same year, for summer demand. The remainder is for "long term carry-over storage for periods of drought" (DWS, 2007, p. 4). This is discussed further in reference to water allocations (section 6.4).

The reservoirs in the WCWSS are interlinked by a pipeline and tunnel system that is operated by the DWS (Gcanga, 2019). By connecting the various dams, water can be pumped from one reservoir or even catchment to another, reducing the "*unnecessary spillage from any one dam, and thereby maximise water resources to the benefit of all water users" (*DWS, 2007, p. D1). As dictated by the 1997 Water Services Act, it is the responsibility of the DWS to operate the system and therefore manage the releases to various water users from all the dams in the WCWSS. The reservoirs supply 'raw water' to the city and the CCT's water treatment plans then provide residents and businesses with potable water (DWS, 2007).

The 2007 reconciliation study already presented possibilities for augmenting the existing surface water supply, this was further developed in the new Cape Town water strategy (City of Cape Town, 2019b). For example, studies were proposed to look into the feasibility of raising the Lower Steenbras Dam and the Upper Campanula Dam in 2007. During the drought, various fresh water springs were connected to the surface reservoir systems. This included the Oranjezicht and Albion springs[13], which were connected to the Moreno reservoir (Ziervogel, 2019). Further development of reservoir infrastructure is supposed to produce another 40-60 ML/ day by 2022 (Enqvist & Ziervogel, 2019).

Various sources highlight the cities dependence of surface reservoirs despite unreliable rainfall (Enqvist & Ziervogel, 2019; Mariño, 2017; CCT, 2019b; CCT DW&S, 2018b; Gcanga, 2019). The history of the use of surface reservoirs as a way to hold water from the winter for use in the summer and the fact that surface water is the cheapest option, explain the continued investment in dams in the WCWSS (CCT, 2019b; DWS, 2018a).

5.2.2 Presence of conditions for effective use of surface reservoirs

The physical, institutional, economic and equitability conditions need to be met so that use of surface reservoirs is effective and sustainable. Table 7 poses whether these conditions are present for reservoirs, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 7, for reservoirs.

Physical conditions space and water availability are especially relevant to surface reservoirs. There is no space left for large new reservoirs - the Berg River Dam is mentioned to be the last logical space for a reservoir (DWS, 2007) - and even the possibility of augmenting existing reservoirs is limited due to bordering natural reserves and buildings. Water availability will also change in the coming years. The high use during the increasingly longer dry period means an increasingly larger storage is needed to bridge rainless months or droughts. The general institutional and economic conditions do not change significantly for surface reservoirs. Regulations do not constrain the construction of new dams and cooperation between the CCT and DWS is strained but satisfactory when it comes to the management of existing dams.

[13] Oranjezicht springs are the group of springs in the neighbourhood Oranjezicht in Cape Town. The Albion spring is in the neighbourhood Newlands.

It is unclear how stakeholders are involved when it comes to dams, specifically. There is enough knowledge and skills, but not enough people to research or implement a new scheme. Reservoirs, while producing relatively cheap water (in price per litre) are an expensive investment and the financial capacity of both the DWS and the CCT is not enough for new investments and needs to focus on operations and maintenance. Reservoirs do not specifically influence accessibility of safe water.

5.3 Rainwater tanks

5.3.1 The use of rainwater tanks in Cape Town

Rainwater tanks have been used for a longer time in Cape Town, but their use really caught on during the drought - especially with richer households (Talbot, 2019). A concern about the increase in use of tanks is that if the rich go off-grid, the grid becomes unaffordable (Jansen, 2019). The operation and maintenance of the WCWSS and the city's water infrastructure has a base-level cost, independent of how much water is consumed. These maintenance costs are shared over all the litres consumed, so when the consumption on the grid drops because rich households are installing raintanks, revenue drops and to compensate the price per litre of grid-water rises (Ziervogel, 2019).

Maura Talbot asserts that this impact is not as large as some assume, because the tanks are not in use consistently. They are used as a security measure, in case of emergency, not as a continuous back-up to the systems piped water from the WCWSS. An average tank of 1000 liters, wouldn't last a regular 4 person household a week - even when consuming at the highest restriction levels of 2018 (50 liters a day).

These new raintanks were part of the new rush to personal "micro-water sources", which also includes boreholes and greywater systems (Ziervogel, 2019: p. 18). The city developed new guidelines for these micro-sources, when it became clear that the various households and businesses were investing in them. These guidelines focused on the importance of health and environmental risks and best practices but explicit new regulation supporting the practice has not been formed(Ziervogel, 2019). While institutions adapted and formed guidelines, the market had difficulty keeping up. Tanks and material necessary for other micro-water sources were often out of stock as supply could not keep up with the demand (Ziervogel, 2019).

5.3.2 Presence of conditions for effective use of rainwater tanks

The physical, institutional, economic and equitability conditions need to be met so that use of rainwater tanks is effective and sustainable. Table 7 poses whether these conditions are present for tanks, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 7, for rainwater tanks.

Rainwater tanks can be installed on a private (household or business) level. This means that certain conditions (operation, stakeholder engagement, human resources and financial capacity) are much less relevant than they are for reservoirs, for example. As rainwater tanks can be installed on a roof or in a garden, space is also irrelevant.

Water availability is especially relevant to tanks, and as a condition it is evaluated as ‘not present’. This is due to the seasonality of rainfall, a tank is quickly refilled during the winter months, but could never bridge the whole summer. With summers becoming drier and longer, rainwater tanks will not be effective as a regular measure and are only practical as a backup for emergency use. The measure specific condition ‘material’ is partially present. Rainwater tanks can usually be bought locally, but during the drought tanks were sold out all across the city. Due to rainwater tanks being mostly a private measure, the minimal financial capacity (of the institutions) is valued a bit better (±) for this measure. All other conditions are evaluated the same as in section 4.7.

5.4 Aquifers

5.4.1 The use of aquifers in Cape Town

The aquifers under Cape Town can be used in two ways: (1) as additional buffers to the WCWSS pumped up through public boreholes and distributed from central locations or (2) by individual households and companies through private boreholes.

Public boreholes

The 2007 reconciliation strategy pushed for the exploration of groundwater use and feasibility studies of various aquifers. For example, improving the management of the Atlantis was proposed to reduce the dependence on the Voëlvei Dam (DWS, 2007). The CCT is currently still investigating the feasibility of augmenting the city’s supply by 100 to 150 million litres per day with the Cape Flats, Atlantis and Table Mountain aquifers could provide (DWS, 2007; CCT DW&S, 2018b). The first public boreholes were installed in the Table Mountain aquifers in 2017 and 159 boreholes were drilled into the Cape Flats in 2018 (Ziervogel, 2019). The water supplied by the initial boreholes is still being tested and further drilling is occurring in all aquifers for both production and monitoring of water levels. In 2018, no groundwater was supplied to the grid as treatment infrastructure was still being developed (Ziervogel, 2019).

Public use of groundwater provides a better opportunity to monitor use and groundwater levels, than private boreholes would. The Reconciliation strategy stressed the importance of a CMA in the process of monitoring the sustainable use of (cross-boundary) aquifers (DWS, 2007). As the WCWSS does not have a CMA, another body would have to take on this role - but it does not seem that this has happened yet.

Using the Cape Flat Aquifer would also present the possibility for Managed Aquifer Recharge (MAR) through reinjection. The high flood risks could be mitigated by reinjecting during rainy seasons (Mauck, 2017). It could also be a way to use treated wastewater. Reuse is still looked down on in Cape Town, and reinjecting treated water to refill aquifers could be a way to make it’s consumption more acceptable (Gcanga, 209).

Private boreholes

As with rainwater tanks, private boreholes were drilled throughout the city to augment private supply of richer households during the drought (Ziervogel, 2019). Unlike tanks, boreholes can continuously supply water and therefore reduce the use of the grid substantially. These boreholes were welcomed during the drought - to alleviate pressure on the system - but they have quite a few limitations. The policies and regulations surrounding boreholes are underdeveloped and it is unclear what is allowed exactly (Enqvist & Ziervogel, 2019). The water act focuses much more on the use of surface water than groundwater and the city need to form new laws to prevent over extraction by citizens and farmers (Gcanga, 2019). For agricultural use, the reconciliation strategy suggest that WUA members need to be trained in aquifer management and will have to “allocate budget for the interpretation and modelling of available monitoring data” (DWS, 2007: p. 18). For urban use, the city responded to the growth in private boreholes with Alternative Water Installation Guidelines (Ziervogel, 2019). Presently, the DWS is in the process of finishing by-laws that would aid the process of groundwater extraction at municipal level (Ziervogel, 2019).

Additionally, while the reduction in consumption of grid-water was necessary during the drought, water from boreholes is not charged. If boreholes are continued to be used after the system recovers, the revenue model of the city will have to be adapted (Ziervogel, 2019).

In general, the use of groundwater creates a more resilient system as sources of water are less directly dependent on climate (as is the case for reservoirs). Interventions, not dependent on rainfall is a sensible as the future effects of climate change are difficult to predict (DWS, 2007). Groundwater was viewed as a quick and cheap option before and at the start of the drought, but this idea has been revised since. Drilling boreholes and constructing infrastructure to test and transport groundwater has proven much slower and costlier than estimated beforehand (Ziervogel, 2019). In cities surrounded by agriculture (e.g. Stellenbosch) high levels of ground pollution making treatment expensive (Gcanga, 2019). It is unclear to what extent this is the case in Cape Town.

Finally, the environmental impact of groundwater extraction is still unclear (Ziervogel, 2019). While the public boreholes will be continuously monitored - the impact of all the smaller private boreholes is more difficult to control.

5.4.2 Presence of conditions for effective use of aquifers

The physical, institutional, economic and equitability conditions need to be met so that use of aquifers is effective and sustainable. Table 7 poses whether these conditions are present for aquifers, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 7, for aquifers.

The condition space is more positive than for reservoirs, because treatment stations and boreholes use less space than a surface reservoir. Aquifers are less affected by yearly fluctuations of rainfall - but also take longer to refill than reservoirs. WIthout managed aquifer recharge, the aquifers could shrink rapidly. As the use of groundwater is relatively new, regulations have not yet been properly formed. This means that thousands of private boreholes, presently being used throughout Cape Town, are not properly monitored and the water use is not charged to the users. This has also led to some operational limitations, as the responsibilities of the DWS and the CCT are somewhat unclear. Groundwater is a national responsibility, but the City is responsible for the implementation of treatment centres and boreholes. New DWS legislation should remedy this confusion, and properly guide groundwater use. The DWS has a lot of information of the aquifers under the WCWSS area, and proper communication between the two parties is essential (Ziervogel, 2019).

5.5 Synthesis of Buffering Measures

Each buffering measure has been implemented to some extent in Cape Town. Surface reservoirs form the foundation of the WCWSS, and while the city has a long history of augmenting their supply through new reservoirs, it has accepted that the Berg River Dam was possibly the last suitable location for a large new reservoir. Urbanisation, agricultural land and nature reserves all impede possibilities of new developments. Additionally, reservoirs are an expensive investment and the absent condition ' financial capacity' would become a problem when operation and maintenance cannot be carried out effectively. Therefore, aside from the augmentations that are currently being implemented for a few existing dams, the measure of additional surface reservoirs is no longer a feasible option for the future.

Rainwater tanks have become popular in Cape Town during the drought. The seasonality of rainfall in the Cape limits the possibility of replacing (part of) a household's grid-consumption with rainwater. This would, at most, be possible in the winter when scarcity is not an issue. Tanks can, however, provide a back-up in the case of an emergency. More research would have to be done about possibilities for implementation on a public level for the groups more vulnerable to Day 0, those that would have difficulty with central pick up locations (e.g. elderly, less-abled people).

The use of aquifers is still in its beginning stages in Cape Town. Private boreholes have popped up everywhere during the drought, but regulations about the monitoring of these boreholes, how much can be consumed sustainably or the quality of water retrieved is still lacking. Public boreholes seem to be a safer option, but these are still in the process of construction and testing. The use of aquifers is a very promising option for the Cape and can be further developed, especially in combination with managed aquifer recharge. Treated effluent (discussed further in chapter 7) can be used as source for recharge, but winter floods on the cape flats could also be tackled in combination with reinjection.

5.6 Conclusion

This chapter discussed each type of buffering measure based on the last subquestions: (4) what measures have been taken in Cape Town?; (5) what measure specific conditions are present in Cape Town?; and (6) which additional measures could be taken in Cape Town?. Rainwater tanks were found to be promising as en emergency measure, for a possible future Day Zero. The further development of public boreholes to use aquifers could substantially augment the WCWSS storage. This use needs to be carefully monitored and better regulations need to be developed to guide this process. The use of aquifers could also be used more sustainably if combined with MAR. Finally, new surface reservoirs are no longer a feasible option due to space restrictions and the dependency on (in the future, uncertain) rainfall.

VI. The Potential for Additional Water Saving Measures

6.1 Introduction

This chapter will discuss to what extent each saving measure has been implemented already and whether the conditions necessary for their effective implementation have been met. All saving measures aim to reduce demand for water, but tackle this issue from different perspectives. In policy documents for the Western Cape Water Supply System (WCWSS) and Cape Town specifically, saving measures are grouped under the term 'demand management'. While examples of demand management are given, documents are not always explicit about which measures they mean specifically. In general demand management is the responsibility of the municipality – as defined by the Reconciliation strategy (DWS, 2007) but some (restrictions, reduction of non-native species and leaks in the WCWSS) are the responsibility of the DWS. The reason to group these measures as demand management is that they hardly ever occur as stand alone measures. Pressure management can be used to reduce leakages and tariffs and allocations can be used to enforce restrictions.

As was done for buffering measures, Table 8 provides an assessment per water saving measure of whether each condition for effective water management is present (+), partially present (±) or absent (-). This is based on the assessment done in chapter 4 (and presented in table 6) and an evaluation of each saving measure. Sections 6.2 through 6.7 will discuss in what way the measure has been implemented, why these values were assigned to each condition and what is possible for the measure in the future.

Table 8: The presence of conditions for the effective implementation of water saving measures

	Physical conditions		Institutional conditions			Economic conditions			Equitability
Measures	Space	Water availability	Facilitating regulations	Operation	Stakeholder engagement	Material	Human resources	Financial capacity	Accessibility
Reducing leakages			±	±	-	±	±	-	±
Pressure management			±	+	+		±	+	±
Water allocation			-	-	-		±	-	±
Removing alien species			±	±	±		±	+	±
Water restrictions			±	±	±		±	-	-
Regulating tariffs			±	±	-		±	-	-

6.2 Reducing leakages

6.2.1 Reducing leakages in Cape Town

Leaks in water infrastructure have a substantial impact on the supply and demand of a system. Leakages in poorer communities led to significant increases in water bills and large protests among the inhabitants in the late 90s (Enqvist & Ziervogel, 2019; Smith, 2004). These protests, among other things, prompted large scale infrastructural repairs and replacement of old pipes in these neighbourhoods. The 2000 drought further stimulated programmes that aimed to reduce the water lost to leaks and pipe bursts. Before the recent three year drought, physical water loss was at 15% in Cape Town, which is much lower South African Cities (CCT, 2019b).

The reduction of non-revenue water is still a focus of the city today. Non-revenue water is water that does not reach consumers as either a billed- or free basic-service. It has been lost in the system due to leakages or other physical losses or seems to be lost due to inaccurate meters and unauthorised connections (CCT, 2019b). The easy, low priced, investments have already been made however, and further reduction of non-revenue water becomes increasingly difficult. It could be noted that by decreasing the water lost in the system before the drought, the city only postponed the water crisis. It increased the water supplied to the system (that is not lost), letting demand grow along with it. When the drought hit, a possible quick fix to increase accessible water (reducing physical loss) had already been implemented and could therefore not be done. This, however, is only an issue when a city is using too much of its resources and not leaving enough of a buffer for dry years - and therefore not a critique of the measure itself.

Water Management Devices (WMDs) were also used from 2007 onwards to detect leakages and overuse in certain households (CCT, 2007). These devices were installed in especially poorer households in debt due to unpaid service bills or those more prone to leakages due to old or poor quality infrastructure (Enqvist & Ziervogel, 2019). The WMDs provided the city with control over water use on household level, as they could turn off the supply in case of a detected leak or if a household used more than the municipality deemed they could afford. As further discussed in section 6.7, there is strong opposition towards WMDs due to their inequitable impact on poorer communities. There effectiveness of identifying leaks is under researched, however. Identifying a leak is only the first step, and solutions other than turning off supply could be implemented, such as free plumbing to fix the leak.

6.2.2 Presence of conditions for the effective reduction of leakages

The conditions for effective water management need to be met so that leaks can be reduced effectively. Table 8 poses whether these conditions are present for the reduction of leakages, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 8.

The physical conditions are irrelevant to reducing leakages. Material (±) is available, but not affordable to many. Leaks in townships are caused by cheap, faulty material, but replacing these is too expensive for the inhabitants themselves. The conditions human resources, financial capacity and operation are not strongly dependent on this measure and the value assigned to their presence is therefore the same as in the conclusion of chapter 4. There is knowledgeable staff but they are overworked (±), There is not enough financial capacity within the community or the municipality for maintenance of the infrastructure (-) and cooperation between institutions is adequate but also not very relevant (±). Community members in townships (stakeholders) are uninformed about the process or monitoring or repairing leaks (-). The found data on if regulations constrained or facilitated the reduction of leakages was inconclusive. More research could be done into the laws and regulations surrounding leakage control in the WCWSS.

6.3 Pressure management

6.3.1 Existing pressure management in Cape Town

Pressure management is a measure that reduces water use by reducing the pressure on taps. It can be viewed as a crisis measure as it can be used in extreme situations, generally in combination with water use restrictions. During the 2015 to 2018 drought, a reduced pressure in the reticulation system added to the set of measures that successfully reduced water use within the city (Enqvist & Ziervogel, 2019). In the first three months of 2018, an estimated 50 million litres of water were saved each day through manual controls and automatic pressure reduction valves within pressure management zones in the city (Ziervogel, 2019). These zones had been developed long before the drought, which enabled the quick response when it was necessary (Ziervogel, 2019).

Pressure management is also important when attempting to reduce leakages. Constant pressure changes were found to substantially damage poor quality plumbing fittings in Khayelitsha (one of Cape Town's largest townships). About 75% of water supplied to the township was estimated to be lost to leaks in the early 2000s. The Khayelitsha Pressure Management Project monitored and reduced pressure fluctuations within the township and saved 40% of the areas demand (about 2.5% of the city's total demand) **(**DWS, 2007; WRP Engineering, 2002**)**. The project itself states that the pressure management system had a payback time (in which the saved cost of water otherwise lost to leakages covered the cost of the project) of two months. The Berg River Scheme, which was approved around the same time, would supply almost 80 million m3 per year at the cost of US$200 million. This is 9 times the supply saved by the pressure system in Khayelitsha, at 890 times the cost (WRP Engineering, 2002). Pressure management, especially compared to the large scale reservoirs that the WCWSS supply is based on, can therefore be an extremely cost effective measure. It is unclear if other projects, like the Khayelitsha Pressure Management Project have been implemented since in other townships, but this would be an extremely cost-efficient way to reduce Cape Town's water waste.

6.3.2 Presence of conditions for effective pressure management

The effective water management conditions need to be met so that use of pressure management is effective. Table 8 poses whether these conditions are present for pressure management as a measure, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 8.

No data was found about regulation on pressure management being facilitating or impeding, thus this value remained unchanged as partially present (±). The problematic cooperation between the national DWS and CCT which impede some larger measures, does not seem to be as important for this measure, as it is implemented on a small local scale within the municipal jurisdiction (+). While the limited involvement of stakeholders was often criticised on a general level, the Khayelitsha Pressure Management Project was praised for its involvement of locals. This made the project extremely successful in a difficult to govern part of Cape Town. If future similar projects are managed in the same way, the condition stakeholder involvement will be met (+). Human resources (±) within the CCT are still tight, but these types of measures could be outsourced. The condition financial capacity is also valued as 'present' (+), because pressure management can be an extremely cost-efficient saving measure. This cost-efficiency takes pressure off the budget for other scarcity measures. Finally, the equitability condition is still given as partially present (±), it does improve equitability as projects like the one in Khayelitsha strongly lower the water bills or the poorest communities in Cape Town, by decreasing leakages caused by fluctuating pressures.

6.4 Allocation of water rights

6.4.1 Allocation of water rights in the WCWSS

The allocation of water rights is not as clearly a saving measure as it is a measure to effectively manage water resources. The DWS allocates water to various users, including industrial, domestic and agricultural.

The allocation of water rights is complicated in the Western Cape, due to the different users and their power imbalances. Agricultural users (irrigation boards and water user associations) are allocated about 40% of the water in the WCWSS (Gcanga, 2019). As explained in section 4.4, an IB or WUA is provided their cumulative water rights, which they then redirect to the individuals users. Some water sources have also been over-allocated: allocations exceed the yield of the WCWSS (Gcanga, 2019 Ziervogel, 2019). This is due to a reduction in supply (ie. the effects of poor maintenance, non-native species and climate), but also an increase in demand (Gcanga, 2019; Talbot, 2019).

New (historically disadvantaged) farmers are promised land and water rights in an already strained system (Gcanga, 2019; Talbot, 2019). This is also why water allocation is a key limitation in the establishment of new WUAs. In some catchment areas, a programme named Verification and Validation identifies whether farmers use only their allocation and not more or possibly less. In cases where an allocation is deemed to large, a part is reallocated to other (newer) farmers. This initiative - while attempting to increase equitability in water use - incentivizes farmers to use their full allocation, even when they do not need it (Talbot, 2019). It has also caused an increase in tension and distrust between farmers and government officials (Gcanga, 2019). Some Irrigation Boards are therefore reserved when it comes to welcoming new farmers, as they might have to share their allocations with them (Gcanga, 2019) and are especially adverse to cooperating with the DWS (Talbot, 2019). Additionally, ecological reserves were hove not sufficiently been taken into account in the past (Gcanga, 2019). Allocations for natural reserves, while necessary, are therefore infringing on existing agricultural and urban allocations.

To be able to reallocate water rights, the government needs to meet various societal en environmental criteria that - in practice - are difficult to meet. It seems to be easy to appeal decisions on allocation and hold up the process for a very long time (Talbot, 2019). The limited capacity of the government to implement new water allocations and then enforce these allocations (by monitoring the use of WUAs and IBs) restricts the effectiveness of this measure in the WCWSS.

Finally, it seems that the over-allocation of water is not only an issue for ecosystems and new farmers, but a problem for the system as a whole. Each year, 30% of the system’s demand occurs during winter rainfall months (DWS, 2007). In a normal year, this demand does not strain the storage capacity of the WCWSS, because as the water is being pumped out, it can be refilled by new runoff. The remaining 70% of demand occurs during the dry summer months, when there is no rain and the agricultural sector demand peaks (DWS, 2007). Half of the system's storage is used each year to cover this 70% of the demand. This means that only half of the stored water is held for long-term use for possible periods of drought. This becomes problematic when a dry year does occur. First, the storage is not (or hardly) refilled, leaving only the remaining half of the supply from the previous year. Secondly, the winter-demand - which is usually replaced by rain - is not restored, increasing the required supply from the storage from 70% to 100%. Finally, dry years tend to increase demand as the agricultural sector needs more water for their crops. This means that the remaining half of the system's storage (which in previous years would have covered 70% of demand) will not be sufficient. In extreme droughts, restrictions will of course reduce demand, but not being able to bridge one dry year is precarious. While the chance for a rainless year is nihil, chances of multi-year droughts (like that of 2015 to 2018) are increasing. The allocation of water needs to be reduced enough to account for the expected droughts in the future.

6.4.2 Presence of conditions for effective water allocation

Water allocation is a complicated, but a necessary measure to prevent over-consumption. For it to work effectively, the institutional, economic and equitability conditions need to be present. Table 8 poses whether these conditions are present for the measure water allocation, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 8.

Based on the sources used for this research, they are not or only partially present for allocation. Regulations are overly complicated and slow down reallocation processes (-). Cooperation between WUAs, IBs and the DWS are strained and sometimes even hostile (-). This is in part due to limited stakeholder engagement (-); commercial and emerging farmers are not well informed or solicited by the regional and national DWS (Talbot, 2019). The conditions human resources (±) and financial capacity (-), as was concluded in chapter 4, are only partly present or absent. The DWS does not seem to have the capacity to deal with appeals against reallocation made by farmers due to financial and human capacity constraints.

6.5 Removal of Alien (non-native) Vegetation

6.5.1 The removal of non-natives in the WCWSS catchments

The use of native vegetation in gardening and parks and simultaneously the removal of alien vegetation in catchment areas can drastically reduce the waste of water. Non-native species reduce runoff and groundwater recharge and in some cases can reach groundwater systems (with long roots) that native species cannot use (therefore reducing groundwater buffers) (Ziervogel, 2019; Cape Nature, n.d.). Climate or drought proof gardens are starting to catch on in the Cape, but are still relatively fringe. The most problematic invasive species in the cape[14] have led to a significant decrease in runoff in reservoir catchment areas; some estimates state 30% less runoff in highly infested areas (Cape Nature, n.d.). The city estimates that clearing non-native species from reservoir catchment areas, could save Cape Town 55 million litres per day (Enqvist & Ziervogel, 2019; CCT 2019b).

[14] In order from most successful species: Rooikrans Black wattle, Port Jackson, Silky hakea, Long-leafed wattle Stinkbean, Australian myrtle, Spider gum, Cluster pine, Blackwood (Cape Nature, n.d.).

In the WCWSS, invasive species are removed through biological, chemical, manual and mechanical means. Biological control includes introducing insects or diseases that affect the species, while chemical control uses herbicide. Plants can also be physically removed by hand when still small (manual) or tools and machines when larger (mechanical). The removal of alien vegetation in the WCWSS is the responsibility of the DWS, but a few challenges were identified that limited removal the past few years. Some city officials thought the DWS acted slowly on removal of non-natives due to a lack of capacity (human capital) (Ziervogel, 2019). Others assumed that not being able to exactly quantify the savings impact (in litres) of removal, as opposed to the certainty of other saving or possibly supply measures, slowed down the willingness of DWS to focus on this measure (Gcanga, 2019**,** Talbot, 2019). Removal of non-natives within the municipality is the CCT's responsibility. The city's new water outlook includes the aim to "improve catchment management with a focus on clearing alien vegetation that can increase system yield" (Ziervogel, 2019, p. 10; CCT DW&S, 2018e). The 2019 Cape Town water strategy identifies the removal of non-natives as a low cost strategy that should be prioritized (CCT, 2019b). It commits to future collaboration with external stakeholders to form both a plan for the clearing and how to finance it.

6.5.2 Presence of conditions for effective removal of non-native vegetation

The conditions for effective water management need to be met so that removal of non-natives is effective and sustainable. Table 8 poses whether these conditions are present, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 8, for the removal of non-native vegetation.

The removal of non-native vegetation is ecologically sensible and has been proposed in both national and municipal legislation as an important saving measure. The presence of conditions for this measure to work are roughly the same as was concluded in chapter 4. This is in part due to a lack of explicit information on the measure. As a lot of non-native species grow on private land, stakeholders need to be involved - but it is unclear if this is the case. The DWS and CCT independently assert that removal needs to be done more consistently, but are legislation is unclear about who should do it. It can be assumed that the same issues with limited human resources plays a role in the DWS lagging behind in removal in the WCWSS. The measure is viewed as a relatively cheap, cost effective method of increasing runoff (by reducing consumption by non-natives). This is why financial capacity is valued als 'partially present'.

6.6 Water restrictions

6.6.1 Existing water restrictions in the WCWSS

Broadly, the national Department of Water and Sanitation (DWS) implements restrictions on the use of water when necessary. This is done when - towards the end of the winter rainfall - an assessment of the WCWSS dam levels provide an indication of the next years supply (DWS, 2007). Restrictions are made in coordination with all users in the WCWSS through the Western Cape Water Supply Consulting Forum (Gcanga, 2019). The forum includes municipal water managers, representatives from the DWS and the department of Agriculture and WUA and IB representatives. While the forum is consulted, restrictions are a top-down decision and can be made by the DWS without their approval (Gcanga, 2019). Water to specific

Water User Associations or Irrigation Boards can be cut off when they exceed their (restricted) allocations. They also pose restrictions on municipal use – but this is enforced by the municipality itself (CCT).

Restrictions in Cape Town are organized in levels 1 through 7. Levels 1 to 3 are required to achieve savings of 10, 20, and 30% while levels 4 to 6 impose city wide restrictions through a maximum use of 600, 500 and 450 million litres. Level 7 restrictions, also known as day zero, were not used during the drought. If imposed, the city can only use 350 million litres a day which would be accomplished by shutting of domestic taps and distributing 25 litres per person per day at central locations or PODs (Points of Distribution). In an assessment of how the city dealt with the three year drought, Ziervogel (2019) summarizes the restrictions posed within the WCWSS:

DATE	RESTRICTION LEVEL (%)			REGULATORY AUTHORITY
	CITY	WCWSS		
	URBAN	URBAN	AGRICULTURE	
1 January 2016	20%			City of Cape Town Level 2.
13 May 2016		20%	20%	DWS DG. Signed, unnumbered gazette
1 November 2016	30%			City of Cape Town Level 3.
1 March 2017			30%	DWS regional director. DWS letter, 23 February 2017
1 June 2017	40%			City of Cape Town Level 4. Target 500 MLD
1 October 2017		40%	50%	DWS DG. Gazette 41145 28th September 2017
12 December 2017		45%	60%	DWS DG. Gazette 41317
1 January 2018	45%			City of Cape Town Level 6.
12 January 2018	45%	60%		DWS DG. Gazette 41381 (extended to groundwater) 5 January 2018
1 February	50%			City of Cape Town Level 6B 450 MLD target
1 December 2018	30%			City of Cape Town Level 3
3 December 2018		10%	10%	DWS DG Gazette 42075.

Figure 10: Restrictions during the Cape Town Drought (taken from Ziervogel, 2019)

Although restrictions are the responsibility of DWS, the city imposed the first voluntary restrictions in January 2016, after a dry 2015 (Enqvist & Ziervogel, 2019, Gcanga, 2019). This, in combination with other saving measures, reduced the use from 1200 million litres per day in the summer of 2015 to 800 million in 2017 (Enqvist & Ziervogel, 2019). The highest restriction level for Cape Town was imposed in February of 2018. Day zero (level 7 restrictions) was estimated to occur in these first months of 2018, but the day itself was postponed first by weeks, then to 2019 and by now indefinitely.

Urban users in the WCWSS are assured water at 98%; “for any given year, there [is] a 49 in 50 probability” that there is sufficient water to meet demands without the use of restrictions (Ziervogel, 2019: pp. 4). The assurance level is only 95% for agricultural users, meaning their restrictions were higher during the drought (60% vs. 40%; Ziervogel, 2019; Gcanga, 2019). In practice, however, restrictions for agricultural users were not properly imposed in the first years of the drought.

The effectiveness of implementing restrictions is limited by the capacity for enforcing these restrictions. Both the CCT and the DWS did not have the capacity to enforce them for municipal and agricultural users. This was later somewhat improved by relocating regional DWS officers to the Western Cape (Zier, 2019). City officials expressed their uncertainty about whether the DWS would enforce the agricultural restrictions at all in 2018, as it had failed to do so in the previous years (Ziervogel, 2019). Within the city, restrictions were enforced through naming and shaming, fining illegitimate use of water (e.g. car washes, gardening) and through Water Management Devices (WMDs).

Naming and shaming occurred on smaller levels (e.g. colleagues were encouraged to share their household water use with each other) but also on large scale with the use of neighbourhood maps where Capetonians could look up their own house and those of their neighbours (Ziervogel, 2019). Naming water consumption of households aims to inspire competition between users to reduce their water use and shame those failing to do so at all. Privacy issues do limit the possibility of this tactic to enforce restrictions, however (McLaren, 2019).

WMDs were installed in homes that used too much water. The CCT started using WMDs in 2007 in households receiving free basic water allocation, to be able to cut off supply in case of excessive use or leaks. The city would also determine what some low-income households could afford – to reduce debt caused by unpaid utility bills among these households – and would shut off water when use exceeded this amount (Beck et al., 2016; Mahlanza, Ziervogel, & Scott, 2016; Yates & Harris, 2018). WMDs have, since the crisis, also started to be targeted at high-income and high-use (over 10.5 kilolitres per month) households, but most are still installed in predominantly non-white, low income neighbourhoods (Enqvist & Ziervogel, 2019; CCT DW&S, 2018b; Ziervogel, 2018).

A key limitation for WMDs (and to a certain extent when naming and shaming) is that the city assumes a household is made up of four inhabitants. Deciding what a household should use, based on the assumption that it includes four people, does not make sense when in practice many more live there. This is discussed further in relation to regulation tariffs in section 6.7 - as it is even more important for this measure. Additionally, the installation of WMDs occurred through subcontractors (instead of the municipality) and in some cases were installed without informed consent of the inhabitants. This became an issue especially during the crisis, when the number of WMD installations increased rapidly (Enqvist & Ziervogel, 2019).

6.6.2 Presence of conditions for effective implementation of restrictions

The conditions for effective water management need to be met so that the use of restrictions is effective. Table 8 poses whether these conditions are present, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 8, for the implementation of restrictions.

In the case of consumption restrictions, the valued presence of each condition (except accessibility) remains unchanged. This measure serves somewhat as an example of why these conditions have been determined as partially present or as absent. While regulations on restrictions already existed, the city disaster plan (including plans for level 7 restrictions and the term day zero) was only published in2017. Cooperation between the DWS and the CCT was difficult and unclear, with parties blaming each other for ineffective enforcement of restrictions. Their collaboration improved somewhat during the drought, but was still minimal. Stakeholder engagement happened a little through neighbourhood meetings and awareness campaign about restrictions (see § 6.8) but did not stray from one-sided 'informing' of policy.

Human resources to monitor and enforce restrictions were limited for both the DWS and the CCT, although both parties did improve this by transferring officials from other departments and regions. Restrictions also further reduced the financial capacity of the CCT (discussed further in § 6.7). Finally, while restrictions in itself do not reduce accessibility to water as defined by the CESCR and the WHO, level 7 restrictions do. Having to wait in long lines to pick up 25 liters of water in central locations is generally a burden for everyone but it could especially be an issue for the sick, elderly or for those with children. Additionally, the method of restricting especially lower income households with WMDs strongly reduces accessibility. Accessibility, as an equitability condition, was therefore indicated to be absent.

6.7 Regulating Tariffs

6.7.1 The regulation of tariffs in Cape Town

The last saving measure is the regulations of tariffs, or the price of water, to encourage saving. Aside from restrictions, changing the price of water is discussed most often as a means to reduce consumption. Determining tariffs is the responsibility of the municipality of Cape Town and consistent review of tariffs "to reflect the scarcity of water supplies" is necessary to reduce water use according to the Reconciliation strategy (DWS, 2007). The city is required to be financially sustainable, meaning tariffs need to cover long term costs of providing water to its inhabitants. To recover these costs, Cape Town has been moving towards block tariffs - in which users pay more per litre when they use more – since the 1960s (Gcanga, 2019; McLaren, 2019; Enqvist & Ziervogel, 2019).

As mentioned in section 4.5, indigent households (earning less than 6000 rand per month) receive free water, medium users cover their own costs and those of the poorest, and high-end users cover the costs of new investments in water infrastructur**e (**Smith, 2004**).** In the past, users were split into 6 blocks: 0-6 kilolitre, 6-10.5kℓ, 10.5-20kℓ, 20-35kℓ, 35-50kℓ and over 50kℓ (CCT DW&S, 2018a). This was changed to only 4 blocks in 2018 (0-6kℓ, 6-10.5kℓ, 10.5-35kℓ and over 35kℓ) to 'recover costs, provide resilience and to simplify the tariff" (CCT DW&S, 2018a, p. 5).

An important drawback with block tariffs has been discussed in 4.5: a reduction in consumption means a reduction in income for the municipality. Depending on disproportionate use to cover the cost of extraction is problematic when supply cannot cover that disproportionate demand. Before the drought, small users (less than 6 kilolitres per month) were exempt from paying. During the drought, however, a large proportion of households dropped their use to below that 6 kilolitre level, meaning the city was losing too much revenue (Wilkinson, 2000; Sorenson, 2017). To cover the gap in the municipal budget due to user cutbacks, tariffs were changed for this lowest block mid 2017 (CCT, 2019a, Yates & Harris, 2018). This happened because of the city's policy to stay "revenue-neutral" during a drought (less consumption means higher tariffs; CCT, 2019b: pp.28. The 2018 water outlook provides a graph showing how each block (or step as they call it) changes prices when a restriction level is changed (Figure 11: CCT DW&S, 2018e); when restriction levels increase, the cost of water increases. To change this, the city's water strategy proposes a "rainless-day fund" as a buffer for years with high restrictions to cover the gaps in budget (CCT, 2019b: pp. 28).

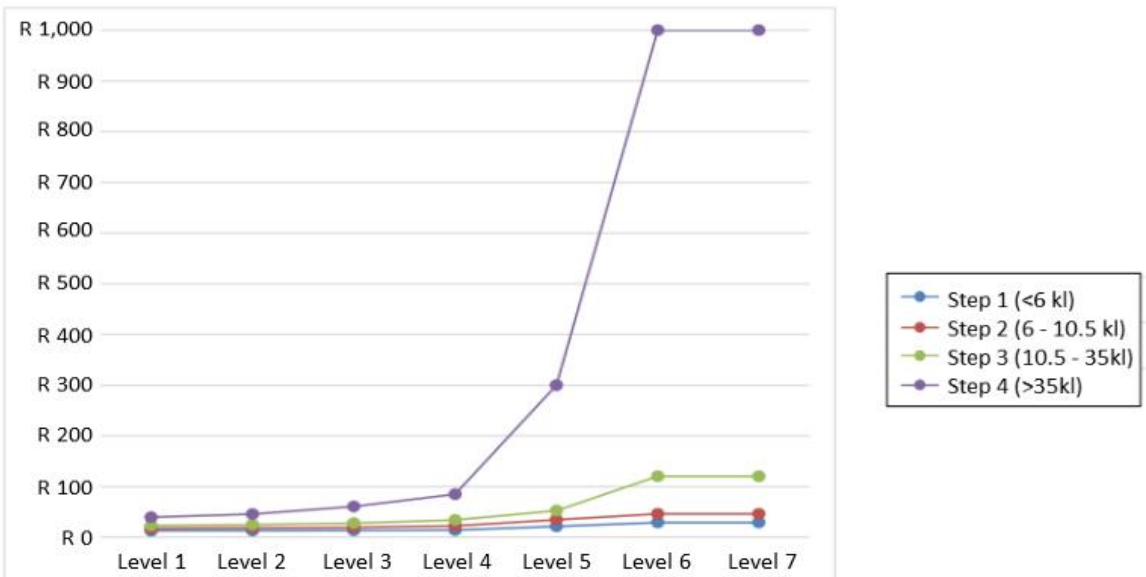

Figure 11: Increase in block (step) prices when restriction levels (x-axis) increase (adapted from CCT DW&S, 2018e)

A second problem with this measure in Cape Town, is that it is dependent on the assumption that each household has four inhabitants. While this could be the case for richer users, it is definitely not for those in poorer communities. These houses often have more inhabitants, including others living on their plot (e.g in unofficial sheds in gardens) (Enqvist & Ziervogel, 2019). Some plots are inhabited by up to 30 people (Smith, 2004). These households, while not using more per person, end up in high-end user blocks and pay more per litre than richer households that might be using much more per person. This limitation is mostly caused by missing information, not knowing how many people are using a tap limits the possibility for equitable block tarifs. Additionally, households that already use less water (due to its unaffordability) have less room to cut back during a drought than large users "with pools and gardens" (Enqvist & Ziervogel, 2019: p.9). This means that the rich can cut back and end up in lower blocks, but the poorer cannot, negating any type of redistribution that the block-tariffs had created (Jansen & Schulz, 2006).

Being able to account for the extreme differences in wealth of Cape Town's inhabitants is difficult. Not enough information is available at the household level - to be able to determine what each person is using. The extreme income differences create a system in which - even with block tariffs - water is basically free for the richest and unaffordable for the poorest communities (Talbot, 2019). A possible solution could be income-based tariffs but much more information and research would be needed to find the feasibility and impacts on equitability of a comparable solution.

Poor communication about the steps DWS and CCT were taking to reconcile supply and demand before and during the drought proved problematic when the city attempted to change tariffs in 2017 and 2018 (Ziervogel, 2019). Capetonians believed they were being punished for poor planning when they were trying to cut back consumption (Armitage, 2018). Research has also found that other incentives, like awareness on the importance of saving or being compared to neighbours, worked better in reducing use than increasing prices (Enqvist & Ziervogel, 2019, McLaren, 2019).

6.7.2 Presence of conditions for effective regulation of tariffs

The conditions for effective water management need to be met so that regulation of tariffs is effective. Table 8 poses whether these conditions are present, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 8, on the regulation of tariffs.

As is the case for restrictions, conditions for regulating tariffs remains somewhat the same as defined in chapter 4. The existing regulations were found to be very problematic during the drought, when the city attempted to stay 'revenue-neutral'. This policy is in the process of changing, however, and a rainless-day fund will dampen the effect of a drought on the municipal budget.This will, hopefully improve the future financial capacity of the city as well. Two conditions for which significantly different conclusions could be made for this measure specifically, are stakeholder engagement and accessibility. The inhabitants of Cape Town were not properly informed or involved about why the city chose to raise tariffs. This strongly affected the chance of the bill passing (some were rejected after protests) or the willingness to pay of the consumers. Finally, accessibility - like for restrictions - was negatively impacted by the tariff system. Because it is based on billing households as a unit, poor households (with many inhabitants) use more than rich households(with only a few inhabitants). They, therefore, pay more per litre than in smaller households and can sometimes - due to this system- not afford their bills.

6.8 Awareness of Water users

Finally, a measure that was not introduced in the theoretical framework is raising awareness. Raising awareness to reduce water use was central to the city's drought strategy. For example, naming level 7 restrictions 'day zero' was in itself an awareness measure. Proper communication between the municipality, DWS and Capetonians through the radio, posters, ads, letters and regular 'water outlook' reports, aided the push for water-wise consumption. Aside from terminology like 'day zero', a few other interventions increased awareness among the city's inhabitants.

Both the Western Cape province and the City of Cape Town showed inhabitants how to live off of 100 liters (and then 87 in September 2017 and 50 litres in 2018) on posters spread in print throughout the city and on social media (Ziervogel, 2019). To further encourage short showers, various South African artists (in cooperation with the municipality, Cape Town Tourism and Sanlam - an insurance company) created two minute shower songs: "when the song ends, so should your shower" (2minuteshowersongs, n.d.).

Figure 12: How to use only 50 liters of water a day, published in early 2018 (WCG, 2018b)

The naming and shaming mentioned as a method to enforce restrictions can be viewed as an awareness campaign. On the 'City Water Map'[15] every household using less than 10.5 kilolitres of water showed up as a green dot of an interactive map (Figure 13). One could therefore see which households were not reaching this goal, without knowing how far off they were.

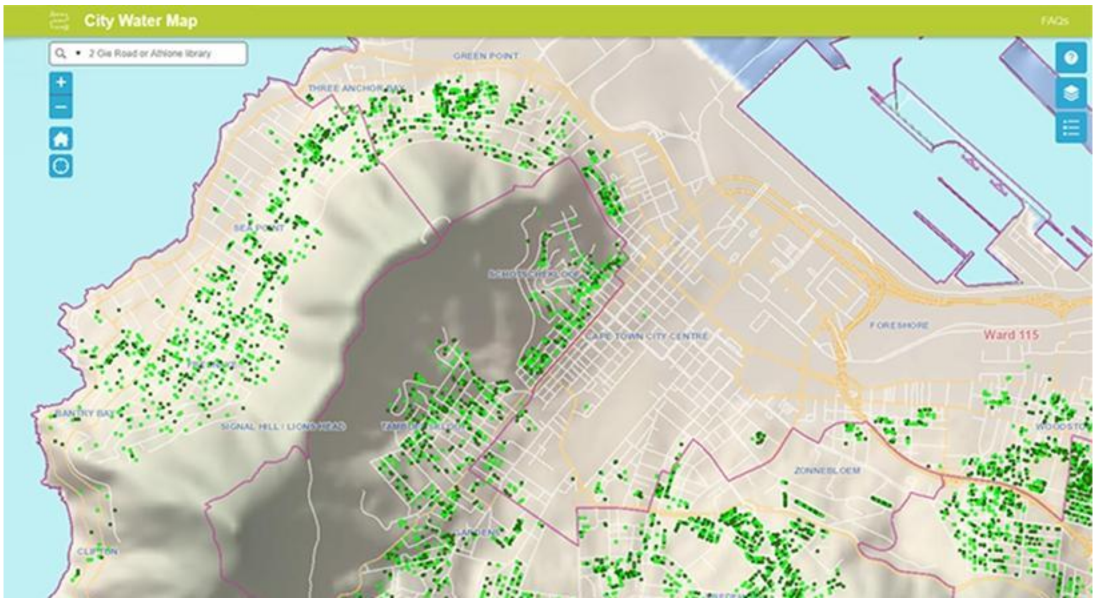

Figure 13[16]: A screenshot of the City Water Map taken in January, 2018 (Gilbert, 2018).

Another source of information for the public was the water dashboard (CCT, n.d.b), which provides a simple and clear overview of the current dam levels (and how that compares to the previous weeks), whether targets for water use have been met this week and water augmentation stats. Water outlook reports in which updates were given on rainfall, the effect the rainfall would have on supply and restrictions and the progress of augmentation projects were published and updated throughout 2018 (CCT DW&S, 2018a, 2018b, 2018c, 2018d & 2018e). These reports are understandable for a large portion of the (English speaking) public and go more into depth on the reasoning behind policy choices. They are less accessible than the dashboard, however, which avoids technical jargon (but is also only available in English).

The term 'Day zero', for level 7 restrictions, originated in the City's 2017 Disaster Plan (as the critical Water Shortages Disaster Plan was named). As mentioned briefly when introducing the history of water management in Cape Town in section 4.2, the impact of the plan was substantial. Whether the use of the term Day zero was positive is disputed as some assert that it did more damage (to the economy through tourism and business investments) than good **(**Lang, 2018**).**

[15] The website, while still online, has been discontinued as of January 2019 but will possibly be used again when necessary at [https://citymaps.capetown.gov.za/waterviewer/]

[16] Dark green dots are households using less than 6000 litres a month, light green use between 6000 and 10 500 litres. Households using more than 10 500 litres a month are not shown.

Each of these interventions had in common that they shifted responsibility from the city, province and DWS for augmenting supply to the public for cutting back use (Ziervogel, 2019). In her analysis of the drought, Ziervogel (2019) links this shift to a quote made by Mayor de Lille in January 2018:

"It is quite unbelievable that a majority of people do not seem to care and are sending all of us headlong towards Day Zero. At this point we must assume that they will not change their behaviour and that the chance of reaching Day Zero on 21 April 2018 is now very likely."

Each of these campaigns was only started up in 2017 or even 2018. A key limitation that was highlighted by various respondents was that people in the WCWSS do not know the cost of maintenance of the WCWSS or of new augmentation schemes and therefore do not appreciate the value of their water (Ziervogel, 2019: Talbot, 2019 Madonsela, 2019). This, in combination with a distrust towards government, led to conspiracy theories on social media (e.g. the drought was made up to be able to privatise water) (Ziervogel, 2019). The city's reluctance to publish information and plans earlier on added to this. As was mentioned in section 4.4, when discussing human capacity, the municipality's call centre was overwhelmed and also lacked knowledge to answer all the questions the public might have had. So, the public should have been informed much earlier, the way it was in 2018. Awareness, while central to the government's tactics close to day zero, could have been implemented earlier and better, to reduce water use in Cape Town.

Even with these setbacks, each of these awareness campaigns (the Water Dashboard, Water Map, Shower songs, posters and the Disaster Plan) were found to be more effective than restrictions or tarif changes in reducing water use on household level. Early reports found people responded strongly to how neighbours were doing and how important it was to save and later to the media panic that followed the publication the City's Disaster Plan (McLaren, 2019; Booysen, Visser, & Burger, 2019; Brick, De Martino, & Visser, 2017; Lang, 2018). The raised awareness of Capetonians was credited with finally being able to cut back to under 500 million litres of water a day, reaching 50% of pre-drought use (Ziervogel, 2019).

6.9 Synthesis

Water demand measures have been central to the WCWSS strategies since the new constitutions, the Water Services Act and the National Water Act. The measures discussed in this paper were reducing leaks, pressure management, allocation of water rights, removal of non-native vegetation, restrictions and the regulation of tariffs. Each of these measures has been implemented to some extent in Cape Town or in the WCWSS.

Programmes set up during the drought in 2000 continuously tackled leakages in poorer communities using pressure management and Water Management Devices. Cape Town has already relatively successfully lowered the proportion of non-revenue water, and brought back physical losses to 15%. The use of WMDs to reduce leaks is quite contested, though. The city needs to make sure informed consent is given when installing the devices, and that the focus stays on reducing leakages and not controlling the water use of poorer households.

While WMDs turn off water during a leak, this does not actually prevent leakages in poor households. These are generally caused by a combination of poor-quality material and fluctuating system pressures. Reducing leaks through pressure management has been a very successful measure in Khayelitsha. It proved extremely cost-effective and reduced loss in the neighbourhood by 40%. Due to its large potential, more research needs to be done about whether projects like the Khayelitsha Pressure Management Project, can be implemented elsewhere in the city. City-wide pressure reduction during the drought was also very successful, but is only a crisis measure and cannot be used on a regular basis.

While the removal of non-native vegetation does happen in the WCWSS, it is not properly monitored and does not occur often enough. There is potential for this measure to be implemented more regularly and more successfully if the DWS and CCT make it a priority. Removal is an uncontested relatively cheap measure.

The removal of non-native vegetation and reduction of water lost to leaks creates room for more consumption (as less water is wasted). This could bring about a pattern of overuse and makes it harder to adapt when the system fails (due to a drought, for example). This consequence can be averted through effective use of water allocation. This measure is used in Cape Town, but due to historical rights of farmers, complex systems of reallocation and new users that need to be given rights as well (emerging farmers, the growing urban population and surrounding ecosystems), water is over-allocated. This measure has the potential to create a larger buffer in the WCWSS to bridge droughts, but regulations need to be restructured to become less ambiguous, complicated and open to speculation.

Water restrictions were widely used reduce consumption during the drought. It was extremely effective as all users cut back drastically to avoid Day Zero. This crisis measures could be used more regularly at lower level restrictions - to prevent the necessity of higher level restrictions. The weakest point of this measure is the absence of financial capacity and how the city compensates for this absence. High level restrictions prompts a drop in use, which in turn cuts back the city's revenue and budget for water management. This compensated with the regulation of tariffs.

While tariffs can be used as a measure to incentivise consumers to save water, the absence of financial capacity causes the measure to become inequitable and therefore ineffective. Regulating tariffs thus seems to be the most problematic measure. The municipality needs much more information about the composition of households to provide a more equitable and affordable, and ultimately more effective, method of revenue collection. However, It does not seem realistic for a city like Cape Town to know how many people live in - especially the poorer - households. Research needs to be done to find another way to make water affordable and incentivize water-wise consumption without punishing large households or run the risk that not enough revenue is collected to cover the cost of water delivery in the municipality.

6.10 Conclusion

This chapter discussed each type of water saving measure based on the last sub questions: (4) what measures have been taken in Cape Town?; (5) what measure specific conditions are present in Cape Town?; and (6) which additional measures could be taken in Cape Town?. Saving measures, usually grouped as demand management in Cape Town, are essential to the city's water management. Each of these measures has been implemented to some extent in Cape Town or in the WCWSS, but not all are as effective.

More focus needs to be placed on the relatively cost-effective measure pressure management and non-native species removal. Both could have a substantial impact on the system, without being strongly affected by the absence of financial capacity. Over-allocation should be tackled to reduce pressure on the WCWSS, but in-depth research into the process of allocation and reallocation is needed to understand in what way. The measures restrictions and tariff regulations were used considerably during the drought. A rainless-day fund would create potential for further use of restrictions, without disproportionately affecting Capetonians.

Finally, a few 'raising awareness' measures were introduced in relation to their role in averting level 7 restrictions in Cape Town. These measures were found to have a significant role in why Cape Town managed to cut down it's consumption to less than 500 million litres on several days.

VII. The Potential for Additional Alternative-supply Measures

7.1 Introduction

This chapter will discuss to what extent each measure for additional alternative-supply has been implemented already and whether the conditions necessary for their effective implementation have been met. Alternative-supply measures aim to generate water supply to the system from sources that aren't directly supplied by rainfall.

As was done for buffering and water saving measures, Table 9 provides an assessment per alternative-supply measure of whether each condition for effective water management is present (+), partially present (±) or absent (-). This is based on the assessment done in chapter 4 (and presented in table 6) and an evaluation of each saving measure. Sections 7.2 and 7.3 will discuss in what way the measure has been implemented, why these values were assigned to each condition and what is possible for the measure in the future. Sections 7.4 and 7.5 give an overview and conclusion of the relevance of and further possibilities for alternative supply as measures.

	Physical conditions		Institutional conditions			Economic conditions			Equitability
Measures	Space	Water availability	Facilitating regulations	Operation	Stakeholder engagement	Material	Human resources	Financial capacity	Accessibility
Reuse	+	+	-	±	±	...	±	-	±
Desalination	+	+	±	±	±	...	±	-	±

Table 9: The presence of conditions for the effective implementation of alternative supply measures

7.2 Wastewater Reuse

7.2.1 Reuse in Cape Town

Grey water reuse in Cape Town is a relatively new intervention and the city is still exploring it's options. According to Cape Town's 2019 water strategy, treated wastewater could provide 70 million liters per day by 2023 (CCT, 2019b). In depth research into the possibilities for reuse was instigated by the reconciliation strategy in 2007 (DWS, 2007). At the time, 60% of water used in the city ended up in the system as wastewater. About 9.6% of this was treated and reused - that is 5.8% of the total amount of water entering the CCT was reused. The remaining 90.4% (of the 60%) was discharged into the sea as 'treated effluent' (DWS, 2007).

The 2007 reconciliation strategy highlighted some possibilities for the reuse of treated effluent, summarised a few concerns about this measure and suggested possible research that could be done to address these concerns (DWS, 2007).

The 9.6% reused effluent was used for local irrigation (of parks, sports areas), for agriculture and for industry (DWS, 2007). These are currently still the main uses of reused water (Gcanga, 2019). The effluent is not reintegrated with the main potable water supply due to a barrier also given by the strategy in 2007: social acceptability (DWS, 2007). While treated effluent is used extensively in other countries as a potable water source, its acceptance as potable source in Cape Town is an issue (Saldías et al., 2016; Gcanga, 2019). The irrigation and industrial purposes form a large enough demand, however, that even if treated effluent remains 'unacceptable' as drinking water, reuse is a viable option for Cape Town to reduce the pressure on other traditional sources of water.

Social acceptability is not the only barrier for the implementation of treatment facilities. The municipalities in the WCWSS have all indicated concern about the "respective water services institutions to effectively operate and maintain treatment of effluent schemes" (DWS, 2007: pp. 42). The perceived inability of treatment plants to operate effectively, to properly remove detergents, drugs and microplastics has also fueled the persistent social rejection of treated effluent.

The final, substantial barrier for the reuse of treated effluent is the lack of a proper legal framework. Policies for reuse were minimal in 2007 and municipalities were unsure how national regulations would develop (DWS, 2007). It is unclear if this has changed since.

The CCT has, over the past decade, explored possibilities for wastewater reuse. Efficient locations for treatment facilities were researched, feasibility studies were done and the Zandvliet treatment facility is now being tested (Gcanga, 2019). The development was determined to be too expensive to scale up quickly as a crisis measure during the drought, but is currently advanced as long term solution. The Zandvliet facility was also found to be much cheaper than treatment facilities in other municipalities, due to Cape Town's extensive studies into the measure (Gcanga, 2019).

Treated effluent could also serve as a source for Managed Aquifer Recharge (MAR). By letting the effluent artificially infiltrate into certain aquifers, groundwater levels are kept in check and further purification of the effluent can occur (Pescod, 1992). Mixing the treated wastewater with a more traditional source could also help with the social acceptability of its consumption (Gcanga, 2019).

Like boreholes, wastewater can also be reused at a private level. In the same way as for the many private boreholes that were installed during drought, guidelines were made to guide the households and business that were collecting greywater and treated effluent for gardening, washing cars, flushing toilets and other secondary uses. The guidelines focus on health and environmental risks and best practices (Ziervogel, 2019).

7.2.2 Presence of conditions for effective water reuse

The conditions for effective water management need to be met so that reuse of water is effective and sustainable. Table 9 poses whether these conditions are present, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 9, for water reuse.

Because the measure has only scarcely been implemented on a public level, it is difficult to assess the conditions stakeholder engagement, material and human resources on a measure specific level. The general conclusions made in chapter 4 can be assumed to be applicable to wastewater reuse. Stakeholder engagement will be important for the further development of this measure, due to its lacking social acceptability and unorthodox image. There was no general assessment of the condition material due to its measure specific nature. This condition is left blank in table 9 for both reuse and desalination due to a lack of information accessible in this research.

The condition water availability is determined to be ‘present’, because water reuse is somewhat independent of the Cape’s increasingly irregular rainfall and only a small part of the water that reaches the sewer as wastewater is currently being treated for reuse. Facilitating regulations seem to be limited. Although some government publications encourage the development and emphasize its importance, actual policy that governs the process of treatment facilities or guides the municipalities in development - are still lacking compared to other measures. Financial capacity, like for the general conclusion, is absent. Planned wastewater reuse is estimated to cost 5rand per kilolitre. This is about the same as for aquifers, but still much more than for general demand management measures (3 rand), or specifically clearing of vegetation (1 to 2 rand; CCT, 2019b). The absence of financial capacity can therefore deter the efficient and sustainable development of wastewater reuse.

7.3 Desalination

7.3.1 Desalination in Cape Town

As was the case for the reuse of treated effluent, desalination was discussed as a possible measure in the WCWSS reconciliation strategy (DWS, 2007). Since then, consistent advancement of the technology used for desalination has significantly reduced its cost of the measure. Further feasibility studies in the CCT has established a price of an estimated 9 rand per kilolitre for the first desalination phase, which will be completed in 2026 (CCT, 2019b). This, again like reuse facilities, is much cheaper than other WCWSS municipalities where estimates of 20 rand per litre have been proposed for the cost of water produced by desalination plants (Gcanga, 2019). Desalination plants are however still significantly more expensive than other measures, in both construction and operation (Enqvist & ZIervogel, 2019). Additionally, the process has a high energy demand and “environmental impacts of additional energy would [...] need to be carefully considered and discounted” (DWS, 2007: p 47).

Regardless of the price, the use of desalination promotes resource diversification (DWS, 2007; Ziervogel, 2019). It is the only augmentation measure that is wholly independent of climate-induced rainfall (CCT, 2019b). This is why it is also taken into account as a possible measure for a ‘ worst-case scenario’, in which demand continues to grow and climate change heavily impacts the supply from the reservoirs (DWS, 2007).

During the drought, the city announced the development of temporary small desalination plants (Gcanga, 2019). These were too difficult and expensive to build on the timeline that was projected - and these plants were cancelled (Ziervogel, 2019; Gcanga, 2019). The city continued on the long term development of the plant that had been announced before the drought.

7.3.2 Presence of conditions for effective desalination

The conditions for effective water management need to be met so that desalination plants will be effectively implemented. Table 9 poses whether these conditions are present, based on the analysis presented in chapter 4 and on further evaluation of the measure specifically. This section briefly elaborates on the findings presented in Table 9, for desalination.

Due to the limited implementation of this measure, it is difficult to say for each condition whether it has been met. For the conditions operation, stakeholder engagement, human resources and accessibility, the values don't change. The condition facilitating regulations is, like in chapter 4, also partially present. Since the reconciliation strategy more than a decade ago, the CCT has invested in various feasibility studies and published about desalination in a few policy documents. While the policy surrounding desalination has been developed, the fact that the municipality announced to develop smaller desalination plants during the drought in a short time span and later cancelled these initiatives were a good example of the slow response of the municipality.

Some officials blamed the fact that the short term, small scale desalination plants planned during the drought, could not be constructed due to the slow response of the system in terms of reallocating budgets (Ziervogel, 2019). As was discussed in section 4.4, however, the function of the Municipal Finance Management Act is to reduce the likelihood of overreactions and wasting funds on projects that would be unwise because they are too expensive or would take too long. This seems to have been the case for these short term desalination plants, proving the relevance of the Municipal Finance Management Act.

7.4 Synthesis

Both wastewater reuse and desalination are being researched in Cape Town, but have not been broadly implemented yet. Both measures are however portrayed in public debate as promising measures for an effective and sustainable future WCWSS.

The reuse of treated effluent has a lot of potential for the city, especially if used in combination with Managed Aquifer Recharge. Research has to be done about the social acceptance of the measure, to better understand the public issues with wastewater reuse. This understanding is necessary in order to effectively develop strategies to improve acceptance and ultimately broader implementation. Additionally, the city can look into concerns about the capabilities of treatment centres, carried out by close monitoring and allocation of funds when necessary. Trust in the management and operation of these centres is indispensable for the development of policy and projects in wastewater reuse.

Desalination is an important measure for resource diversification. Its use would render the city less dependent on rainfall. Due to the uncertain impacts of climate change, and the continuously growing CCT population, desalination should be considered an important alternative. Desalination is however, relatively expensive. It costs almost twice as much as the use of most aquifers and wastewater reuse, and about 6 times as much per litre supplied as removing non-native vegetation costs per litre saved. The strain this will put on an already strained budget is substantial. This does not mean that there is no place and necessity for desalination plants in an efficient and sustainable water management system. Research and policy efforts should focus on finding the right circumstances (location, position in the network, funding) for desalination plants and technological innovation, in order to implement the measure more broadly.

7.5 Conclusion

This chapter discussed both the alternative supply measures wastewater reuse and desalination based on the last sub-questions: (4) what measures have been taken in Cape Town?; (5) what measure specific conditions are present in Cape Town?; and (6) which additional measures could be taken in Cape Town?.
Wastewater reuse is a cost-efficient measure with substantial potential for the city. Its social acceptability still forms a serious barrier that needs to be overcome, however. Desalination, on the hand is a popular measure that will diversify the city's resources for water as it is not dependent on rainfall. Further development of the measure might make it cheaper, but it will remain the most expensive measure the city is implementing to reduce water scarcity.

VIII. Conclusions and Recommendations

8.1 Introduction

This thesis aimed to on the one hand, summarize the measures that can be taken to avoid future water scarcity in Cape Town and on the other, assess the conditions necessary for these measures to work both effectively and fairly, answering the question:

To what extent are the institutional, physical, economic and equitability conditions - required for the implementation of measures to effectively reduce water shortages- present in Cape Town?

This question was tackled through 6 sub-questions, each answered throughout the research:

1. What general conditions are required for effective water management? (chapter 2)
2. Which measures to tackle water scarcity are proposed in literature? (chapter 2)
3. Which general conditions are present in Cape Town? (chapter 4)
4. What measures have been taken in Cape Town? (chapters 5, 6 and 7)
5. What measure specific conditions are present in Cape Town? (chapters 5, 6 and 7)
6. Which additional measures could be taken in Cape Town? (chapters 5, 6 and 7)

This conclusion will provide a summary of the findings for each sub-question and answer the main research question.

8.2 Answers to research questions

8.2.1 What conditions are required for effective water management?

The first sub-question aimed to find what general conditions are required for effective water management. These conditions were found through an extensive literature review based on three discourses that address water management: The Integrated Water Resource Management discourse, the Climate Change Adaptation discourse and the Sustainable Development discourse. The found conditions were categorized based on the type of water scarcity: physical, economic and institutional. The equitability categorization was added to include the accessibility of water as a condition.

The physical conditions were space and water availability. These are both measure specific conditions, meaning a summary of possible assets or barriers for either could be formed, but it cannot be determined in general terms whether there is enough space or enough water for effective water management. The institutional conditions are facilitating regulations, effective (co)operation and sufficient stakeholder engagement. All three are general, meaning these conditions are relevant to all measures (to varying extents) and general conclusions can therefore be made about to what extent the condition is present. The economic conditions were determined to be available materials, enough human resources and financial capacity. Whether the condition material can be met, like space and water, is dependent on the measure. Human resources and financial capacity are general conditions. Finally, the equitability condition, accessibility, was based on the human right to water. This condition needs to be met before any measure can be deemed successful.

8.2.2 Which measures to tackle water scarcity are proposed in literature?

The second sub-question addresses the possible measures that can be used to tackle water scarcity. These measures were categorized as either a buffering, saving or alternative supply measure.

Buffering measures aim to augment supply by buffering water when it is available for when it is scarce. It includes surface reservoirs, rainwater tanks and aquifers. Saving measures aim to reduce demand for water and includes reducing leakages, pressure management, water allocation, removing non-native species, restriction and regulating tariffs. The two alternative-supply measures suggested were the reuse of wastewater and desalination. Both measures reduce the pressure on traditional sources, by providing alternative supplies.

8.2.3 Which general conditions are present in Cape Town?

Chapter 4 tackles the third subquestion by assessing to what extent general conditions are present in Cape Town. No general conclusions could be made about the conditions water availability, space and material (as they are measure specific).

The institutional conditions were all found to be partially present:

Cooperation:	Cooperation between two key institutions, the national Department of Water and Sanitation (DWS) and the City of Cape Town municipality (CCT) was inadequate. This was due to political tensions between the parties that govern the CCT and the DWS and an uncertain division of responsibilities. Additionally, some institutions that should benefit the process do not exist in practice. This is the case for the Water Management Agency which would have been responsible for cooperation between parties.
Facilitating Regulations:	In general, regulations do not impede the implementation of measures but were also not found to be especially facilitating. They slow down new developments with processes meant to avoid mismanagement but then prevent quick adaptable policy changes.
Stakeholder engagement:	Stakeholder engagement is more important to some measures than others, but the process of informing and involving stakeholders is - broadly - insufficient. Communication with the public was minimal before the drought, which led to a mistrust towards the government - especially when drastic measures needed to be taken during the drought. Communication has strongly improved during the drought.

The economic condition human resources was also found to be partially present, while the condition financial capacity was absent.

Human resources:	While there was skill and knowledge present in both the DWS and CCT to effectively implement scarcity measures, the capacity of both institutions is limited. Staff was lost due to budget cuts or overworked during the drought. This strongly limited the capability of both institutions to properly cooperate with each other or to communicate with citizens.
Financial capacity:	The financial capacity of the CCT and DWS is the only condition to be valued as absent on a general level. DWS' stressed budget limited their ability to actively participate in a steering committee overseeing the measures being implemented in the WCWSS. This can be seen as a crucial cause for insufficient strategic water management in the WCWSS. City funding also became an issue during the drought when cuts in consumption meant simultaneous cuts in the city's revenue.

Finally, the equitability condition 'accessibility' was indicated as partially present.

Accessibility:	93.2% of the Western Cape population have access to safe drinking water, but the accessibility of safe water is not consistent throughout the population. The most vulnerable are communities in informal settlements and townships. 10.4% of the province's inhabitants retrieve their water from a source outside their yard, which is not always safe to drink from and not always safe to access. 1% of the Western Cape Province has no access to piped water at all.

8.2.4 What measures have been taken in Cape Town?

Every measure proposed in the theoretical framework (and as summarized in section 8.2.2.), has to some extent been taken in Cape Town or is in the process of development and testing. The Western Cape Water Supply System has been based on surface reservoirs since the first one was built in the 1840s. The DWS and CCT have been attempting to diversify by investing in the use of groundwater aquifers through public boreholes, desalination plants and the reuse of treated effluent. The Cape Flats and Table mountain aquifers will start delivering water to the system in 2020, with others following suit soon after. Wastewater reuse and desalination will take a few more years to develop, but will most likely be implemented in the future. Rainwater tanks have, during the drought, gained popularity as a private measure for middle class and richer households. They are used as an emergency measure, and not to continuously reduce the need for water from the grid.

Saving measures have been central to the city's water management strategy since the Water Service Act and National Water Act. Programmes aimed at reducing leakages have been very successful at reducing water wasted in the city. Pressure management is used widely as a crisis measure, but has also been applied on a regular basis to reduce pressure-induced leakages in poorer neighbourhoods. The removal of non-native vegetation in the catchment areas of the WCWSS is carried out by the DWS, and is highlighted as important task that the city will also focus on more in the future for their own catchment areas. Very little was found about reducing non-native vegetation on private land.

Finally, water allocations, restrictions and the regulation of tariffs is used substantially in the WCWSS. Water allocations are decided by the DWS, for the whole WCWSS. Restrictions are determined by the DWS as well, but the CCT can also decide to implement them for their own citizens. Tariffs are also the responsibility of the city. They are based on a household's consumption block (in kilolitres) and the current restriction level. HIgher consumption blocks pay more per litre, and the price increases when restrictions are in place.

8.2.5 What measure specific conditions are present in Cape Town?

There are three measure specific conditions: space, water availability and material. Each relevant to different measures.

The least is known about the condition 'material'. No general observations could be made about this condition and little could be found when looking at the presence of the condition for both desalination and wastewater reuse. Material for both rainwater tanks and fixing leaks is available in Cape Town, but not affordable for poorer households. Thus, tanks are used primarily by richer households and leaks occur primarily in poorer households. Additionally, while available before the drought, rainwater tanks sold out everywhere when the measure was picked up by the rich. In the long run, however, households can still buy these materials.

Water availability, also a measure specific condition, is dependent on the source of the water needed for the measure. The buffering measures are ach dependent on rainfall to increase supply. In the future, rainfall is likely to become less regular, with long dry periods in between short wet periods. Buffers need to be large enough to bridge these dry periods if they are to be used regularly, which is why the condition was valued as absent for rainwater tanks and partially present for the larger buffers. As discussed, the condition water availability is present for desalination as it is completely independent of climate-dependent rainfall.

The last measure-specific condition is space. The lack of space is the main reason the new surface reservoirs are no longer a viable option for the WCWSS. The condition is present for desalination and wastewater reuse treatment plants. This is due to extensive research done by the CCT, into the costs and feasibility of various locations in the city.

The presence of general conditions has been fully evaluated in chapter four and summarised above. The presence is adjusted per measure, which was especially the case for the condition financial capacity. When looking at measures specifically, the conditions fluctuates between present and absent. The most positively valued measures, in terms of presence of conditions, are pressure management, removing non-native vegetation and desalination. The most negatively valued measures are regulating tariffs and the allocation of water rights. Pressure management and the removal on non-natives were both exceedingly effective due to their cost-efficiency. Thus, the generally absent financial capacity has a smaller impact on these measures. The condition was also highly relevant to the negatively valued measure regulating tariffs. The condition accessibility was not met for this measure specifically, because increases in tariffs that tried to compensate for the missing financial capacity, made water service bills unaffordable for a group of Capetonians. The conditions for the measure desalination were also valued relatively positively, even though it is rather expensive and the condition financial capacity was found to be absent. This is due to space and water availability being present, however.

Table 10 provides a summary of the values assigned to each condition, for each measure. Whether the condition is present (+), partially present (±) or absent (-) is, as mentioned, based on the analysis presented in chapter 4 and on further evaluation of the measures specifically in chapters 5 through 7.

Table 10: Summary of the presence of measure specific conditions per measure (as presented throughout chapters 5, 6 and 7)

		Physical conditions		Institutional conditions			Economic conditions			Equitability
Measures		Space	Water availability	Facilitating regulations	Operation	Stakeholder engagement	Material	Human resources	Financial capacity	Accessibility
Buffering	Surface reservoirs	-	±	±	±	±		±	-	±
	Rainwater tanks		-	±	±	±	±	±	±	±
	Aquifers (MAR)		±	-	±	±		±	-	±
Saving	Reducing leakages			±	±	-	±	±	-	±
	Pressure management			±	+	+		±	+	±
	Water allocation			-	-	-		±	-	±
	Removing alien species			±	±	±		±	+	±
	Water restrictions			±	±	±		±	-	-
	Regulating tariffs			±	±	-		±	-	-
Alt. Use	Reuse	+	+	-	±	±	...	±	-	±
	Desalination	+	+	±	±	±	...	±	-	±

8.2.6 Which additional measures could be taken in Cape Town

This section presents the measures that can be taken without significant changes in existing conditions and secondly describes measures that can be implemented if some conditions are improved.

The removal of non-native species in catchment areas and the implementation of pressure management schemes with the goal to reduce leaks in poorer communities are both relatively cheap, cost-effective measures that could be used more extensively. Both have been used before, but are not implemented to their full extent. Removal of vegetation could occur more frequently, and be monitored better. The pressure management project in Khayelitsha was very successful and similar projects for other neighborhoods could possibly prevent a lot of water waste. The use of rainwater tanks as emergency back-up, could also be expanded, possibly to a public level for certain public institutions and vulnerable groups (schools, elderly, less abled people).

Public boreholes are also a very promising option for the Cape and could be further developed, especially in combination with managed aquifer recharge with for example, treated effluent or rainwater from winter floods on the cape flats.

There are a few more measures that could be implemented effectively if one or two conditions are improved. For instance, the effectivity of water restrictions and tariff regulations were strongly impacted by the absence of financial capacity. With the help of a rainless day fund, as suggested in the 2019 water strategy (CCT, 2019b, both these measures would become more equitable and effective. Additionally, the alternative-supply measures desalination and wastewater reuse are promising future measures. For desalination, financial capacity first needs to be improved. For the implementation of wastewater reuse, facilitating regulations need to be developed to guide the monitoring and operation of treatment facilities.

Water allocation is a problematic measure due to the absence of facilitating regulations, proper cooperation between institutions, satisfactory stakeholder involvement and financial capacity. It is, however, *necessary* to reallocate rights to emerging farmers and natural reserves. This needs to occur while simultaneously reducing the proportion of allocated water in the system to create a larger buffer in the WCWSS to bridge droughts. The above mentioned four conditions need to be improved for this measure, or the WCWSS will not be able to bridge another multi year drought in an acceptable manner.

Finally, aside from the augmentations that are currently being implemented for a few existing dams, additional surface reservoirs are no longer a feasible option for the future. There is no more space for them, and the city needs to diversify their resources to measures that are less dependent on consistent yearly rainfall.

8.3 Discussion

The drought in Cape Town has received a substantial amount of (international) attention over the last few years, and with it came reporters, academic researchers and government employees that wanted to understand different aspects of the drought. Since the beginning of 2018, 54 peer-reviewed articles have been published (to Scopus) specifically about Day zero in Cape Town. Appendix C presents an extensive (but not exhaustive) list of articles published in 2018 and 2019 (until September) about water management that were not used in this thesis due to their focus on a certain part of a measure or due to the fact that they were published after the start of the analysis. The overwhelming amount of research done about the Cape Town case shows how significant this topic is at the moment. The rate in which new research emerged also had a couple of important consequences for this study.

Firstly, articles were constantly being published, also during the data collection and analysis process. While useful, a choice had to be made to stop reading new articles once starting my analysis. This means that certain, possibly useful new publications were omitted in this research. This includes "Making sense of Day zero" by Shepherd (2019), "Planning for water resilience" by Rodina (2019) and "Municipal finance and resilience lessons for urban infrastructure management" by Simpson et al., (2019)[17] among many others.

Secondly, research fatigue among various stakeholder groups also influenced the data collection process itself. Most rejected interview requests had to do with potential interviewees already being involved in other research on the drought or having been so in the past. The municipality also tightened their policies for interviews with researchers during the drought. While unclear beforehand, after speaking to other researchers, it became apparent that official permission from the city was necessary for researchers to speak to municipal officers. Obtaining such permission would take a few weeks to a few months, and was made stricter due to the overwhelming requests for interviews.

These circumstances brought about one of the key limitations or this research. All interviews were done with researchers either from universities or companies. Initially, this was to understand the institutional systems and structures in the Western Cape (as discussed in the methodology). Once that understanding had been formed, interviews with different stakeholders would have provided a new perspective on the drought and water management in general. For instance, farmers, or a representative of farmers like Agri SA, would have provided a better understanding of the poor relationship between the national Department of Water and Sanitation and their irrigation boards or water user associations. While informal conversations with inhabitants of Cape Town and people that work in the tourism sector did confirm findings provided in the academic assessments and governmental publications used for this research, a well organized representative reflection of some conclusions (possibly in the form of focus groups) would have given the presented conclusions added scientific value.

Aside from the limited number and type of respondents, this research presented a couple of other limitations that need to be acknowledged.

First, both the preceding literature study and expert interviews were influenced by the (inexplicit) norms and values of the authors or interviewees. An example of this is the discussion surrounding water accessibility. How the right to water is defined depends on the indicators that researchers use to measure access to water. Does that person have access to a tap (measured perhaps in distance) or can that person afford the access to the tap (measured in expendable income and cost of water)? These definitions of norms in water management are not always made explicit and it is possible that certain terms were therefore interpreted differently in this paper, than they were actually meant to be.

Secondly, the scope of this research is the city of Cape Town as a part of the Western Cape Water Supply System. While the research does address the significant differences between different neighbourhoods, communities and ethnicities, it still assesses each measure and condition for the city as a whole. Cape Town, up until the early 2000s, was made up of very different municipalities. The different groups always lived separately, often with natural or industrial zones as buffers in between neighbourhoods. The

[17] The reference for these three articles are added in Appendix C

presence of conditions can be assessed for the city as a whole, but the findings may not all be fully relevant to some of its neighbourhoods. Measures also affect the distinct groups in different ways. The panic about day zero seemed to impact every Capetonian, but for the 10% of inhabitants of Khayelitsha that do not have access to any form of piped water or sanitation it was a non-issue. Increasing the cost of water seemed to have little effect on upper middle class consumers, compared to naming and shaming or awareness tactics. But the tariff increases made water unaffordable for less well-off households. Many papers addressing water management measures in Cape Town, propose solutions as if the city represents a homogeneous community of water users, rather than an aggregation of very different groups. Further research about how the different Capetonian communities react to different water-saving measures would be imperative for further development of demand management policies in the city.

8.4 Recommendations: towards water wisdom in Cape Town

8.4.1 Scientific recommendations

While research is consistently published about water management in Cape Town in general, about Day Zero and about the development of specific measures, this study proposes a few important knowledge gaps that are important to address in the future.

The effectiveness of the WCWSS's water rights allocation was widely critiqued in papers and interviews. The measure is, however, necessary to govern consumption by different users. Research into the current South African regulations on water rights and (re)allocation could provide insight into why reallocation procedure are so slow and vulnerable to longlasting appeals processes. It could also suggest means by which the procedure could be made more equitable for all water users (including commercial and emerging farmers, ecosystems, domestic and industrial users).

Additionally, research could be done about the combination of treated effluent reuse and Managed Aquifer Recharge (MAR) in Cape Town. This would create a broader understanding of the risks linked to the reuse of effluent (possible build up of salts, drugs, plastics) and of the social acceptance of the measure. MAR also presents opportunities when using the winter rains that tend to flood the Cape Flats, but further research is also necessary for this, to figure out how this technology would work in practice.

Finally, research that addresses the differences between Cape Town's residents (highlighted above in the discussion in §8.3) is necessary for further development of demand management policies by the municipality. For example, it is unclear why exactly willingness to pay dropped when the water tariffs were changed during the drought. New research could look into the affordability of water for different groups in Cape Town; how much of their income is spent on their water bills and why are households in debt to the municipality? Another example is research that attempts to find a more equitable manner to collect revenue from users than the existing block-tariffs and takes into account the varying sizes of households. Currently poorer households with more residents tend to be unjustly grouped in higher consumption blocks, because - as a household - they use more than the municipality suggests for a four-person household. The price or water consumption for these groups is therefore higher per litre than for some richer (but smaller) households. Further research on revenue collection methods could propose a method of billing that does not disproportionately burden the poor.

8.4.2 Policy recommendations

The policy recommendations that can be taken from this study centre around the implementation of measures for which conditions were roughly found to be present, the further development of some conditions so that additional measures will become more effective, and making sure the research suggested in §8.4.1 is carried out.

It is suggested that both the City of Cape Town and the national Department of Water and Sanitation focus more on the consistent removal and monitoring of non-native vegetation. Additionally, the CCT should explore the possibilities for pressure management projects (such as the one in Khayelitsha) in other neighbourhoods to prevent a lot of water waste. After further research into the possibilities of combining MAR and the use of treated effluent, this could be implemented by the CCT. The municipality also need to make sure the use of private boreholes is well monitored, while developing a plan for revenue collection from the use of these private boreholes.

As discussed, the method of revenue collection currently, does not take into account large household numbers and places the financial burden of bridging a drought with the consumers. This is not equitable or sustainable. A rainless-day fund, as proposed in the city's 2019 water strategy, would aid to bridge a period of low consumption without burdening the city's residents.

The recent focus on diversification in some reports needs to be further developed in public policy. While desalination is an expensive measure, it could provide as a back-up in a worst case scenario in which climate change has strongly affected rainfall in the Cape and demand has continued to grow. Surface reservoirs, on the other hand require space that is no longer available and have become an unreliable source due to the changing climate. The development of new reservoirs is therefore not a viable option for further augmentation of the WCWSS buffer capacity and DWS and CCT policy should reflect this. The allocation of water rights also needs to be structurally revised. Research proposed in §8.4.1 will hopefully present a more effective procedure of reallocation. To make sure the WCWSS can bridge another multi-year drought, less than the current 50% of the system's storage needs to be used on a yearly basis.

Finally, the Water Services Act introduced the Catchment Management Agency in 1997 to help aid cooperation between all water management institutions at catchment level. The Berg-Olifants Water Management Area (of which Cape Town and the WCWSS are a part) has never had a CMA, meaning the WCWSS does not have an institution responsible for the cooperation between these different parties. It was unclear why this is the case, but a CMA would be crucial to a better managed system. It would take over regional tasks of the DWS and possibly improve relations with local irrigation boards, water user associations and the CCT.

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Yates, J. S., & Harris, L. M. (2018). Hybrid regulatory landscapes: The human right to water, variegated neoliberal water governance, and policy transfer in Cape Town, South Africa, and Accra, Ghana. World Development, 110, 75–87

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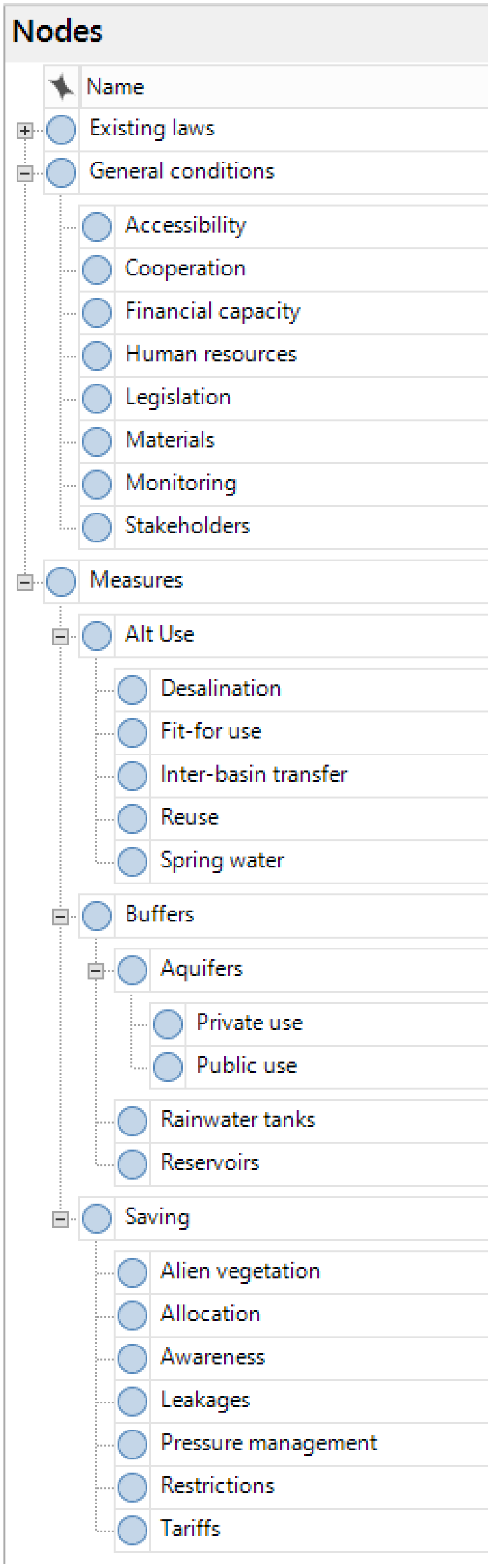
Ziervogel, G. (2019). Unpacking the Cape Town drought: Lessons learned. Cape Town, South Africa: Cities Support Programme and National Treasury of South Africa

Appendix A: Nvivo nodes and subnodes



Appendix B: Interviews

Albert Jansen In Utrecht on February 20th, 2019

CEO and founder - Water Innovation Consulting, inventor of 'Hemelswater'

Tested how the conditions found in section 2.2.2., would work in practice by discussing the issues surrounding the implementation of rainwater tanks in eastern Africa.

Daphina Miesijan In Utrecht on February 28th, 2019

Researcher - Utrecht University

Discussed issues surrounding equitability and international laws on water management. She explained the development and possible implementations of the human right to water, on which the condition accessibility is based.

Boipelo Madonsela In Cape Town on March 12th, 2019

Researcher - University of Cape Town

About her article on CBA of Cape Town, Integrated Water Resource Management in the city, existing measures in and around Cape Town, about governance capacities and the general institutional conditions

Amanda Gcanga In Cape Town on March 22th, 2019

Researcher - Stellenbosch University

This interview provided a general understanding of the institutional and organisational structures (and weaknesses) surrounding the WCWSS

Maura Talbot In Cape Town on March 28th, 2019

Consultant - CES Environmental and Social Services

Interview (28 March, 2019):

This interview provided a perspective on local governance of shared reservoirs, the development of small privatised measures, how the city deals with environmental and social impact of an intervention and about cooperation between rural water users and irrigation techniques.

Megan McLaren In Cape Town on April 29th, 2019

Researcher - University of Cape Town

Discussed financial restrictions when implementing water management measures and research (done by her colleague Martine Visser) surrounding economic incentives, privacy vs naming and shaming and cooperation with municipality (Booysen et al., 2019; Brick, De Martino & Visser, 2017).

Appendix C: Articles about Water Management in Cape Town

These articles were found, solely based on the search "Cape Town" and "water" and the search "Cape Town" and "Day Zero" for the years 2018 and 2019 (untill September). A few irrelevant articles were removed from the list. The articles used in this report from 2018 and 2019 can be added to this list, as none of the papers listed below were used or referenced.

Buffering measures:

Groundwater use:

Luker, E., & Harris, L. M. (2018). Developing new urban water supplies: Investigating motivations and barriers to groundwater use in cape town. International Journal of Water Resources Development, doi:10.1080/07900627.2018.1509787

Meyer, B. E., & Jacobs, H. E. (2019). Garden irrigation as household end-use in the presence of supplementary groundwater supply. Water SA, 45(3), 447-455. doi:10.17159/wsa/2019.v45.i3.6741

Nkosi, S. H., & Daniel Chowdhury, S. P. (2018). Automated irrigation and water level management system using raspberry PI. Paper presented at the 2018 IEEE PES/IAS PowerAfrica, PowerAfrica 2018, 804-809. doi:10.1109/PowerAfrica.2018.8521109 Retrieved from www.scopus.com

Rainwater use

Kanyarusoke, K. (2018). Solar water purifiers for small rural african homesteads: Evaluation of alternative designs. Paper presented at the IOP Conference Series: Earth and Environmental Science, , 188(1) doi:10.1088/1755-1315/188/1/012004 Retrieved from www.scopus.com

Demand Management:

Water demand general:

Booysen, M. J., Ripunda, C., & Visser, M. (2019). Results from a water-saving maintenance campaign at cape town schools in the run-up to day zero. Sustainable Cities and Society, 50 doi:10.1016/j.scs.2019.101639

Lawens, M., & Mutsvangwa, C. (2018). Application of multiple regression analysis in projecting the water demand for the city of cape town. Water Practice and Technology, 13(3), 705-711. doi:10.2166/WPT.2018.082

Regulating Tariffs:

Booysen, M. J., Wijesiri, B., Ripunda, C., & Goonetilleke, A. (2019). Fees and governance: Towards sustainability in water resources management at schools in post-apartheid south africa. Sustainable Cities and Society, 51 doi:10.1016/j.scs.2019.101694

Removal of Non-native vegetation

Potgieter, L. J., Gaertner, M., Irlich, U. M., O'Farrell, P. J., Stafford, L., Vogt, H., & Richardson, D. M. (2018). Managing urban plant invasions: A multi-criteria prioritization approach. Environmental Management, 62(6), 1168-1185. doi:10.1007/s00267-018-1088-4

Efficient irrigation

Storm, M. E., Gouws, R., & Grobler, L. J. (2018). Novel measurement and verification of irrigation pumping energy conservation under incentive-based programmes. Journal of Energy in Southern Africa, 29(3), 10-21. doi:10.17159/2413-3051/2018/v29i3a3058

Alternative-Supply measures:

Wastewater reuse:

Ahmed, A. S., Bahreini, G., Ho, D., Sridhar, G., Gupta, M., Wessels, C., . . . Nakhla, G. (2019). Fate of cellulose in primary and secondary treatment at municipal water resource recovery facilities. Water Environment Research, doi:10.1002/wer.1145

Alsalhy, Q. F., Al-Ani, F. H., & Al-Najar, A. E. (2018). A new sponge-GAC-sponge membrane module for submerged membrane bioreactor use in hospital wastewater treatment. Biochemical Engineering Journal, 133, 130-139. doi:10.1016/j.bej.2018.02.007

Alsalhy, Q. F., Al-Ani, F. H., Al-Najar, A. E., & Jabuk, S. I. A. (2018). A study of the effect of embedding ZnO-NPs on PVC membrane performance use in actual hospital wastewater treatment by membrane bioreactor. Chemical Engineering and Processing - Process Intensification, 130, 262-274. doi:10.1016/j.cep.2018.06.019

Bolton, C. R., & Randall, D. G. (2019). Development of an integrated wetland microbial fuel cell and sand filtration system for greywater treatment. Journal of Environmental Chemical Engineering, 7(4) doi:10.1016/j.jece.2019.103249

Bonthuys, J. (2018). Cape town drought places sewerage systems under pressure. Water Wheel, 17(3), 12-15. Retrieved from www.scopus.com

Di Trapani, D., Mannina, G., & Viviani, G. (2018). Membrane bioreactors for wastewater reuse: Respirometric assessment of biomass activity during a two year survey. Journal of Cleaner Production, 202, 311-320. doi:10.1016/j.jclepro.2018.08.014

Ebrahim, W., & Randall, D. G. (2019). Implications of different toilet flushing solutions on the precipitation potential of urine. Journal of Water Process Engineering, 31 doi:10.1016/j.jwpe.2019.100847

Mannina, G., Ekama, G. A., Capodici, M., Cosenza, A., Di Trapani, D., & Ødegaard, H. (2018). Integrated fixed-film activated sludge membrane bioreactors versus membrane bioreactors for nutrient removal: A comprehensive comparison. Journal of Environmental Management, 226, 347-357. doi:10.1016/j.jenvman.2018.08.006

Icebergs as supply-measure:

de Waal, R. J. O., Bekker, A., & Heyns, P. S. (2018). Indirect load case estimation for propeller-ice moments from shaft line torque measurements. Cold Regions Science and Technology, 151, 237-248. doi:10.1016/j.coldregions.2018.03.016

Malan, N. (2018). Are icebergs a realistic option for augmenting cape town's water supply? Water Wheel, 17(2), 32-34. Retrieved from www.scopus.com

Desalination:

Crookes, D. J. (2018). Does the construction of a desalination plant necessarily imply that water tariffs will increase? A system dynamics analysis. Water Resources and Economics, 21, 29-39. doi:10.1016/j.wre.2017.11.002

Myburgh, J., Ismail, F., & Nemraoui, O. (2019). Mathematical modelling and simulation of an inclined solar water desalination unit. Paper presented at the Proceedings of the Conference on the Industrial and Commercial use of Energy, ICUE, , 2018-August Retrieved from www.scopus.com

Conditions

Financial capacity

Simpson, N. P., Simpson, K. J., Shearing, C. D., & Cirolia, L. R. (2019). Municipal finance and resilience lessons for urban infrastructure management: A case study from the cape town drought. International Journal of Urban Sustainable Development, doi:10.1080/19463138.2019.1642203

Institutional: decision making processes and facilitating regulations:

Caball, R., & Malekpour, S. (2019). Decision making under crisis: Lessons from the millennium drought in australia. International Journal of Disaster Risk Reduction, 34, 387-396. doi:10.1016/j.ijdrr.2018.12.008

Chipako, T. L., & Randall, D. G. (2019). Urinals for water savings and nutrient recovery: A feasibility study. Water SA, 45(2), 266-277. doi:10.4314/wsa.v45i2.14

Harris, L. M. (2019). Assessing states: Water service delivery and evolving state–society relations in accra, ghana and cape town, south africa. Environment and Planning C: Politics and Space, doi:10.1177/2399654419859365

The Lancet Planetary Health. (2018). Water crisis in cape town: A failure in governance. The Lancet Planetary Health, 2(3), e95. doi:10.1016/S2542-5196(18)30032-9

Stakeholder Engagement:

Harris, L. M., Kleiber, D., Rodina, L., Yaylaci, S., Goldin, J., & Owen, G. (2018). Water materialities and citizen engagement: Testing the implications of water access and quality for community engagement in ghana and south africa. Society and Natural Resources, 31(1), 89-105. doi:10.1080/08941920.2017.1364818

Tremblay, C., & Harris, L. (2018). Critical video engagements: Empathy, subjectivity and changing narratives of water resources through participatory video. Geoforum, 90, 174-182. doi:10.1016/j.geoforum.2018.02.012

Climate impacts and processes:

Jury, M. R. (2018). Climate trends across south africa since 1980. Water SA, 44(2), 297-307. doi:10.4314/wsa.v44i2.15

Kusangaya, S., Warburton Toucher, M. L., & van Garderen, E. A. (2018). Evaluation of uncertainty in capturing the spatial variability and magnitudes of extreme hydrological events for the uMngeni catchment, south africa. Journal of Hydrology, 557, 931-946. doi:10.1016/j.jhydrol.2018.01.017

Mahlalela, P. T., Blamey, R. C., & Reason, C. J. C. (2019). Mechanisms behind early winter rainfall variability in the southwestern cape, south africa. Climate Dynamics, 53(1-2), 21-39. doi:10.1007/s00382-018-4571-y

Sousa, P. M., Blamey, R. C., Reason, C. J. C., Ramos, A. M., & Trigo, R. M. (2018). The 'day zero' cape town drought and the poleward migration of moisture corridors. Environmental Research Letters, 13(12) doi:10.1088/1748-9326/aaebc7

General:

Balbi, S., Selomane, O., Sitas, N., Blanchard, R., Kotzee, I., O'Farrell, P., & Villa, F. (2019). Human dependence on natural resources in rapidly urbanising south african regions. Environmental Research Letters, 14(4) doi:10.1088/1748-9326/aafe43

Elder, J. D., Burgess, R. A., & Beruvides, M. G. (2018). Ethical critical infrastructure decision making in perpetual sustainability. Paper presented at the 39th International Annual Conference of the American Society for Engineering Management, ASEM 2018: Bridging the Gap between Engineering and Business, 232-241. Retrieved from www.scopus.com

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LaVanchy, G. T., Kerwin, M. W., & Adamson, J. K. (2019). Beyond ‘Day zero’: Insights and lessons from cape town (south africa). [超越“零日”:来自开普敦(南非)的见解和教训] Hydrogeology Journal, 27(5), 1537-1540. doi:10.1007/s10040-019-01979-0

Maxmen, A. (2018). Cape town scientists prepare for 'day zero': As water crisis brews, researchers plan to modify studies and prioritize public health. Nature, 554(7690), 13-14. doi:10.1038/d41586-018-01134-x

McIntyre-Mills, J., & Wirawan, R. (2018). Cascading risks of climate change on water security and the potential for rapid adapatation consequences of modernity', potential of the double hermeneutic and implications for human security. Paper presented at the 62nd Annual Meeting of the International Society for the Systems Sciences, ISSS 2018: Innovation and Optimization in Nature and Design, 1-34. Retrieved from www.scopus.com

Miller, J. (2019). Managing urban water: The role of isotope hydrology and what the cape town water crisis taught us. IAEA Bulletin, 60(1), 29-30. Retrieved from www.scopus.com

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Robins, S. (2019). ‘Day zero’, hydraulic citizenship and the defence of the commons in cape town: A case study of the politics of water and its infrastructures (2017–2018). Journal of Southern African Studies, doi:10.1080/03057070.2019.1552424

Rodina, L. (2019). Planning for water resilience: Competing agendas among cape town's planners and water managers. Environmental Science and Policy, 99, 10-16. doi:10.1016/j.envsci.2019.05.016

Shepherd, N. (2019). Making sense of "day zero": Slow catastrophes, anthropocene futures, and the story of cape town's water crisis. Water (Switzerland), 11(9) doi:10.3390/w11091744

Simpson, N. P., Shearing, C. D., & Dupont, B. (2019). Climate gating: A case study of emerging responses to anthropocene risks. Climate Risk Management, 26 doi:10.1016/j.crm.2019.100196

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Strunz, S., Marselle, M., & Schröter, M. (2019). Leaving the "sustainability or collapse" narrative behind. Sustainability Science, doi:10.1007/s11625-019-00673-0

Van Belle, J. -., & Hlabano, M. (2019). Building urban resilience in the face of severe drought through the innovative use of open data. Paper presented at the 2019 4th MEC International Conference on Big Data and Smart City, ICBDSC 2019, doi:10.1109/ICBDSC.2019.8645586 Retrieved from www.scopus.com

Zhang, H., Xu, Y., & Kanyerere, T. (2019). A modelling approach to improving water security in a drought-prone area, west coast, south africa. Physics and Chemistry of the Earth, doi:10.1016/j.pce.2019.08.005