TRANSITIONING TOWARDS WATER SUPPLY DIVERSIFICATION: POSSIBILITIES FOR GROUNDWATER IN CAPE TOWN, SOUTH AFRICA

by

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Abstract

Due in part to negative climate change impacts on water availability, and the fact that urban populations across the globe are growing, cities are experiencing increasing stress on their water resources. Therefore, new options for urban water demand and supply management are being considered to address this concern. In the case of Cape Town, South Africa, overall water demand is increasing despite a successful water demand management campaign, while water supplies are dwindling. These conditions are aggravated by a recent severe drought that began in 2015. Transitions towards additional bulk water supplies are therefore needed, and the City has addressed this through plans for future water supply diversification in the form of large-scale groundwater development. However, given the historical focus on surface water infrastructure in Cape Town, there are significant obstacles in adding new sources, such as aquifers, into the supply chain. This Masters' of Science thesis will present the findings of a research study that was aimed at analyzing the motivations, barriers and possibilities for groundwater governance in Cape Town, with particular attention to the expert perspective. Findings are based on three months of fieldwork in Cape Town, where data was collected through in-depth interviews with water experts and professionals involved in the Cape Town water sector, as well as field observations and water policy and document analysis. Chapter 2 of this work outlines the motivations and barriers for groundwater integration. This chapter emphasizes the benefits of groundwater for water security and resilience, while maintaining that fragmented roles and responsibilities to do with groundwater governance present significant challenges. Chapter 3 explores an existing groundwater scheme in Cape Town and presents three lessons learned for future groundwater policy development. Lessons learned include aquifer recharge zone protection, sufficient field operator training and consistent institutional support for groundwater knowledge leaders. The main goal of this thesis is to provide insight into the motivations and challenges associated with water supply diversification, and sustainable groundwater use in

particular. These insights are relevant for broader discussions of water governance transitions in light of changing water demand and supply dynamics, as well as hydrological regime changes.

Lay Summary

New options for urban water management are being considered as cities experience increasing stress on their water resources. In the City of Cape Town, there are plans for new groundwater supply development. However, there are significant obstacles in adding new water sources into the supply chain. This thesis presents a study about the possibilities for groundwater in Cape Town from the expert perspective. The first chapter of this work outlines the motivations and barriers for future groundwater use. This chapter emphasizes the benefits of groundwater for water security, while maintaining that unclear groundwater responsibilities present significant challenges. The second chapter explores an existing groundwater scheme and presents three lessons learned for future groundwater policy development. The main goal of this thesis is to provide insight into the dynamics associated with new water supplies, and sustainable groundwater use in particular, when discussing changes in the way that urban water is managed.

Preface

This thesis is original, unpublished and independent work of the author, E. Luker. It was written in collaboration with the Comparative Water Governance in Urban Sites of Africa research project (CWGAR) conducted by the EDGES Research Collaborative. None of the text of this thesis is taken from published or collaborative articles.

The fieldwork reported in Chapters 2- 4 was covered by UBC Behavioural Research Ethics Board Certificate number #H16-00226.

The research interviews that make up the bulk of the data collected and analyzed for the purpose of this thesis were conducted, in part, collaboratively with PhD candidate (at the time of this writing) Lucy Rodina. Dr. Leila Harris identified my region of study and provided me the opportunity to design my thesis research around the larger CWGAR project. Dr. Leila Harris, Dr. Mark Johnson and Dr. Jordi Honey-Rosés provided feedback and comments on thesis chapter drafts, as well helpful suggestions and ideas.

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List of Abbreviations and Acronyms

AWRMS	Atlantis Water Resource Management Scheme
CCT	City of Cape Town
CFA	Cape Flats Aquifer
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
MAR	Managed Aquifer Recharge
PHA	Philippi Horticultural Area
O&M	Operation and Maintenance
SUWM	Sustainable Urban Water Management
TMG	Table Mountain Group Aquifer
WCWSS	Western Cape Water Supply System
WRC	Water Research Commission
WSUD	Water Sensitive Urban Design

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Thank you all.

Dedication

For my grandmother, my Nanny, Melva Murphy (Luker),

A true inspiration and woman of strength.

For my grandfather, my Poppy, Samuel Luker,

A lover of new knowledge and dinner table debates.

Chapter 1: Introduction and Context

1.1 Conceptual Framework

1.1.1 Water Governance Transitions

We are living in a generation of cities. Populations are growing in cities as job opportunities and proximity to amenities make urban centres increasingly attractive. This is mounting stress on the natural resources needed by dense urban populations. Indeed, increases in water demand related to increasing populations is a major driver of global water stress, in addition to other factors such as climate change projections (Vorosmarty et al. 2000). Urban water professionals and researchers globally are responding to increases in water stress and constraints in cities due to urban population growth by moving towards more sustainable management of urban water.

Water management describes the “activities of analyzing and monitoring, developing and implementing measures to keep the state of a water resource within desirable bounds” (Pahl-Wostl et al. 2012, Knieper & Pahl-Wostl 2016). Thus, any reference to the term “water management” in this thesis refers to the actions taken to ensure a specific water resource is kept in a desirable state. The rules under which water management functions are embedded in the broader context of water governance, which “takes into account the different actors and networks that help formulate and implement water policy” (Pahl-Wostl et al. 2012, Knieper & Pahl-Wostl 2016). However, the term “governance” is a much larger term that can cause some confusion. Bakker notes that “governance” can include any practice of coordination and decision-making between different actors (2010). Additionally, water governance is related to a suite of processes within informal and formal institutions, but also related to the understandings, norms, values, and expectations to do with water. Bakker goes on to explain that using a broad definition of water governance in this way, while much broader than is the norm in the water management literature, can help us understand some of the more persistent failures and fragmentation of different governance models (2010). Therefore, in this thesis, when referring to activities of governance, I am referring to these broader formal and informal coordination and decision-making processes between individual actors and larger bodies. As systems of water management are expressed through governance structures, i.e. the larger processes of political culture and power (Bakker 2010), examining water sector transitions can provide a better understanding about any corresponding changes in larger governance priorities and responsibilities.

There is a large, multi-faceted body of work around governance transitions, and water institutional transitions in particular. Here, I am using the term "institution" in reference to formal institutions, defined as the "official political and bureaucratic regulatory structures," as opposed to informal institutions, which can be defined as "socially and culturally shared norms" (Glaas et al. 2010). In particular, formal water institutions can be narrowly defined as the rules and authorities that delineate actions and determine the outcomes of decisions made about water development, allocation, use and management (Saleth & Dinar 2005). This definition clarifies the role of water institutions in reflecting the larger processes of governance, and the importance of this lens when discussing water-related responsibilities, such as water allocation and use.

Past societal values affect changes within our current institutions, thus present day societal values will impact the institutional structures of the near future (Cortner 1998). This is relevant to governance changes in water institutions globally because there have been significant shifts in the last decade surrounding the perceptions of what makes for sustainable water management and governance. "New" forms of sustainable water management emphasize parallel foci on water demand and supply management; diversifying into using non-traditional water sources; introducing the concept of "fit-for-purpose," or treating water quality to minimum standards for its use; and decentralization of water governance responsibilities and authority (Mitchell 2006). Introducing these new water management mechanisms are one piece of the governance shifts being implemented by various water institutions globally, and is preferred over full structural rearrangements because of the implementation difficulties and complexity underlying environmental policy (Briassoulis 2004).

Shifts towards water governance prioritizing resource sustainability has translated into a greater range of mechanisms that move beyond conventional approaches to water management. New mechanisms are predominantly organized into new frameworks that approach urban water management from different ways. This thesis is written from the point of view of exploring these new approaches to urban water management, and how they can be applied to emergent plans for water supply diversification, using the City of Cape Town, South Africa as a case study. My specific research lens uses two proposed groundwater schemes in Cape Town as examples for future transitions in groundwater governance. While my work speaks specifically to Cape Town's water future, my research findings are also relevant to the larger shift towards sustainable urban water management and long-term water supply planning and diversification in water scarce regions globally. The following section will give an overview of the urban water management frameworks that are relevant for my work and most prevalent in the literature.

1.1.2 Overview of Urban Water Management Frameworks

In the urban water management literature, there are a fair number of different frameworks that are discussed, however most are based on similar foundational concepts and theories. Management frameworks provide bounded and structured guidance for interventions that generate benefit, utility and effective management of natural resources (Medema et al. 2008). Due to the fact that urban water management has entered "an era of the sustainable allocation of a scarce resource," the fundamental focus of these approaches is on the process of operationalising sustainable water systems (Pearson et al. 2010).

The two most relevant frameworks for my work are Sustainable Urban Water Management and Water Sensitive Urban Design, which I detail below. Two frameworks I will additionally mention are Integrated Water Resource Management, which focuses on the integration and coordination of land and water management at different scales and in different management sectors, and Adaptive Management, which is centered around explicitly addressing unpredictable relationships between society and natural systems while still taking management action (Medema et al. 2008). It is important to fully understand the tools and frameworks available to those working in, and researching, water management in order to build further insight into the present urban water management landscape.

A major framework being used in the urban water management literature is Sustainable Urban Water Management (SUWM). This approach to urban water management was born out of the Brundtland Commission report and Agenda 21, which prioritized sustainable development in 1987 (Larsen & Gujer 1997). SUWM emphasizes the idea of managing the "total water cycle," and confronting past linear and technical approaches that failed to incorporate natural water cycles into their impermeable, structural management practices (Brown & Farrelly 2009). In 1999, Sweden began a 6-year research program entitled "Sustainable Urban Water Management," with the mandate of creating urban areas where water can be safely used, reused and then returned to nature (Helstrom et al. 2000). This program encapsulates the principles of SUWM: community wellbeing, ecological health and sustainable development, which are associated with the co-evolution of green issues and water policy developments (Marlow et al. 2013). Notably, SUWM has relatively large consensus and support from the academic community, but has struggled to find mainstream adoption for applied, transformational agendas in communities of practice (Brown & Farrelly 2009, Marlow et al. 2013).

A second notable framework is Water Sensitive Urban Design (WSUD), which describes an emergent water management paradigm, and future aspirations of traditionally managed urban water institutions (Wong & Eadie 2000, Donofrio et al. 2009). WSUD outlines ways to use urban water along the water cycle, such as harvested stormwater and rainwater. By building water flows into urban design, WSUD presents a set of principles with which to integrate the conventional fields associated with water service provision, such as engineering and construction, with key environmental values associated with water resource and aquatic environmental protection (Wong & Brown 2009). In 2008, Brown et al. built on this framework by introducing the new concept of a “water sensitive city,” which was the final goal of a six phase “urban water transitions framework” (Brown et al. 2008a). A water sensitive city: (1) maintains access to a diversity of water sources, (2) prioritizes ecosystem services to support both the human and natural systems, and (3) provides socio-political capital to water sensitive decision-making (Wong & Brown 2009). WSUD and the water sensitive city conceptual frameworks has seen significant global uptake in the last decade, both in the practitioner and academic communities, in countries such as Singapore (Luan 2010, Brown et al. 2008b), the United Kingdom (Ashley et al. 2013), Australia (Brown et al. 2008b, City of Melbourne 2009) and South Africa (Armitage et al. 2014, City of Johannesburg 2012).

With increasing water scarcity comes the need for unconventional and innovative approaches to balancing water demand and supply. One clear thread that connects water governance transitions with more sustainable and sensitive design of urban water systems is the shift towards access to diverse water supply (Wong & Brown 2009) and using alternative water sources (Armitage et al. 2014). This conceptual overview provides the context of my research, which is focused on water supply diversification in semi-arid, urban areas, more specifically groundwater governance in the City of Cape Town (CCT). This thesis focuses on the current groundwater landscape of the CCT, and the possibilities for future groundwater schemes given transitions in water governance towards alternative water sources, as well as an ongoing drought at the time of this writing. A more detailed account of the groundwater planning context of the CCT is in Section 1.3. Section 1.2 will outline my specific research questions and objectives, in order to structure the goals of my thesis, as well as provide insight into my research approach and methodology, which form the basis of this chapter.

Building on the conceptual foundations of urban water management frameworks and transitions in urban water interests, I now take a targeted look at a water source that can be a new, emerging resource or an traditional, overexploited water resource depending on the context: groundwater.

1.1.3 Global Context of Groundwater

Historically, groundwater is a water resource that has many proven benefits. It provides safe potable water to approximately 2 billion people worldwide, and 40% of global food production relies primarily on improved irrigation from groundwater sources (Morris et al. 2003). However, groundwater has also been overexploited in many different global contexts (Gleeson et al. 2012a). Thus, it is important for emerging stakeholders in groundwater management and governance to avoid abstracting groundwater unsustainably. There is a large body of work related to best management practices for groundwater (Gleeson et al. 2012b, Jakeman et al. 2016), groundwater governance frameworks (Riemann et al. 2012) and collaborative decision-making for groundwater resources (Brown et al. 2016), which are useful for groundwater planning in both rural and urban contexts. However, for countries like South Africa that have past and current legacies of “uneven and combined development” (Bond 2006), it can difficult to find relevance in these principles when other governance priorities, such as poverty reduction, are most pressing. Lessons learned from other countries more clearly on the development spectrum are thus harder to apply to cities such as Cape Town, South Africa, which experiences significant inequality and poverty (Lemanski 2007) as well as substantial wealth. This development argument is also parallel to the difficulties in comparing groundwater governance narratives due to key differences in the geological makeup of aquifers, which is further explained in Chapter 3, Section 3.2. Some groundwater policy contexts in developed and developing countries put Cape Town's groundwater story partly in perspective.

Perth, Australia (Turral & Fullagar 2007) and Phoenix, U.S.A, (Jacobs et al. 2004, White et al. 2008) are potentially instructive for Cape Town in that they are similarly semi-arid, urban areas that are experiencing similar water constraints and highly variable seasonal rainfall. These cities have had clear groundwater allocation and extraction procedures in place for the last 20+ years. However, even with concrete frameworks in place, these urban centers have experienced tumultuous social and environmental effects as a result of short sighted groundwater management (Turral & Fullagar 2007, Jacobs et al. 2004, White et al. 2008). These effects include major disputes over water rights, overexploitation of groundwater and water quality concerns, such as saltwater intrusion. These long terms planning frameworks are in stark contrast to Cape Town's limited groundwater planning, and also add to the complexities behind ensuring sustainable long-term groundwater abstraction.

To give some context for groundwater management in developing countries: following the boom in groundwater use across South Asia in the 1970s, the densely populated states of Punjab, Pakistan and Gujarat, India, saw significant socio-hydrological problems arise from groundwater drawdown. This was due to mismanaged groundwater policies, deterioration in groundwater quality and declining farmer livelihoods due to an insufficient water supply for irrigation (van Steenbergen & Oliemans 2001, Shah et al. 2008). Indeed, the overexploitation of groundwater resources in India has led to a drastic decline in groundwater levels, which is threatening the livelihoods and food security of 90 million households (Zaveri et al. 2016).

Notably, this extreme groundwater drawdown in India has been attributed to groundwater usage outstripping natural aquifer recharge rates (Cook-Anderson 2009) because of a misguided groundwater policy that has had an insufficient focus on water conservation (Biswas et al. 2017). This example provides insight on the social and ecological problems that can arise when water supply development is not accompanied by water demand management initiatives.

Interestingly, the groundwater narrative in Cape Town is unique from these global examples of groundwater overexploitation in that it is a water resource that has thus far been mostly used by Cape Town residents and small-scale farmers through informal boreholes, as opposed to being used by a centralised system (Colvin & Saayman 2007). In contrast to the experiences of India, municipal demand side management mechanisms in Cape Town have significantly reduced water demand despite a growing population (see Section 1.3.1). In addition, Cape Town is different from these narratives because the residential and formal agricultural sectors have been largely dependent on surface water. While supply capacity is a poor indicator of groundwater abstraction sustainability, from these examples, it is clear that heavy reliance on groundwater has been highly problematic in the past, and has been a driver behind groundwater mismanagement in different global contexts. Thus, it is imperative that Cape Town strive to learn from these examples (as well as local lessons learned, which are outlined in Chapter 3), and avoid similar issues of contested water rights, groundwater drawdown and effects on local livelihoods and lifestyles.

1.2 Research Questions and Objectives

My research explores the broad concepts of urban water planning in water scarce regions through the general question of: What are the perceptions of long term water supply planning in an urban, semi-arid area, given past histories of surface water dependence and current changing patterns of water scarcity?

Building off of this broad question, I bounded my study with two directed questions:

1. What are the expert perceptions surrounding integrating large-scale groundwater sources into the water supply system of Cape Town, South Africa?
2. How can institutional knowledge from past groundwater projects inform future groundwater schemes and governance practices?

These targeted questions make up the two body chapters of my thesis respectively. Chapter 2 provides a higher-level characterization of the perceptions of groundwater planning and policy development from experts involved in groundwater decisions at the CCT. Chapter 3 examines a nested case study within the case of Cape Town, and develops some lessons learned for future groundwater projects. To be clear, my research is focused on the possibilities for future groundwater use in Cape Town, and what that type of water supply diversification might look like. I am speaking from the point of view that groundwater will be in Cape Town's water future. This should not go without a note of caution that surrounds large infrastructure changes, and any potential negative externalities associated groundwater drawdown or aquifer contamination.

The overall objectives of this research are to provide insight on what the water future of Cape Town might look like given current water planning activities and hydrological regime changes, and to contribute to the urban water management literature concerning water governance transitions concerning increasing interest in the sustainable management of urban water.

1.3 Site Context and Methodology

1.3.1 Cape Town Context

1.3.1.1 Cape Town Water Supply History

The history of water allocation and access in South Africa is impacted by the geographical and resource distribution boundaries drawn according to race, and solidified during the apartheid era. Under apartheid, the white minority government established control over the bulk of the country's water, and in turn developed well-defined water institutions and laws that ensured future access to South Africa's scarce water resources (van Koppen et al. 2003). As a result, investment in pipes, reticulation systems, dams, inter-basin transfers and the general provision of water supplies predominantly served white South Africans, which resulted in inequitable distribution of water (Goldin 2010). An implication of this inequity to do with water access is that experiences in citizenship and state power understanding are currently highly differentiated across spatial and racial lines (Rodina and Harris 2016).

Presently, 97.3% of Cape Town citizens have access to water provided by the local water scheme (Statistics South Africa 2011a) known as the Western Cape Water Supply System (WCWSS). This system supplies water to the Cape Town metropolitan area, as well as the major nearby suburbs and agricultural areas (Figure 1). As the City of Cape Town Metro is so densely populated, the water management area that contains the City of Cape Town (CCT) makes up more than 80% of the whole Western Cape Province population (Western Cape Government 2013). Thus, the CCT is the major stakeholder of the WCWSS. At present, 1.5% of the CCT's water comes from groundwater sources, while 98.5% comes from surface water sources in the form of five major dams (CCT 2014a); an overall mix that that is largely consistent across major urban areas in South Africa. This leaves the system highly vulnerable to changes in surface water availability, such as changing precipitation patterns or increased evaporation (Herrfahrdt-Pähle 2010). Understanding the vulnerabilities of the WCWSS appears to be particularly important at present due to the drought that the CCT is experiencing at the time of this writing.

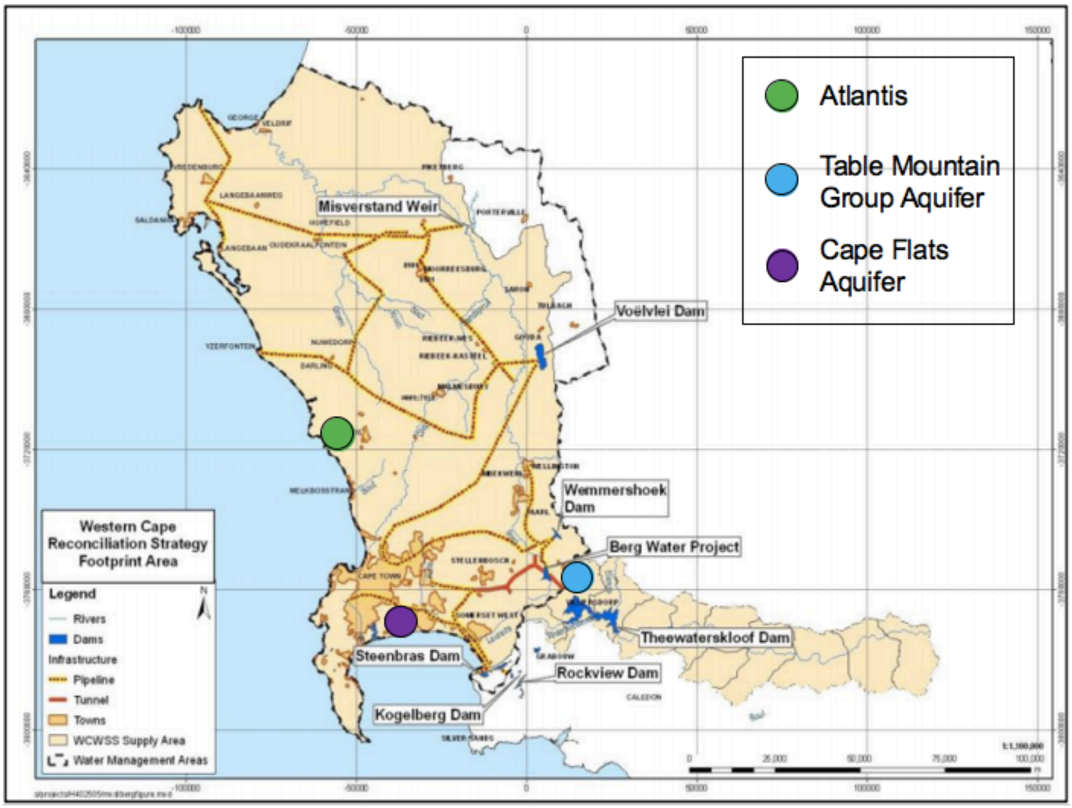

Figure 1: The Western Cape Water Supply System (WCWSS) and identified important groundwater areas for the purposes of this thesis: Atlantis, Cape Flats Aquifer (CFA) and Table Mountain Group Aquifer (TMG). Note: Aquifer locations are approximate as future abstraction sites are yet to be determined at the time of this writing; locations are based on current groundwater level monitoring stations. Source: The Department of Water and Sanitation of South Africa, Western Cape Water Supply System Reconciliation Strategy (2007), reprinted with permission.

Recent evidence from the Southern Africa region points to shorter rainy seasons coupled with more extreme rainfall events in the future, which could enhance drought periods, exacerbate the risks of flooding and soil erosion, and put regional food security into question (Pohl et al. 2017). Indeed, the year 2015 was the driest year in South Africa in 112 years (South Africa Weather Service 2016). The country is currently (June 2017) experiencing an intense two-year drought, the end date of which is highly uncertain due to rainfall variability and ongoing climate change effects (Baigrie 2017). South Africa's Department of Water and Sanitation (previously known as the Department of Water Affairs) identified the greater Cape Town region as the first major urban area in South Africa where water demand will exceed total potential water yield if the expected economic and population growth scenarios or impacts of regional climate change are realised (Mukheiber & Ziervogel 2007).

Climate change is expected to exacerbate existing water-related stressors, such as the prevalence of droughts, while also reducing stream flows and groundwater recharge rates (ADAM 2009). Increasing urban water demand, due mainly to population growth (Ziervogel et al. 2010), when coupled with climate change impacts is projected to significantly reduce the water resource capacity of the Cape Metropolitan Region over the next three decades (New 2002). Furthermore, it is expected that the region will be characterized as "chronically water scarce" by 2025 (Herrfahrdt-Pähle 2010), which prompts concern over water availability for water processes throughout the water cycle, including: surface runoff and discharge, infiltration, and deep percolation of infiltrated water into regional aquifers. Indeed, the impacts on groundwater level responses to precipitation inputs from the 2009 drought in Cape Town appear to have been noticeable from 2010-2013, for both mountainous and coastal aquifers in the CCT metropolitan areas (refer to Figures 2 and 3 in Chapter 2).

In response to the ongoing drought, the CCT has rolled out water restriction levels in stages, according to assessments of dam water storage levels and water demand projections for the duration of the 2017 dry season. As of February 1st, 2017, the CCT implemented Level 3B restrictions (CCT 2017), which had never been used for the metro before, and Level 4 restrictions on June 1st, 2017, thus marking two increasingly unprecedented institutional decisions.

Historically, demand-based approaches such as water restrictions have been a main focus of the City. A Water Demand Management and Water Conservation (WDM/WC) policy was rolled out in 2001 (DWAF 2007, CCT 2016), which included pressure management, leak detection, leak repairs, and implementing water management devices, such as smart meters. While the WDM/WC policy has been celebrated globally for its success, smart meters have been likened to "debt-recovery strategies in disguise" that tend to target poorer households (Wilson and Pereira 2012). According to the Western Cape Reconciliation Strategy Update in 2014, the CCT reduced non-revenue water from to 23.3% in 2008/09 to 21.8% in 2013/14, and water losses from 22.6% to 14.7% (DWA 2014). Additionally, this research found that over the last decade approximately, the WDM/WC policy resulted in a relative plateau in overall water demand for the City. However, since 2014 overall demand has begun to rise. This is mainly attributed to economic and population growth (CCT 2016), and has sparked conversations about expediting the development of increased water supplies (Winter 2017). This conversation also builds upon scenario modelling evidence that shows how WDM/WC needs to be complemented by regional supply augmentation to ensure system efficiency (DWAF 2007, Ziervogel et al. 2010), and the consensus that the CCT Metro area has reached watershed capacity for dams after the construction of the Berg River Dam in 2009 (Joubert et al. 2003). Mounting institutional investment into the water supply diversification possibilities for the CCT (DWS 2014) presents an opportunity for the region to continue the trajectory towards the pillar of "access to diverse water sources" within the water sensitive city framework.

In 2007, the national Department of Water and Sanitation (DWS), in conjunction with the CCT, created a Reconciliation Strategy, prescribing what supply augmentation schemes were possible for the Western Cape Water Supply System over the next 20 years (DWAF 2007). Refer to Table 1 for details on the responsibilities of the three main levels of government in South Africa with regards to water management and governance. The DWS and CCT updated this strategy most recently in 2014 (DWS 2014). The strategy outlines four augmentation schemes: (1) river to dam inter-basin transfer, (2) deep aquifer groundwater for bulk water supply, (3) shallow aquifer storage of recycled wastewater and stormwater, and (4) desalination. The strategy describes what the four schemes might look like in 11 different scenarios, given different water demand projections, environmental dam releases and climate change impact scenarios (DWAF 2007). Given that the second and third supply schemes are centered around groundwater development, the upscaling of the contribution of groundwater sources in the future becomes clear, which provides an opportunity for water sensitive thinking when designing these two schemes.

Table 1: Primary South African governmental institutions and their departmental responsibilities with regards to water governance in Cape Town. Note: this table does not include Non-Governmental Organizations, Catchment Management Agencies, Regional Water Utilities, Water User Associations and informal institutions, as they are outside the scale and scope of this research.

GOVERNMENTAL INSTITUTION	RELEVANT DEPARTMENT	ROLE AND RESPONSIBILITIES
CITY OF CAPE TOWN (CCT)	Department of Water and Sanitation	• Water service authority. • Water infrastructure management and supply planning for the City. • Table Mountain Group Aquifer feasibility studies and future planning.
WESTERN CAPE GOVERNMENT	Department of Environmental Affairs and Development Planning	• Environmental protection and sustainable development for the Province. • Little involvement in water management or governance.
SOUTH AFRICAN GOVERNMENT	Department of Water and Sanitation	• Water resource governance. • Formulation and implementation of water policy for the country. • Cape Flats Aquifer feasibility studies and future planning.

Indeed, there has been a successful effort in producing a specific WSUD framework for South Africa, with major roots in Cape Town (Armitage et al. 2014). Armitage et al. (2014) outline a set of guidelines for implementing WSUD projects in South Africa, and focus on a number of fundamental issues, including: fragmented institutional structure, supporting WSUD knowledge leaders also known as “champions,” and adaptability and uncertainty to climate change effects. Additionally, the University of Cape Town launched the Future Water Institute late in 2016, with the aim of conducting research on the topic of water scarcity and based completely on WSUD principles “within an over-arching systems framework supported by strong sociological, technical, environmental, legislative and governance expertise” (Future Water Institute 2017). With the academic community’s support, the South African Department of Water and Sanitation (DWS), along with municipal steering committees, has attempted to follow the shift towards WSUD processes and has focused on developing a long-term plan for sustainable urban water management in the nine diverse provinces of South Africa.

1.3.2 Methodology

1.3.2.1 Field Methods

I conducted three months of fieldwork in Cape Town, South Africa in the winter of 2016 (June-September), and was hosted by the Environmental and Geographic Sciences Department at the University of Cape Town. While in South Africa, I completed 15 in-depth interviews with experts and stakeholders in the water sector of Cape Town, some of which were conducted collaboratively. Interviewees ranged from managers and department heads from the City of Cape Town who are involved with the decisions, plans and management of local water resources; consultants and technical experts hired by the City to complete aquifer feasibility studies; and NGO workers and farmers involved in conversations about local groundwater discussions (see Table 2). Since groundwater has been used as small-scale resource in the past, the number of decision-makers, water managers and consultants involved in groundwater governance and planning in the CCT is limited. Therefore, I am confident that it is inclusive of the range of views and perspectives of these experts in the CCT region.

I chose to interview those at the local government level because the feasibility studies to do with local groundwater projects are currently being managed by the CCT and local consultancies. A limitation of this method is that my research lacks insight into the higher-level water governance vision that the national government could have provided. However, the major higher-level water governance and water policy implementation by the South African Government was completed prior to my work, such as the Reconciliation Strategy in 2007 and the Strategy Update in 2014. While there is ongoing influence from the national government, my interests lay mainly within the scope of CCT urban water planning. I chose not to approach the Western Cape Government because there is no provincial mandate related to water planning or governance outside of environmental protection (refer to Table 1). If the timing of my fieldwork had been less constrained, I might have liked to include participants from the national Department of Water and Sanitation regional office, in order to gain additional insights and groundwater perceptions. However, this was not a priority of my M.Sc. research.

Table 2: Detailed breakdown of the organizations interviewed for this thesis, and their affiliation or relevance to my research. Note: The number of interviewees refers to the number of individuals interviewed (18), resulting in a total of 15 interviews.

SECTOR	ORGANISATION	AFFILIATION OR RELEVANCE	NUMBER OF INTERVIEWEES
LOCAL GOVERNMENT	City of Cape Town	Water and Sanitation: Water Demand Management and Strategy Branch	1
		Water and Sanitation: Bulk Water Branch	3
		Water and Sanitation: Reticulation Branch	2
		Stormwater and Sustainability Branch	3
		Department of Spatial Planning	1

SECTOR	ORGANISATION	AFFILIATION OR RELEVANCE	NUMBER OF INTERVIEWEES
CONSULTANCIES AND RESEARCH ORGANISATIONS	Council for Scientific and Industrial Research	Atlantis	1
	Umvoto Africa	Table Mountain Group and Cape Flats aquifers	2
	Hydrologic Consulting	Cape Flats aquifer	1
NON-GOVERNMENTAL ORGANISATIONS	Environmental Monitoring Group	Broader community issues of water and climate change	1
	Philippi Horticulture Area Farm and Food Campaign	Cape Flats aquifer protection	2
ACADEMIA	University of Cape Town	Cape Flats aquifer	1

My general strategy when choosing interviewees was to obtain a range of perspectives across the CCT water sector from those who have meaningful input into water resource planning and management, with a specific focus on those with an interest in, or mandate related to, groundwater issues. When developing my specific interviewee sampling rationale, I worked with several local academics from the University of Cape Town and the University of the Western Cape, as well as a doctoral researcher from UBC. These academics also helped me to gain introductions and contacts at the City and with relevant groundwater experts. Myself and my colleague worked together to develop an interviewee sample that addressed both of our research interests. Our collaborative efforts were also important to avoid interview research fatigue, add legitimacy to our work and extend our research net wider than one person alone could individually cast.

I interviewed experts from the hydrogeological consultancies who were contracted by the City to complete a number of regional groundwater feasibility projects. These experts were an important group to include in my interviewing sample, as well as City water managers. The Department of Water and Sanitation at the City of Cape Town has several, very different branches that handle the many aspects of water management; I focused on securing interviews with managers who had knowledge about the role of groundwater in Cape Town, both current and future. This included managers from Bulk Water, Water Demand Management & Strategy, and one manager from the Water Reticulation branch in order to gain a more general understanding of the procedures in water management farther away from bulk water resources and further along the supply chain.

As I had several distinct categories of interviewees, I developed three different interview questionnaire templates: Local Government, Expert, and NGO (Appendix I), which were later tailored to the expertise of the expert participant. The three templates covered perceptions of how the water future might look like in the City of Cape Town over the next 20 years, and how groundwater and groundwater governance is integrated into that vision. The emphasis of interview questions was placed on exploring the perceptions behind the barriers and opportunities for large-scale groundwater use in the CCT. I was interested in how the next two decades might look in the context of a shift away from surface water dependence to the inclusion of alternative water sources, most notably groundwater. My interviews also covered general characterizations of water demand and supply priorities; new, updated or rewritten water policies; and the framework behind the water supply augmentation schemes outlined in the Western Cape Water Reconciliation Strategy.

In addition to interviews in the field, I also completed several supplementary fieldwork activities, namely: visits to four key water infrastructure sites, attending the National Groundwater Strategy Workshop for the Western Cape, and organizing meetings with key scholars engaged in groundwater research, from both the University of Cape Town and the University of the Western Cape. Document and policy reviews also made up a significant portion of my methodology, as this informed my interview questionnaire and protocol and overall research conceptualization and fact-checking.

1.3.2.1 Data Analysis

After returning from the field my interview recordings were transcribed by a third party. I then analyzed in two rounds. I initially synthesized my findings from what was said in interviews, noted in my field log, and observed in the field, about groundwater opportunities and barriers. This process broadly structured my main results. In order to supplement this process, I then ingested the transcriptions into NVivo 11.2 software (NVivo 2014) and coded my transcripts for themes relevant to groundwater perceptions, as well as general institutional perceptions of urban water management, such as: drought management, Water Sensitive Urban Design, and stormwater concerns. Themes were ranked and categorized according to the frequency of mentions, as well as the coverage of mentions in relation to the entire interview transcript length. These thematic findings added details to my overall results section, detailed in Chapter 2 and 3.

1.4 Thesis Outline

The body of work in this thesis is organized into two research chapters. Chapter 2 is written from the perspective of the hurdles and barriers most commonly discussed in the urban water management literature, and relates these to the groundwater perceptions from experts in the City of Cape (CCT) water sector. To begin, I provide context on the current exploratory activities that the CCT is currently undertaking surrounding two key groundwater sites, and outline how these two proposed schemes fit into the larger water planning context of Cape Town. While barriers are a key part of urban water management decisions, so too are the motivations behind promoting sustainable urban water management and in the pursuit of a water sensitive city. Due to these factors, I first detail the motivations for future groundwater schemes and then move into the barriers and challenges to future groundwater governance. I conclude my findings concerning CCT groundwater perceptions with two policy recommendations surrounding climate change factors in water modelling and broadening water resource definitions to include multiple types of water sources. This chapter is aimed at providing a characterization of the CCT groundwater narrative in terms of what opportunities and barriers may exist surrounding future groundwater integration, and to offer insight from other barrier and opportunity frameworks that have been examined in the urban water management literature. Conclusions offer a new look at the governance transition towards water supply diversification in Cape Town.

Chapter 3 uses a nested case study approach to explore the importance of institutional memory and learning when it comes to water supply side interventions. The town of Atlantis has had a groundwater scheme in place since the early 1980s, and shares some similarities with the proposed Cape Flats aquifer scheme. Therefore, the case of Atlantis is used to provide three lessons learned that could provide added understanding when designing the CFA scheme regarding aquifer recharge zone protection, field operator training and support for groundwater champions, or knowledge leaders. This chapter is grounded in the literatures of institutional and social learning, and groundwater best management practices. I also review Cape Town's full groundwater history with the intention of emphasizing the large amount of knowledge the CCT has in terms of innovative groundwater planning and management. However, this context outlines how inconsistent investment and insufficient field training has resulted in some neglect of the Atlantis groundwater scheme. As a result, the goal of Chapter 3 is to focus on the institutional knowledge around groundwater that already exists in the CCT and how best to support this type of learning for future groundwater leadership.

Chapter 2: Groundwater Planning and Governance: Perceptions of Transitions in the Water Sector of Cape Town, South Africa

2.1. Introduction

Integrating new water supplies into urban water systems is increasingly important alongside demand-side interventions to increase the sustainability of said systems (Jacobs et al. 2004). In the context of the City of Cape Town (CCT) in South Africa, where demand management mechanisms are approaching a threshold of efficiency (personal communication with CCT water manager 2016), there is pressing need to address the long-term sustainability of water supplies. This chapter seeks to explore the motivations and barriers to water supply diversification, namely groundwater integration for the CCT. This research contributes to the urban water management literature by building on existing tools and approaches such as Water Sensitive Urban Design, and applies those tools by linking them with expert perceptions related to long-term water supply planning in the CCT.

In this chapter I developed my arguments to answer my first targeted research question: What are the expert perceptions surrounding integrating large-scale groundwater sources into the Western Cape Water Supply System in Cape Town, South Africa? I examine this question in several sections, beginning with an overview of my conceptual approach, founded in the urban water management literature, which provides further context about the Cape Town water supply and groundwater planning history. Section 2.2 briefly covers my field and analysis research methods. Section 2.3 provides the first look at my main research findings, namely the motivations behind groundwater development, Section 2.3 continues my results and explores two institutional barriers surrounding groundwater governance in Cape Town. Section 2.5 outlines the challenges related to integrating large-scale groundwater resources into the

Western Cape Water Supply System (WCWSS). Finally, Section 2.6 presents policy recommendations aimed at promoting understanding of the possibilities related to groundwater in Cape Town's future and Section 2.7 summarizes my main findings and gives concluding statements for this chapter.

2.1.1 Urban Water Management Hurdles

In recent years there has been significant scholarly work done on the barriers that have hindered the sustainable management and development of urban water systems. Two threads of study, namely institutional barriers and conventional path dependencies, are especially pertinent to my research themes of groundwater integration and water supply diversification. In 2009, Brown & Farrelly identified 12 "institutional barrier typologies" related to Sustainable Urban Water Management (SUWM) internationally, in order to systematically review why SUWM implementation tends to fail beyond individual, isolated projects. These barrier typologies are useful in linking challenges within Cape Town's water management structure to a larger body of literature on institutional barriers to sustainable urban water management that are experienced in diverse regions of the globe. In particular, two barriers they identify are relevant for this research: an uncoordinated institutional framework, and unclear roles and responsibilities within an institutional mandate. These two barriers were shown to significantly hinder any SUWM frameworks from being effectively adopted at a municipal scale. It is important to note that these barriers are socio-institutional and thus concern responsibility, commitment, and coordination, as opposed to the technical feasibility of specific sustainable urban water solutions (Brown & Farrelly 2009).

Another growing argument in the urban water management literature is that conventional, centralised urban water management approaches are experiencing "entrapment" by technological path dependencies (Brown et al. 2011). In other words, it is easier to abide by the status quo rather than attempt to innovate change within the urban water sector. This is understandable, as shifting towards total cycle management require intensive financial investment and governance restructuring. However, being locked-in to conventional water systems has been shown to limit urban water sectors from diversifying or accommodating new more flexible approaches that could increase resilience to increasing water stress (Brown et al. 2011). Therefore, it is important to examine the drivers of such technocratic path dependencies, as I do in my analysis of challenges to groundwater integration in Section 2.5. This approach targets the long-term water planning pathways that are most constrained, according to my research, by the dependence of Cape Town on surface water and dams for 98.5% of its bulk water supply. The following section adds contextual background to this urban water management overview, by describing the history of groundwater and current groundwater planning activities in the CCT.

2.1.2 Groundwater Exploration in Cape Town

Groundwater makes up 1.5% of the bulk water sources from the Western Cape Water Supply System (WCWSS), and the vast majority of this 1.5% provides the small town of Atlantis with potable water. The town of Atlantis is north of Cape Town, and has a population of about 67,000 people (Statistics South Africa 2011b), who are provided water through an innovative Managed Aquifer Recharge (MAR) scheme (DWA 2010), which will be detailed in Chapter 3. Figures 2 and 3 provide details on the precipitation and groundwater levels that characterize the region of Atlantis, in comparison to the other two areas of proposed groundwater development: The Table Mountain Group aquifer and the Cape Flats aquifer.

In order to develop Cape Town's groundwater resources further, the CCT has begun exploratory studies into the Table Mountain Group (TMG) aquifer as a potential new bulk water source (CCT 2014a). The TMG aquifer has been estimated to have a recharge rate of 7-30% of mean annual precipitation and hold a potential annual yield of 100 million m^3 (Colvin & Saayman 2007), which is about one quarter of Cape Town's current annual water consumption;

approximately 399 million m^3 (CCT 2014a). Please refer to Figures 2 and 3 for details on the annual precipitation and groundwater levels for the TMG area. The aquifer abstraction site is located in the mountainous region close to the Theewaterskloof dam, owned by the South African Department of Water and Sanitation (DWS), which is where abstracted water would be stored (DWS 2014). While this may incite some governance obstacles for coordinating water rights between the CCT and the national DWS, having an available reservoir infrastructure nearby cuts down on construction costs. It is also an isolated region so integrating the TMG into the WCWSS will be costly. Ultimately, the capacity of the TMG and the investment that the CCT has put into feasibility studies are significant. When these two points are added to the emphasis on the TMG in the Reconciliation Strategy as a key augmentation scheme, one idea becomes clear: groundwater is going to become a much larger portion of urban water supply when the TMG is integrated into Cape Town's bulk water supply.

Parallel to the ongoing TMG feasibility studies, the national DWS, with the support of the CCT, has been looking into the Cape Flats aquifer (CFA) to play a role in a recycled water scheme for the future. The aquifer would act as both water storage and filtration for treated wastewater and harvested stormwater (DWAF 2008). This scheme also has the potential of lowering the naturally high water table through groundwater abstraction to aid in flood mitigation, even as the aquifer acts as bulk water storage (Winter 2017). This site has a much higher water table compared to the TMG (Figure 3), while experiencing somewhat less annual precipitation than the TMG area (Figure 2), which is at higher elevation and experiences an overall wetter climate.

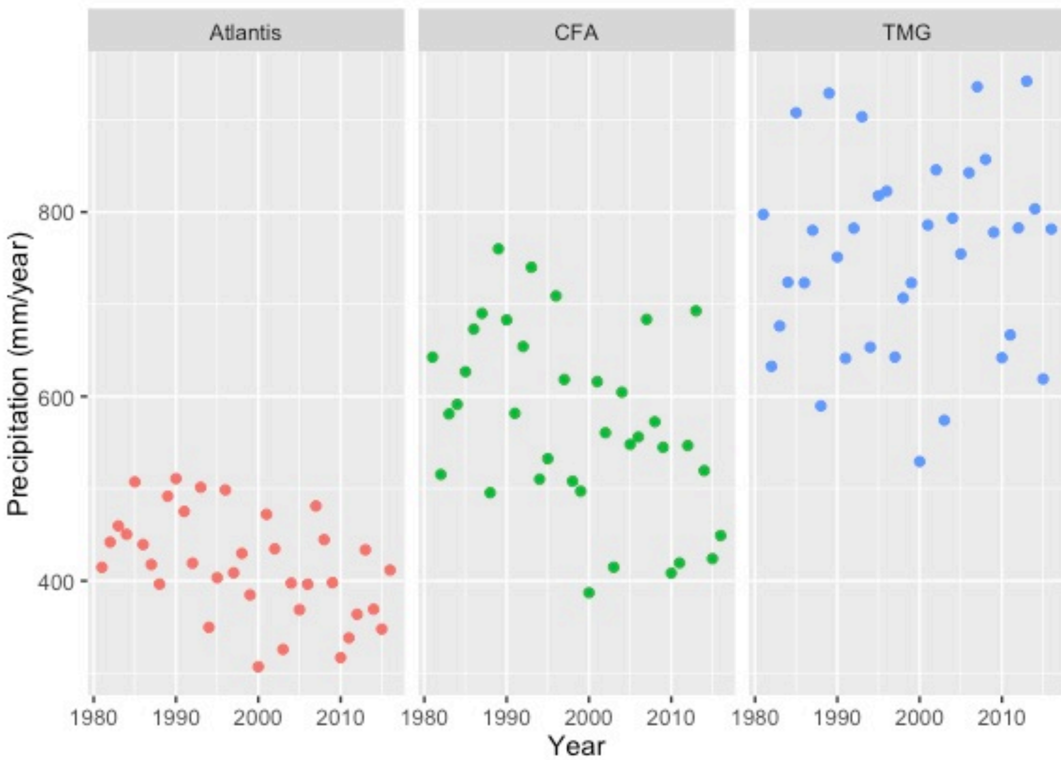

Figure 2: Annual precipitation for the three relevant groundwater areas in this thesis: Atlantis, the Cape Flats Aquifer (CFA), and the Table Mountain Group aquifer (TMG). Data obtained from the open-access CHIRPS database (1981-2016).

The CFA is located directly under the Cape Flats region, which is a heavily urbanized suburb of the City Metro, and is mostly made up by the townships of Philippi, Khayelitsha, Mitchell's Plains and Blue Downs. The Cape Flats area also already has a significant network of groundwater users. In particular, the Philippi Horticultural Area (PHA) uses groundwater for irrigation purpose. The PHA occupies 2639 hectares of agricultural land, with 38 large-scale farms, that are either independently operated or rented out in parcels that range from 2ha to 300ha small holder farms (Battersby-Lennard & Haysom 2012). The PHA has encountered several hurdles when ensuring the quality and quantity of local groundwater resources for irrigation, such as protesting new silica sand mining developments in the productive aquifer recharge areas of the PHA, which is thought to negatively impact groundwater quality. In response to these challenges, an advocacy group, the PHA Food and Farm Campaign, has been formed to speak on behalf of local groundwater users.

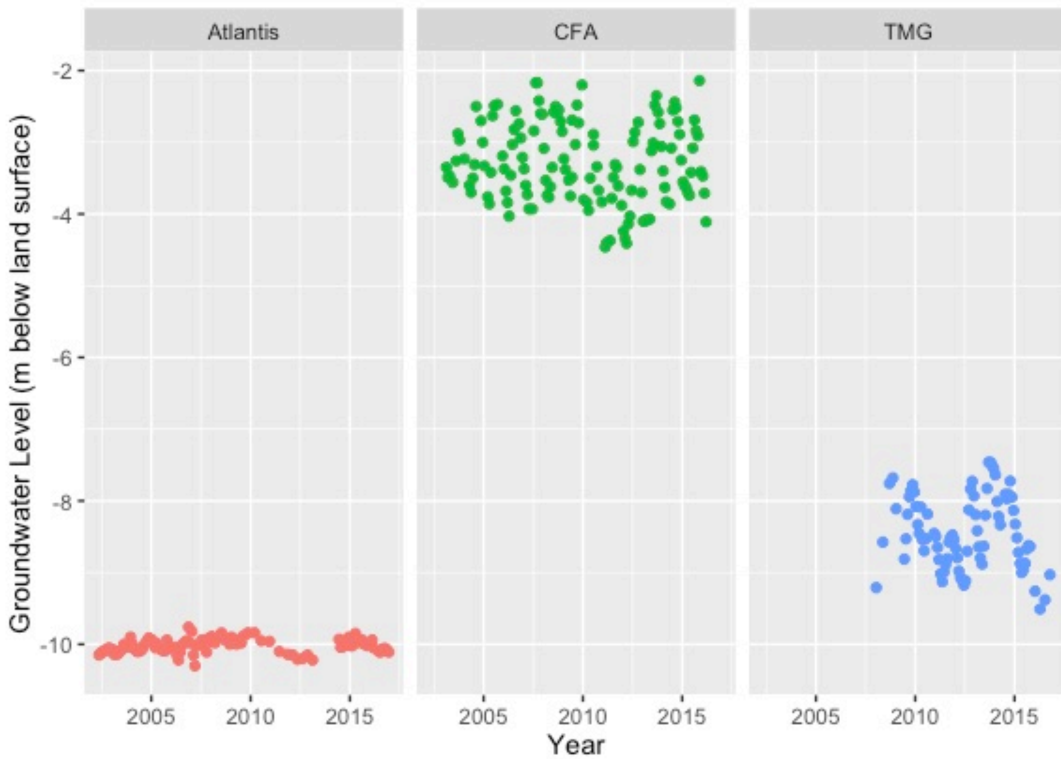

Figure 3: Groundwater levels for the three relevant groundwater areas in this thesis: Atlantis, the Cape Flats Aquifer (CFA), and the Table Mountain Group aquifer (TMG). Data obtained from the National Department of Water and Sanitation for the Berg Watershed Management Area, Atlantis (2002-2016), CFA (2003-2016) and TMG (2008-2016).

Given the historical legacy of Cape Town's townships receiving poor access to water and sanitation services (Ziervogel et al. 2010, Goldin 2010), and lack of formal drainage or sewerage system for greywater (Smith & Hanson 2003), exploring the potential of the CFA as a water infrastructure site has given rise to some water quality concerns. Abstraction and infiltration sites have been proposed close to the Cape Flats Water Treatment Works in order to reduce infrastructure costs. However, the specific design of the scheme is still flexible as plans are being written in conjunction with ongoing borehole pumping tests and geological survey work (DWAF 2008).

2.2. Methodology

My research findings stem from the 15 expert interviews with City water managers, groundwater consultants and water-related NGOs explained in more detail in Chapter 1, Section 1.3.2.1. These research interviews covered topics related to: perceptions of future groundwater use in Cape Town, any obstacles encountered with groundwater planning or decision-making, and current water governance priorities and how they have shifted in the last decade. The purpose of these themes was to better understand how the water future of Cape Town might look like, and how groundwater will fit into this future water governance landscape. The interviews were partially done collaboratively with a doctoral researcher from UBC and other colleagues at the University of Cape Town. I also had the opportunity to visit key bulk water infrastructure sites, such as the Steenbras Dam, which were key in understanding the current layout and capacity of the Western Cape Water Supply System (WCWSS).

In addition to interviews done in the field, I did a significant amount of water policy and document analysis. This type of analysis was essential in order to understand the timelines of water supply planning at the City related to further dam development and the success of water demand management mechanisms. An additional reason for this approach was to become familiar with policies to do with drought management, stormwater impacts, wastewater treatment and environmental protection, all of which are indirectly related to my work. This background added to my understanding of the political perspective on the current drought and how groundwater schemes may fit into future drought management procedures.

Throughout the following Results sections, it is important to remember that my findings are based on the scope of my research participants, who represent hydrogeological consultancies, bulk water planning, water demand management and stormwater planning perspectives. These experts make up one piece of the CCT water sector, and the larger institutional framework of the CCT. As only 2% of the WCWSS is currently designed to supply groundwater to the users of the system, any large-scale integration of groundwater is going to require substantial structural and organizational change within the water management of the CCT and the technical operations of the WCWSS. My work seeks to understand this transition from the perspective of those experts currently involved in municipal groundwater planning discussions.

The following Section 2.3 was developed through my analysis of policy documents, supplemented with expert interview data, and synthesizes research findings about the relevant water governance landscape and the institutional motivations surrounding local groundwater resources in Cape Town.

2.3. Groundwater Motivations

> *"In the planning we do, groundwater has definitely been prioritised as a resource that we need to look at developing and exploiting for water supply." – Interviewee #5, CCT Water Manager*

An outstanding perception among my research participants was that groundwater is firmly placed in the water future of the City. One of the most notable findings from my interview analysis was that groundwater was discussed as the most significant next step towards water supply augmentation. All 15 interviewees viewed groundwater as a clear opportunity for augmenting Cape Town's water supply system, beyond the other three augmentation schemes laid out in the Reconciliation Strategy. Thus, overall perceptions of groundwater sources being used by CCT in the future are largely positive and accepting, which corresponds to the Strategy's agenda.

I further explored the positive perceptions of groundwater through interview transcript coding analysis, in order to fully understand and identify the specific opportunities and benefits of groundwater integration. I identified three major categories of opportunities that were most frequently cited as the benefits of future groundwater use: (1) promoting water security, (2) increasing water supply system resilience and (3) addressing negative alternative water resource attitudes, both in the private and public spheres.

2.3.1 Water Security

A variety of perspectives from my interviewees associated groundwater with increased water security, which can be defined as “an acceptable level of water-related risks to humans and ecosystems, coupled with the availability of water of sufficient quantity and quality to support livelihoods, national security, human health, and ecosystem services” (Bakker 2012). The term “water security” was positively associated with groundwater particularly in relation to drought periods, where participants mentioned that in the future, groundwater would act as a more effective buffer to drought than surface water. The literature also views groundwater sources in Cape Town as important for future drought periods, with the Cape Flats aquifer scheme likened to a “survival strategy” due to the chronic water shortages that Cape Town is currently experiencing (Sorenson 2017). From one perspective of the City, the contribution of groundwater was equated with surface water quantities, with one interviewee noting that: “[w]e have about five to six major dams, so groundwater can add, maybe, in equivalence, say of one of them” (Interview #2). Another CCT water manager summed up the relationship between water security and groundwater during drought periods: “And then while it still has to be decided how we'll do it, there’s obviously benefits for when you go into a drought situation because then you could use your groundwater scheme” (Interview #5). The City opinion appears to be that groundwater will be less susceptible to drought impacts, and thus can be a safety net in times of increased water scarcity.

According to my interviews, aquifer use was the obvious choice for promoting water security from the groundwater stakeholder perspective. A participant, who is a farmer from the Philippi Horticultural Area (PHA), and uses groundwater on his farm, noted: “[i]t's an amazing resource for us. In fact, you know, in the drought period we can… We operate normally. We don't have a problem with water" (Interview #13). This perspective exemplifies the groundwater user viewpoint, illustrating how current farmers, who are the largest group of informal groundwater users in the area, benefit from small scale use of the Cape Flats aquifer. This perception of groundwater as a drought buffer not only exists in the abstract at the City level, but is echoed by those who have applied experience with local groundwater sources during drought years. While the City struggles with dam levels and strict water restrictions, the farmers of the PHA seem to function normally even during periods of water constraints.

2.3.2 Water Supply System Resilience

The key benefit of groundwater discussed by operational and technical experts, both at the City and from consultancies, was that the integration of groundwater into the WCWSS would increase the resilience of the system. Here resilience can be defined as "the capacity to absorb shocks while maintaining functions" (McDaniels et al. 2008). One water manager from the CCT summed up the contribution of groundwater to system resilience in this statement: "I think diversifying our resources mix, putting more emphasis on groundwater surely can help us in terms of resilience" (Interview #10). Groundwater was thought to positively impact water extremes, such as floods and droughts, where the underground reservoirs could function as extra storage in wet periods and extra supply in dry periods. Using groundwater sources were also associated with a decrease in water quality issues because the CCT could use groundwater in times of surface water contamination, or when dam levels got too low to be of appropriate quality. Finally, participants noted that groundwater could act as redundant infrastructure, or back-up water supply infrastructure, if a pipe connected to a major dam was blocked or if any other surface water infrastructure malfunctioned. Therefore, research participants associated heightened water system resilience with groundwater in times of water availability extremes, water quality issues and equipment malfunctions.

A high level of resilience already reportedly exists within the WCWSS, due to the integration of bulk water infrastructure. An interviewee cited an example of this built system resilience, which happened in 2015:

> *"Last summer was a problem with the Voëlvlei Dam, and Cape Town managed to cut the supply from Voëlvlei Dam, which normally supplies the northern suburbs, like Durbanville, Bellville, etc. So, they cut one down to 20% without impacting on the supply in the areas because they could supply from the other dams into the same area. So that's what I mean with an integrated system. And that's… That's a resilience that's already there." (Interviewee #15, hydrogeologist)*

Groundwater would increase resilience for the WCWSS specifically by providing the integration of new water sources and adding infrastructure redundancy, both of which would provide a safety net in times of emergencies. This is important because, according to one participant, while well-planned integration of groundwater can increase system resilience, poor integration might actually weaken the resilience of the system to system failures and water variability:

> *"So, what would be important, if you add groundwater into the mix, is to see how it's integrated into that integrated system. So, if you have a big wellfield somewhere with a single pipeline and that single pipeline goes to that specific reservoir, then that doesn't add to resilience. It actually would take resilience away that's already there. But if it's… If it's getting into that integrated system, then certainly you add to your different sources." (Interviewee #15, hydrogeologist)*

This quote explains that just adding a new source into your water supply system is not enough to increase the resilience of the system to shocks, but rather new sources must be integrated, i.e. through multiple pipe connections, to the larger system. This topic of integration is key for the design of additional infrastructure built for groundwater supply augmentation. An effectively, integrated water supply system is where the largest opportunity for sustainable, large-scale groundwater use may lie, but also where careful consideration is required in order to enhance, not take away, system resilience.

2.3.3 Public Water Resource Attitudes

An unexpected result from discussions about groundwater opportunities was the frequently mentioned association of groundwater with dispelling negative perceptions of non-surface water sources, mainly treated stormwater and wastewater. When discussing communication strategies regarding effluent reuse, one CCT water manager said: “what we do realise is that if we use aquifer recharge as a strategy it might help us along that journey” (Interviewee #10). As Cape Town has historically used mostly surface water sources, there is concern about the quality of alternative water sources from both the City management team and the public. This is due to several reasons, mostly regarding uncertainty in management mechanisms and in water source quality.

My research findings highlighted that treated wastewater quality concerns are largely associated with the CFA (rather than the TMG) because it lies under the Cape Flats area, which is associated with polluted runoff from townships areas that are not serviced with a formal sewer network or drainage system. However, including a managed aquifer recharge system along with the recycled wastewater scheme is seen as an opportunity for groundwater to change these perceptions in that using the CFA as a filtration mechanism will aid in better water treatment and begin to build a more positive public opinion around using recycled water as potable water.

In terms of harvested stormwater, a benefit of introducing groundwater schemes to the stormwater management landscape of Cape Town is that a large component of the Cape Flats scheme is to recycle treated stormwater, as well as wastewater, through the mechanisms of managed aquifer recharge. At least one participant emphasized that this may shift the perception of stormwater towards that of a usable and beneficial resource, as opposed to a burden on the urban system. When discussing desired changes to the Department, a CCT stormwater manager emphasized that: “[t]hat’s part of how we need to sell the whole stormwater issue. So, at the moment, our rivers and stuff are effectively just seen as drains; no one sees them as an asset or a resource. And the opening lines of the strategy or some of the opening comments is that we need to see the water as a resource and the rivers as an asset" (Interview #4). Branching out to groundwater may be the next step in not only supply augmentation, but a step towards a shift in water resource attitudes for the City in general. Additionally, using the suite of water supply and reuse options that groundwater, wastewater and stormwater could provide in the CFA scheme, may bring the CCT closer to becoming a water sensitive city (Wong & Brown 2009).

By identifying the elements of water security, resilience and positive attitudes that groundwater will perhaps contribute to the water future of the CCT, I have explored the benefits that are associated with future groundwater use by the City. With these motivations clear, I now move into the institutional barriers and other challenges, which make up the complete groundwater governance landscape of Cape Town. The following Section 2.4 and 2.5 will examine the multiple hurdles that exist along with the above three groundwater motivations.

2.4. Institutional Barriers

> *"[I]n the 1960s/70s in South Africa there was a big build program for dams. And that's when most of our major dams were built, 50s, 60s, 70s. [M]y perception [is that] groundwater has generally developed where there were no other options, like in small towns. But I think there's this increased awareness that groundwater, and one is the resource that must be protected and one that should be utilised and developed for water supply." – Interviewee #5, CCT water manager*

This quote from an interview with a CCT water manager provides evidence that in the past Cape Town has viewed groundwater as a resource for emergencies and water extremes, offering limited incentive to develop groundwater resources because there was little need. However, as drought is projected to increase in frequency and intensity in South Africa due to climate change effects (New 2002), and with the reality of the current drought's severity (Baigrie 2017), the development of new water sources is quickly becoming necessary. Given the intensive effort that is currently being placed on groundwater development, it is increasingly important to understand the governance barriers that may lie beyond the management of groundwater, and may be limiting the possibilities for groundwater resources to augment the water supply for Cape Town.

Specifically, when discussing the groundwater plans for Cape Town's water future, it is important to recognize that in addition to widespread, water demand management, the water sector of Cape Town has significantly depended on surface water. My research found that this limited institutional experience in governing large-scale, alternative water sources is coupled with two particular institutional barriers limiting the groundwater scheme planning process. The following section highlights two aspects of the Cape Town institutional framework that present significant barriers for groundwater governance, and they can be summarised as "an uncoordinated institutional framework" and "unclear, fragmented roles and responsibilities," using Brown & Farrelly's (2009) institutional barrier framework.

2.4.1 Uncoordinated Institutional Groundwater Framework

Since the end of the apartheid era in 1994, the CCT has seen several fundamental institutional and jurisdictional changes. In 1996, 58 local municipalities combined to form seven larger municipalities governed by local authorities, one of which was Cape Town Central (CCT 2011). These seven smaller municipalities joined together in 2000 to form the City of Cape Town metropolitan municipality, or "Unicity" (CCT 2011). In the water sector, these multiple transitions have incited widespread change in governing responsibilities and roles for water governance and management, as well as gaps in institutional memory (Interview #9). One groundwater stakeholder that was notably affected by these changes was the town of Atlantis.

Atlantis was formed in the late 1960s under the authority of the Divisional Council of the Cape (DCC), which was responsible for the creation, design and construction of the Atlantis managed aquifer recharge (MAR) scheme throughout the early 1980s (DWA 2010). The DCC formed a body of groundwater knowledge over this time period, and when they transitioned into the Western Cape Regional Services Council, most of the old DCC staff stayed on, preserving that institutional memory and groundwater passion (Interview #11). However, when the Cape Metropolitan Council and the formal City of Cape Town was formed in 2000, this institutionally embedded groundwater knowledge was lost because the new organisation' priorities and specialities lay with dams and surface water. Thus, the CCT was unwillingly "saddled with a groundwater system" (Interview #11), resulting in inconsistencies in resources devoted to governing groundwater. There is a consensus amongst my research participants who work or have worked in Atlantis, that the water supply scheme, as well as the town in general, have been largely neglected in terms of City investment into water infrastructure upgrades. Further, two of my research participants suggested that the past approach to institutional restructuring in the CCT has led to the loss of groundwater knowledge in the case of Atlantis, and has led to higher uncertainty in decision-making surrounding local groundwater resources.

My research therefore indicates that changes in the municipal jurisdictions of the CCT have resulted in an uncoordinated institutional framework for groundwater, characterized by conflicting institutional priorities in water sources, a lack of relevant expertise and the oversight of groundwater in funding and planning decisions. Notably, Brown and Farrelly saw a link between the presence of uncoordinated institutional frameworks and poor inter-organizational collaboration and coordination (2009), which is also seen in this example of Atlantis. There was reportedly little coordination between the larger CCT and the local groundwater staff in Atlantis, which ultimately resulted in less investment of resources into the Atlantis groundwater scheme. This example of the transition between a groundwater-centric approach in Atlantis, to the CCT institutional framework that prioritizes surface water, shows how a lack of inter-organizational coordination acted as a barrier for groundwater planning by negatively impacted the condition of the Atlantis groundwater infrastructure.

2.4.3 Unclear and Fragmented Groundwater Responsibilities

In conjunction with the political transitions beginning in 1994, historically there has been an institutional focus on surface water and dam development in the CCT, as well as Water Demand Management and Water Conservation (WDM/WC) (CCT 2016). According to participants of the National Groundwater Strategy workshop I attended for the Western Cape Province in 2016, the CCT has de-emphasized the importance of hydrogeological knowledge by prioritizing dam development. Notably, this has translated into an apparent lack of support for groundwater champions, or individuals at the City that take a leadership role in pushing groundwater initiatives forward (National Groundwater Strategy Workshop 2016). The absence of groundwater champions is especially interesting because champion support is one of the outlined pillars of WSUD (Armitage et al. 2014).

One interviewee who had worked for the CCT Stormwater Sustainability Branch noted that the first wave of champions who have been pushing the WSUD agenda for the City, as well as those interested in pursuing alternative sources such as groundwater, are from the generation that is currently moving into retirement (Interview #7). Two other participants mentioned a similar lack of people to push these projects in the new CCT framework, and cited this lack of champions as a major institutional barrier because current groundwater planning activities are inconsistent in terms of adhering to planned timelines and funding schedules for consultants (Interview #12). Therefore, a new wave of champions may be needed in order to follow through with the CCT groundwater plans; such champions also offer a potential way to address the insufficient priority that has thus far been given to groundwater. The success of new champions would be dependent on the level of integration of a groundwater mandate in the different water branches of the CCT water sector (Interview #15). The necessity of integrating a groundwater mandate across the DWS is clear, as water demand and supply priorities extend beyond the scope of just one branch and require departmental coordination and cooperation (Interview #11).

One participant further discussed the fact that the water managers who are interested in pushing groundwater planning initiatives are not the ones in charge of operations (Interview #9) and so do not have an appropriate role with which to motivate the City towards a more portfolio-based approach to water supply. This exemplifies the fragmented roles and responsibilities for groundwater responsibilities within the CCT, which is identified in the international literature as a common institutional barrier within organizations, as well as amongst and between other organizations (Bakker & Cook 2001, Brown & Farrelly 2009). In the literature, fragmentation has been linked to decreased ability to manage water resources in relation to urbanization, resource extraction and climate change effects (Bakker & Cook 2011), all of which are relevant to the case of Cape Town. With growing populations, planned groundwater abstraction and increasingly variable rainfall, fragmented responsibilities surrounding future water planning act as a significant institutional barrier for stakeholders from the CCT to provide consistent support for groundwater scheme development.

Ultimately, what is important in this context is that a surface water centric governance approach will not be appropriate for groundwater governance and management because these two water sources require different knowledge and management mechanisms (Jakeman et al. 2016). New structures are therefore needed to accommodate these unprecedented changes to the water supply framework of Cape Town. While motivated by significant expected benefits from groundwater, (Section 2.3), groundwater source development remains a clear challenge for the City because of uncoordinated institutional efforts and fragmented roles surrounding groundwater governance. However, my research also found four path dependencies driven by the historic focus on surface water and dam development, and thus are acting as additional challenges for future groundwater planning and governance.

2.5. Conventional Path Dependencies

I have examined challenges behind groundwater integration into the WCWSS in the context of the "path dependencies" (Brown et al. 2011) related to surface water and the traditional status quo. Brown et al. explain that: "technological 'lock-in', path dependency and path constitution…collectively result in systemic barriers to change, preventing alternative and more resilient trajectories for urban water management" (2011). Therefore, I felt the term "conventional path dependencies" was more appropriate for this work than "groundwater challenges" because challenges surrounding water supply diversification are more directly related to the disincentives for change, as opposed to the change itself. In the following section I examine the path dependencies dis-incentivizing water supply diversification planning, particularly those associated with the future TMG and CFA groundwater schemes. They are separated into four main categories: (1) groundwater management perceptions, (2) hesitation in climate change modelling, (3) financial drivers and (4) uncertain environmental impacts.

2.5.1 Groundwater Management Perceptions

As groundwater is firmly in Cape Town's water future, I was interested in the perceptions of groundwater as a resource by the City and the consultancies doing groundwater feasibility studies for the CFA and TMG, to compare groundwater attitudes with the reality of future large-scale use. When presented with questions about tangible changes to the existing supply system there was a high level of hesitation, especially as the only existing groundwater project, Atlantis, has seen management difficulties. One interviewee historically involved with the operations of the Atlantis scheme said: "[t]here's a nervousness with the management of [groundwater]. How do you manage it effectively when you can't manage a smaller scheme like Atlantis effectively?"

This presents evidence that the City is aware that groundwater requires different management practices than surface water, however these practices may not be fully understood yet.

Furthermore, the outside perspective about the City's resource attitudes of groundwater do not seem to match with the reality that groundwater will be a major future resource: "Yes, so the city – yes, they just – it's not their main prerogative, in a way, because it isn't a resource yet for them. So, they're more interested in the things that are a resource – so the surface water bodies, and that kind of thing." (Interview #6). This quote suggests that a public perception is that the City is prioritising other water source development, despite the academic consensus in the early 2000's that any new dam development would be highly disruptive ecologically (Joubert et al. 2003), and multiple research participants from the City that agreed the dam potential for area was effectively tapped.

Even though interviewees involved in bulk water planning spoke positively about some groundwater benefits regarding water security, water resilience and water resource attitudes (Section 2.3), groundwater has ultimately been viewed as an emergency resource or for rural use, and surface water has been used for the vast majority of the citizens of Cape Town. This is reflected in the perceptions of groundwater for the CCT, because they seem to be following this traditional attitude towards the utility of groundwater. While water alternatives are needed for the WCWSS, there appears to be a mismatch in the perceptions of these sources. It seems that groundwater is viewed as having high potential as an augmentation option for the CCT, but will also come with a new set of management difficulties and resource definitions, which challenge the transition towards groundwater use.

2.5.2 Hesitation in Climate Change Modelling

An interesting finding from this research is that climate change scepticism exists in the CCT water sector, but not about the impacts of regional climate change itself. This scepticism exists in terms of how climate change impacts should be acknowledged in the City's future water modelling scenarios. This is notable because of the larger arguments in the urban water management literature about water managers being slow to take up the projected timelines or effects of climate change due to a lack of evidence or high uncertainty, and the implications of drawing conclusions from high levels of uncertainty (White et al. 2008, Tribbia et al. 2008, Beck & Krueger 2016). As groundwater is seen as a water resource for extreme water scarcity, and especially with the ongoing drought, climate change awareness plays an important role in Cape Town in determining the proactive planning and allocation of water resources.

This research shows that CCT drought management does not actively account for climate change at present, with one CCT water manager stating that: "[y]ou don't manage drought by building new resources. You manage drought with restrictions" (Interview #10). This perspective of drought management is missing a key element: drought may no longer be a discrete event within larger hydrological patterns. If water is becoming increasingly scarce and this is being felt by an increased prevalence of hydrological drought, then by simply relying on water restrictions, a hydrological drought could become a management drought. This ties into the concept of non-stationarity, which states that previous methods of water management can no longer be used when predicting or planning for water extremes, such as drought and floods, because their dynamics are now tied to a much more variable climate than before (Milly et al. 2008). This perspective of drought as a temporary event, and only building new supplies when demand outstrips supply, is not capturing the bigger picture in Cape Town where water scarcity is arguably becoming a more pressing concern. Droughts seem to be categorized as separate from the acknowledged larger changes in rainfall variability and storage patterns, however this perspective is missing the inextricable ties between climate changes effects and water availability.

The Reconciliation Strategy for the Western Cape illustrates 11 different water supply diversification model scenarios, all with different assumptions and factors built into the models. However, the scenarios which incorporate climate change, are not used by the City in their planning discussions: "[It's] not yet felt…It's one of the scenarios, you're right. Because we haven't been able to measure it" (Interview #10, CCT water manager). This can be argued as a substantial institutional barrier to groundwater supply development. If water supply modelling is not taking into account warmer temperatures and increasing rainfall variability, there may be incorrect projections of water demand and supply dynamics that further delay supply side interventions that go unrealised. In summary, understanding of conventional surface water modelling is high, and when compared to the uncertainties associated with climate change impacts and how they are reflected in water modelling, dependence on conventional modelling and scenario building appears to be a significant path dependency on traditional approaches to demand and supply projections.

2.5.3 Financial Drivers

All City interviewees voiced acceptance of the plans for using groundwater in the future, with the shift towards water alternatives being a "forced shift, not a voluntary shift" (Interview #2, CCT water manager). This shift is ongoing, and difficult to lead because alternative sources are not cheaply or readily available, as surface water has been in the past. Costs of the future water supply augmentation scheme seemed to be the major factor in promoting groundwater as the next step after river to dam transfer, as opposed to desalination, with one CCT water manager outlining the next steps as: "This pumping from one dam to another, that's the next scheme. After that maybe we have that TMG aquifer, Table Mountain range. Then after that maybe we go into either direct reuse or a desalination plant. So, the desalination plant is always, sort of, towards the end because it's the most expensive one" (Interview #5). However, the cost of groundwater feasibility studies and geological surveys were also the obstacles limiting groundwater planning for the City. Comparisons between the expense of surface water and groundwater feasibility studies were frequently mentioned as one of the reasons for the delay in pilot drilling for the TMG and for feasibility studies in the CFA. Borehole drilling and pumping tests for both sites were associated with high costs, as well as building new infrastructure for either scheme. The CFA requires the construction of pipelines and seepage basins, while the TMG requires major pipelines and the drilling of very deep boreholes, up to 1000 m deep in the fractured rock of the Table Mountain Group. While this finding is unsurprising, it is important to note that cost is both a barrier and opportunity for groundwater integration, simply because it is the least expensive option in a list of expensive projects that are inevitable according to the Reconciliation Strategy.

It seems that in preparation for drought years, such as the ongoing drought that began in 2015, proactive approaches to water planning are being undermined by the worry that any more expensive water source alternatives could soon be irrelevant if surface water sources are replenished. It seems that fear of losing money on alternative source investments is outweighing the importance of planning for a potential hydrological regime characterized by climate variability, which will need permanent solutions to increased water scarcity. This is an interesting finding because this fear is an applied example of how political risk and professional agency fear can entrap the status quo of water system organization (Brown et al. 2011) from a groundwater perspective.

2.5.4 Uncertain Environmental Impacts

Knowledge barriers were frequently mentioned by participants as a barrier to groundwater scheme planning, centered around the uncertainty that exists when planning and designing a groundwater abstraction scheme. “The thing with groundwater that is uncertain is its effect on the environment” one CCT manager said (Interview #5), and this uncertainty in environmental impacts surrounding groundwater abstraction was frequently echoed by other

CCT water managers and consultants. Uncertainty behind the sustainability of abstraction is a concern to both the CCT and local environmental NGOs (ex. Cape Nature).

Another factor exacerbating uncertainty in groundwater development is that in 2003 the National DWS disbanded the National Geohydrology Directorate, which meant that there was a loss in technical hydrogeological expertise in governmental roles across the country. This disbanding was done with the goal of spreading hydrogeological knowledge across branches, but instead “limited functions and operations” (National Groundwater Strategy Workshop 2016). Without people both knowledgeable and passionate about groundwater in specified roles of groundwater planning leadership, there has been a general feeling of the responsibilities for groundwater planning falling through the cracks, which was repeated several times at the National Groundwater Strategy Workshop, and evident as an institutional barrier as well.

Generally, there seems to be a lack of intention to move forward on augmentation schemes, even given the current drought. From observations in the field, it seemed like this hesitation was linked to the unknown or unseen aspects of groundwater, and this notion of groundwater being unseen, and thus less understood or appreciated is also echoed in the literature (Jakeman et al. 2016). One interviewee summed up this thought by comparing the will and the motivation of the City.

> *Interviewee #11:* *“But TMG… I think 20 years is a short time. Because the will isn’t properly there.”*
>
> *Interviewer:* *“The will…? You mean the motivation, the will as in…?”*
>
> *Interviewee #11:* *“Yes, the motivation, yes, yes. Well… No, I think, the will. Because, motivation… There’s lots of motivation, I think. But, then you must still get the people to…To do it, you know, to will to do it.” (Hydrogeologist)*

I argue that it is helpful to understand this quote as relating groundwater development motivations to the benefits identified in Section 2.4 and the lack of will as related to conventional path dependencies. Individuals may be motivated to move towards water diversification in order to prepare for drought and other future climate change impacts, but this is insufficient if there is little political will to fill gaps in hydrogeological understanding and clarify groundwater responsibilities. Overall, my research suggests that reconciliation is required between groundwater motivations and the barriers behind transitioning towards groundwater scheme development. Building on the idea of reconciling these notions associated with groundwater, I took a further step in identifying two main policy recommendations for future groundwater governance in the CCT.

2.6. Policy Recommendations and Institutional Transitions

In this section, I will connect the motivations for, and barriers to sustainable groundwater governance to the context of Cape Town's institutional constraints identified in Section 2.3. Based on this municipal context and the current landscape of hydrological drought, I will discuss two policy recommendations for Cape Town's groundwater future that are part of this research. I have used the larger institutional barriers to frame my policy recommendations because these root causes are deeply embedded in the Cape Town water governance context, and thus it is within these institutions where my suggestions are the most meaningful.

My research has identified two recommendations that could build greater understanding for future groundwater governance, focusing on the roles and responsibilities relevant to the hydrogeological experts and CCT water managers who were made up my interview sample. The first, larger policy recommendation is (1) to utilize the water demand and supply scenarios that factor in climate change effects. This recommendation goes along with a larger argument for an institutional shift towards integrating climate change effects when managing for drought and in hydrological modelling at the City. The second recommendation is (2) for larger scale use of WSUD processes when assessing and approving new development projects, both private and public. This recommendation is born out of the historic reliance on surface water, and the new shift that is happening at the CCT towards capitalizing on alternative sources, such as groundwater, stormwater and wastewater.

2.6.1 Climate Change Factors

Drought episodes are no longer functioning under an envelope of predictable probability. The local hydrological regime changes that have been seen (New 2002) are part of a larger global phenomenon that is sparking changes in water management and governance regionally (Pohl et al. 2017) and internationally (Milly et al. 2008). If water availability patterns are changing, then there is a clear argument for factoring in climate change effects when writing new emergency drought management protocol. Cape Town is currently in this position as several Water Acts and policies are presently being rewritten or newly written (ex. the Stormwater Impacts Policy and the National Groundwater Strategy respectively).

I am arguing for building in additional levers beyond residential water restrictions, and extending the drought management sphere to include water supply-side interventions, such as groundwater as a bulk water source and drought buffer (refer to Section 2.3). A focus on proactive climate change-driven approaches to water scarcity through a portfolio of water sources will better equip the CCT to handle unexpected decreases in precipitation inputs and increase the resilience of the WCWSS to drought. This recommendation links back to the need to decrease uncertainty around groundwater resources. In addition, this suggestion aims at increasing coordination between the CCT and external consultant organisations that are conducting the hydrological models and other technical studies for the City.

2.6.2 Water Resources Definitions

My second policy recommendation addresses the historic focus on water demand management, and surface water and dam development. This past trajectory is no longer possible to continue as my research has suggested that the watershed has reached dam capacity. I suggest a move to instead incorporate themes of WSUD and green infrastructure broadly into new development projects. A shift such as this would extend definitions of useful water resources beyond conventional approaches, and instead move towards increasing the efficiency of how urban water is used and how it flows through the CCT system. A notion already started through the proposed plan for the CFA to use harvested stormwater and treated wastewater. A few other examples of this approach to greener infrastructure could be strengthening regulations on the types of water used for watering green space (i.e. non-potable sources for green space irrigation as mandatory), or incentivizing new green infrastructure mechanisms, such as rain gardens and bioswales, in new development projects (Armitage et al. 2014). Excitingly, this shift has already started, with the creation of the Future Water Institute at the University of Cape Town, and the institutional support that could be provided through the new National Groundwater Strategy (DWS 2016).

This recommendation aims to build on the foundation that has already started to take shape, as well as to strengthen and clarify the roles and responsibilities related to groundwater governance at the CCT. Encouraging new definitions of water resources could present new ways for groundwater motivations to overcome the institutional barriers and surface water path dependencies, and thus reconcile the motivations and barriers behind groundwater development. It would benefit Cape Town in the long term to encourage and invest in the WSUD movement, and to coordinate efforts with the research and consultancy communities such as the Future Water Institute, to push for a more drought resilient water supply system built on diversified water supply sources.

2.7. Conclusions

This chapter displays some of the possible challenges associated with urban water supply diversification, while in pursuit of greater security and resilience in times of water scarcity. The main argument in this chapter is for stronger institutional support during governance transitions towards alternative water supply scenarios. I suggest doing this by clarifying the institutional frameworks and the roles and responsibilities of those who are responsible for effective water supply planning, and to capitalize on the motivations for bring these new supplies online. One caveat to this argument is that demand-side and supply-side interventions be concurrent, and as was previously mentioned, demand management has been largely addressed in the case of Cape Town.

Groundwater is going to become a much larger contributor to the WCWSS, as both bulk water and for storage and filtration. However, perceptions of the resource have not yet caught up with this reality. While the challenges for integrating groundwater sources into the WCWSS are significant, the TMG and CFA schemes make up a significant portion of the Reconciliation Strategy and thus are an inevitable addition to the WCWSS. These two methods of augmenting supply while simultaneously including numerous other water sources, such as stormwater and wastewater, have high potential for increasing the resilience of the WCWSS to hydrological drought events. I argue that reconciling the motivations and barriers to groundwater governance is a goal that the City has thus far been largely underrepresented in the planning procedures responsible for upscaling groundwater development.

The goal of the recommendations for including climate change factors into city modelling and broadening water resource definitions, is to provide tangible ideas for strengthening the institutional support for future groundwater scheme development and large-scale use. Aspirational goals are seldom enough to incentivize integrating new projects or perspectives into an informed and accomplished institution like the CCT Department of Water and Sanitation. I am hopeful that incorporating more widespread and larger scale WSUD principles into Cape Town’s water system will shift the focus to using urban water more efficiently. Based on my research, this would involve focusing on the high potential of new sources to alleviate the water constraints associated with the severe drought in the Western Cape of South Africa.

I believe identifying and addressing these intangible barriers to alternative water source development has the potential to pave the way for a smoother transition from a surface water centric approach to a more portfolio based approach to water supply in Cape Town. This shift is pivotal to increase the resilience of an already water scarce region, to increasing water stress and drought periods. The research contribution from this chapter is to provide a detailed look at the current and future groundwater landscapes of Cape Town, and to provide recommendations to continue the discussion about how institutions can use portfolio-based approaches to water supply to address path dependencies which may be keeping them “locked-in” to less resilient approaches to urban water management.

Chapter 3: Lessons Learned from Past Groundwater Projects in Atlantis: Informing Future Governance Practices for the Cape Flats Aquifer

3.1. Introduction

Groundwater is not a new resource in South Africa, especially in rural areas. What *is* new is the need for groundwater regulation in urban areas as 22% of urban metropolitan areas in South Africa reported using groundwater sources in 2012, and 34% of urban areas used a combination groundwater and surface water (Adams et al. 2015). However, there has been a lack of strong groundwater regulation at the federal, provincial and municipal scales, in part due to low institutional capacity for any groundwater governance themes beyond the technical aspects of groundwater provision (Pietersen et al. 2011). Awareness is increasing about the need for additional water supplies from groundwater sources; since 2008, in most South African reconciliation strategies, groundwater has been considered the first supply augmentation option following water conservation and demand management mechanisms (WRC 2014). With the significant upscaling of groundwater projects at all scales of government, comes unprecedented need for new water management and governance strategies, as well as new institutional tools for addressing the uncertainty and context specificity that comes along with aquifer management. This line of thinking builds on the arguments from Chapter 2, which emphasized the need for clarifying the roles and responsibilities associated with these strategies for more consistent institutional support in groundwater governance.

This chapter will examine lessons learned from past groundwater projects implemented by the City of Cape Town, in order to inform about potential future avenues that may benefit the design and operations of future large-scale groundwater use. Section 3.1 focuses on institutional and social learning, relevant to context of this approach to make my case, because tools associated with this emergent learning process have been discussed at length in the literature as perhaps being key to sustainable and resilient water management practices (Mostert et al. 2008, Pahl-Wostl et al. 2007, Pahl-Wostl et al. 2008). Additionally, arguments from the groundwater best management practices literature, as well as groundwater governance frameworks proposed in South Africa, frame my approach for this chapter. Section 3.2 will explain the specific methods relevant for the Results in Section 3.3. The results section examines the ongoing groundwater supply scheme in Atlantis, a suburb of the Cape Town Metro, as an experiment that current groundwater planning in the Cape Flats area of Cape Town may be able to learn from. It is broken up into three lessons learned: (1) maintaining water quality through aquifer protection, (2) sufficient field training for borehole operators, and (3) consistent institutional support for local groundwater champions. Section 3.4 discusses these three lessons learned, grounding my findings in the conceptual foundations of institutional memory and knowledge leadership.

3.1.1 Institutional and Social Learning

The fundamental connectivity of the water cycle, as well as most water sources being a common pool resource, means that the water uses of one individual will always affect those of others. Thus, untangling the rules and responsibilities of water institutions is essential in order to equitably and sustainably organize a water supply system. Indeed, in dry climates especially, or in areas where water demand or pollutant loads are increasing, these rippling effects can be significant without institutional arrangements to clarify the rules governing a water system (Meinzen-Dick 2007). Over time, as natural resource regimes become entrenched, social institutional structures can remain unchanged regardless of their inefficacy, and thus become less resilient to environmental stressors (Young 2009). Historically, as was mentioned in Chapter 1, water resource management has been dominated by technical, structural solutions that largely failed to take into account the natural dynamics of watersheds, which has contributed to a number of environmental costs on society such as high levels of pollution in receiving urban waterways (Brown et al. 2011). These past technocratic path dependencies have been discussed as barriers to sustainable water management (Brown & Farrelly 2009), and also as a driver behind increasing vulnerability to institutional stressors (Young 2009), such as water demand outstripping supply. Different models of collaborative water governance are indeed still emerging, and this has marked a paradigm shift in the recent past away from natural resource governance regimes functioning as a "government" unit, which previously acted as a single decision-making authority for technical experts (Pahl-Wostl et al. 2008).

To address these notions of hierarchical governance, as well as technical water management priorities, there has been significant growth in recognizing the contribution of institutional and social learning to the sustainability of water institutions (Pahl-Wostl et al. 2007, Ison et al. 2007, Mostert et al. 2008, Pahl-Wostl et al. 2008). In my work, institutional and social learning can be defined by a change in understanding that goes beyond the individual to become situated within wider institutional units or communities of practice through interactions between actors within an institution (adapted from Reed et al. 2010). To define institutional and social learning, I use an adapted definition from Reed et al. (2010), who originally only included social learning in their definition. I use this literature framing as basis for exploring the process of institutional change in Cape Town towards the integration of alternative water supply sources.

In this chapter I seek to answer the question: How can institutional knowledge from past groundwater projects inform future groundwater schemes and governance practices? Thus, this chapter speaks to how institutional and social learning may have contributed, and perhaps could contribute further, to the design and conceptualization of future water supply schemes and governance practices. The groundwater scheme in Atlantis, which has been using an artificial recharge system originally designed in the late 1970s, is a useful case study because it has several characteristics similar to those of the Cape Flats aquifer. These similarities include: coastal geography, some hydrogeological aspects such as a shallow aquifer depth and sandy soil, and the overall jurisdictional policies that govern the region. By using the example of Atlantis, an existing groundwater project in the CCT, I approach the pursuit of strengthening water institutions by using the tool of institutional and social learning to glean lessons learned from past groundwater practices. Some key lessons learned that will be outlined in Section 3.3 are to do with land use planning, wellfield maintenance training and institutional support for groundwater knowledge leaders. The resulting discussion from these lessons learned highlights the importance of institutional memory and leadership in pushing new water supply agendas forward. Before I delve into these results, I first discuss the literature on groundwater best management practices and the site context in order to provide background on this nested case study.

3.1.2 A Review of Relevant Groundwater Best Management Practices

The responsibility of developing and designing an unprecedented groundwater abstraction project, in terms of capacity and scale in the Western Cape, is daunting considering the specificity of aquifers, and groundwater dynamics and behaviour. This is relevant for this chapter because I will be drawing conclusions from one aquifer system about another, but in pursuit of larger lessons learned for groundwater governance and management practices; not to inform on any technical metrics or operational procedures. When discussing the nature of aquifer characteristics in pursuit of understanding a groundwater system and what sustainable groundwater abstraction might look like, it is important to know that aquifers are heavily context specific and can differ significantly in many aspects. Aquifer characteristics are dependent on a host of factors, such as: location in relation to the coast, depth, presence of an impermeable layer confining the water-bearing aquifer from the land surface, and the types of spaces through which groundwater travels, such as fractures in rock due to weathering or through unconsolidated materials that were never a solid layer (DWA 2011).

Due in part to these wide range of types and aspects of aquifers, as well as the high uncertainty surrounding estimates of groundwater recharge and other groundwater/surface water interactions, our abilities to predict sustainable groundwater abstraction rates are highly imperfect (Seward et al. 2006). The groundwater best management practices literature has worked towards addressing the high uncertainty involved in these types of predictions by developing several theories and tools, such as quantitative groundwater mapping (MacDonald et al. 2012) and modelling groundwater recharge in response to change in precipitation patters (Taylor et al. 2012).

The historical groundwater planning method of using a safe yield or sustainable yield, defined as the amount of water that can be withdrawn from an aquifer without producing a negative result, has undergone significant criticism because its concepts were largely theoretical and so some quantitative applications were subsequently flawed (Morris et al. 2003). Fundamentally, some groundwater systems cannot be made to be sustainable due to one of several reasons, such as recharge rates being very slow (Kalf & Woolley 2005). An overexploited aquifer, one where the groundwater has been abstracted faster than it can recharge, is associated with a number is negative consequences. Reversible effects are ones such as the groundwater transmission rate to the baseflow, an example of a semi-reversible effect is reduction in the groundwater table, and a reversible effect could be proximity to saline or polluted water (Morris et al. 2003). There are numerous mechanisms to renew groundwater sustainability and mitigate aquifer depletion and most of these techniques surround agricultural irrigation. Some examples are: agricultural water-saving measures like low-pressure pipes, linking water-saving measures to the process of issuing groundwater permits, incentivising the installation of more efficient irrigation technology, and groundwater resource managers appreciating the need for abstraction rates meeting sustainable targets (Foster et al. 2004).

In addition to groundwater planning related to abstraction rates, the discourse around constructing policy timelines to match the timelines of groundwater dynamics, fully understanding long term groundwater behaviours, and the particular focus in the South African groundwater literature around aquifer protection, are also of high relevance to my work. Typically, groundwater policy horizons are on the time scales of 5-20 years, however aquifer depletion and contamination effects are observed on much longer, multigenerational timelines. Therefore, it is argued that groundwater policy, such as sustainability of abstraction goals, be in the scales of 50-100 years (Gleeson et al. 2012b). This is relevant to the Cape Town context because the Reconciliation Strategy which outlines the projected timelines for groundwater developments being added to the Western Cape Water Supply System (WCWSS) are set for 20 years in the future (DWAF 2007), which is demonstrably too short according to Gleeson et al. (2012b). These short timelines are also true concerning groundwater monitoring data in Cape

Town: groundwater level baseline data for the TMG aquifer is only publically available from 2008, the CFA monitoring period is from 2003, and Atlantis has the longest baseline dataset from 1979-1989, and then from 2002 onwards (source: data obtained from the DWS in 2016). As groundwater dynamics occur on a multigenerational timescale, it may be important in the future to extend timelines in order to better understand groundwater dynamics in the regions applicable for future groundwater schemes, in addition to encourage realistic groundwater planning and policy timelines.

There is a growing body of work on aquifer protection; this discourse began in the 1980s but seems to have fizzled out until recently. For example, Riemann et al. discuss specifically a groundwater management framework for South African municipalities and focus their arguments around aquifer protection and utilization (2011). They argue that aquifer protection is essential for pollution control and remediation and can be effectively managed through land-use planning, while sustainable aquifer utilization can be assisted through thorough groundwater assessments and consistent wellfield maintenance (Riemann et al. 2011). Connecting these grounding elements to the groundwater policy context of South Africa and Cape Town, as well as water policy history, is a key part of my overall research goals for this work. Within this broader context, this chapter offers insight into how groundwater best management practices from the literature and lessons learned from the case of Atlantis can inform future groundwater policy development in the CCT.

3.2. Methodology

My research findings stem from 15 expert interviews with City water managers, groundwater consultants and water-related NGOs, which covered: perceptions of Cape Town's water future in relation to future groundwater schemes; working solutions to regional water scarcity; and past institutional memory about issues for groundwater management and governance in Atlantis. The interviews were planned and conducted in collaboration with a doctoral researcher from UBC, and assisted by our academic hosts and other water professionals at the University of Cape Town.

I supplemented the understanding gained from these interviews with key water infrastructure site visits, most notably to the groundwater recharge operations area in Atlantis and the Cape Flats Water Treatment Works, where water abstracted from the future CFA scheme is proposed to be treated. These visits were central for understanding the operations of built water infrastructure relevant to my arguments surrounding Atlantis and the CFA, but also to explore the perspectives from field operators and technicians who guided us on the tours. As I was especially interested in lessons learned from past institutional activities, the current operational structures happening in groundwater recharge and wastewater treatment were especially important to examine. Thus, these infrastructure visits added understanding of current successes and weaknesses for wastewater treatment in the Cape Flats, as well as groundwater recharge in Atlantis. Understanding these processes gave me the opportunity to see how the CFA scheme might map onto, and compare to, current operations in the future.

In addition to fieldwork, I undertook a significant amount of water policy and document analysis relevant to future groundwater planning and the history of the Atlantis scheme. This idea was sparked by interviews with some of the key groundwater champions responsible for the functionality of the Atlantis MAR project. Document and policy analysis was essential in order to understand the early motivations behind the Atlantis groundwater scheme, as well as current technical challenges and benefits of potable water supply to the town. Additionally, it was imperative to fully recognize the history of groundwater in Cape Town, as well as in South Africa, to be able to point to future changes in the WCWSS and how past institutional memory may be able to inform these changes in water supply.

3.3. Cape Town Groundwater History

The South African National Water Policy of 1997 pronounced that all water, including groundwater, would be considered a public resource and thus water ownership was no longer possible, only a right or authorization for its use, with the national government acting as a trustee (Pietersen et al. 2011). Notably, this Act gave groundwater the same status as surface water; surface water had previously been considered a much more valuable and usable bulk water supply source. Before the 1997 Act however, groundwater was being used in the CCT at a very small scale in the town of Atlantis, as well as through widespread private, informal boreholes, which are commonplace in Cape Town. The situation of Atlantis is unique because it is the only area within the Cape Town Metro supplied by the WCWSS to use groundwater for potable water, and uses a Managed Aquifer Recharge (MAR) scheme that was initially developed in 1979; marking an early period of innovation in the CCT water sector.

3.3.1 Atlantis

Atlantis was originally an isolated town built for industry, and the settlement of coloured[1] populations during apartheid-era South Africa in the early 1970s, and declared a "National Growth Point" in 1976 (Tredoux et al. 2011). To incite industrial growth, the CCT offered a number of incentives, including touting the high water quality and "soft" water of the region, which brought in several companies mostly from the textile industry (DWA 2010). With growing industry came a growing population, and soon the regional surface water source, the Silwerstroom Spring, was not sufficient to supply the town with water. Groundwater exploitation was initially a placeholder to supply the town with bulk water until a pipeline could be built from the Berg River, but both economic feasibility and technical efficiency caused groundwater to

[1] "Coloured" was a racial designation used during apartheid-era in South Africa that referred to people of mixed race.

become a permanent source of water supply for Atlantis (DWA 2010). Artificial recharge played a large role in supply augmentation because natural groundwater recharge became insufficient to meet water demand. The scheme evolved to use a combination of urban stormwater and treated wastewater that were infiltrated into the aquifer to maximise the amount of available groundwater. The Atlantis Water Resources Management System (AWRMS) indeed pioneered managed aquifer recharge as a major tool for bulk water supply development in southern Africa (Tredoux 2011).

As the water management system was being built almost parallel to urban development, the town planning process was able to take the MAR scheme into account by designing the wastewater system to separate industrial and domestic effluent. This assured higher quality wastewater when reclaiming greywater, and thus noxious industrial chemicals never contaminated the process of artificial recharge. The AWRMS itself saw many revisions and changes over the last three decades, and now groundwater supplies about 50% of Atlantis' domestic water (DWA 2010). This water supply system design and operation process is framed as a success in innovation for water scarce regions, and was used as an example for future MAR schemes following its conception in South Africa.

Multiple groundwater infrastructure challenges and costs are clear in the case of Atlantis. The age of this scheme now appears to be showing, with the realisation of several problems to do with investment and maintaining aging infrastructure built in the 1980s. There have been major issues to do with biofouling and iron-related clogging of boreholes as well. The apparent lack of investment has been made clear through the lack of infrastructure upgrades and inconsistent funding for consultancy contracts for monitoring groundwater quantity and quality. Additionally, there are a large number of boreholes sitting in hibernation because there is not enough field staff to keep them in production, thus the wellfield is not functioning optimally

(DWA 2010). This has put limitations on the monitoring capacity of the project, both for borehole productivity and groundwater levels and quality.

Past groundwater project histories and management approaches are relevant to the future groundwater landscape of Cape Town. As previously mentioned, two sites are proposed to house new large-scale water augmentation schemes, and both involve groundwater. The Table Mountain Group aquifer (TMG) is proposed to be a groundwater abstraction project for bulk water supply, while the Cape Flats aquifer (CFA) scheme will use harvested stormwater and treated wastewater to artificially recharge the aquifer. For comparison, Figures 2 and 3 in Chapter 2 show that the water table for Atlantis is lower than that of the CFA and TMG, and experiences less precipitation that the other two sites, meaning that the groundwater scheme in Atlantis is built in a relatively drier climate than the other two proposed groundwater schemes. Additionally, Appendix B shows that the aquifer in Atlantis could be less dynamically connected to changes in annual rainfall compared to the CFA and TMG areas, but this could also be due to a range of other factors, such as the geological characteristics of the three aquifers.

3.3.2 The Cape Flats Aquifer

Both schemes are still in the conceptualization phase as pilot studies and feasibility studies are still ongoing. For the CFA in particular, no pilot scheme had been designed at the time of this research (personal communication 2016). This scheme is of particular interest to me because it will be a unique project that combines the three traditional silos of water management and governance: surface water (in the form of stormwater), wastewater and groundwater. This presents an opportunity for new innovation in Cape Town's urban watershed management approach. The CFA scheme is a possibility for alternative water sources to be concretely used, and thus seen as having higher value and utility for both water managers and water users.

The CFA opportunity does present new challenges beyond just integrating an aquifer into a conventional surface water and dam system. The Caps Flats region is defined largely by dense, sprawling informal settlements and diverse township communities with high rates of unemployment and poverty, as well as inflows of new migrants. A survey in the townships of Khayelitsha and Nyanga in 2002 found that 52% of households reported no income at all, while 64% of adults were reported to be unemployed (de Swardt et al. 2005). In this area there is also high competition for limited resources, such as land and fuel, and high prevalence of violence and conflict (Turok & Watson 2001). In addition to social vulnerability, the Cape Flats aquifer recharge zones are located in these township areas, and most sources of surface water contaminants in this area have been shown to affect the aquifer water quality (Adams & Jovanovic 2005). Figure 2 in Chapter 2 shows that the CFA may be more responsive to drought periods as well, with groundwater levels fluctuating more noticeably from the drought in 2009, relative to groundwater levels in the TMG and Atlantis. The dimensions of resource distribution, recharge, urbanization and poverty produce a complex location in which to effectively govern a new groundwater supply scheme for Cape Town. The Cape Flats area also already has a significant network of groundwater users. In particular, the farmers' collective in the Philippi Horticultural Area (PHA) uses groundwater for irrigation purpose. With this groundwater policy and development context in mind, this chapter will explore possibilities for institutional memory and groundwater leadership for the ongoing design of the CFA scheme. These arguments are based on past lessons learned in Atlantis, and from the groundwater and institutional learning literature more broadly.

3.4. Lessons Learned from Atlantis for the Cape Flats Aquifer Scheme

"They're going to have to consider groundwater extraction as a big alternative. My perspective has always been that Atlantis is your experiment, one of your biggest schemes. And that's why they need to get Atlantis to work. There are all sorts of problems with Atlantis." (Interviewee #9, hydrogeologist)

This quote indicates several things that will frame this results section: (1) groundwater abstraction needs additional acknowledgement about its large future contribution as a water source, (2) an evident perception of several problems with the ongoing groundwater recharge and abstraction activities in Atlantis and, (3) a clear perception of connectedness between Atlantis and future groundwater projects in Cape Town. Therefore, Atlantis is viewed in this chapter as an experiment that can inform future groundwater projects under the same water institutional framework. To be clear, the goal of this comparison is to explore possibilities for future groundwater management and any corresponding shifts of institutional responsibility, in addition to how this might look in the Cape Town context. Aquifer characteristics are known to vary significantly, and using generalized parameters for aquifer assessments risks losing significant information about site complexity. Effectively understanding and describing these geological and hydrological complexities often requires detail characterization of a site, thus comparing aquifer sites must be done with substantial operational and hydrogeological data (Illman et al. 2011). This adds further emphasis to the importance of fully understanding a groundwater and aquifer system in order to best contribute to water planning horizons. Thus, any comparisons drawn between Atlantis and the Cape Flats aquifer are largely related to governance, as opposed to operations related.

My research found that interview participants frequently compared the Atlantis scheme and the future CFA scheme. This was due to the fact that the proposed CFA scheme will also use Managed Aquifer Recharge (MAR) of alternative water sources, the aquifer characteristics and geography are relatively similar (both are primary coastal aquifers), and it is also located in an urbanized location. As both sites have experienced significant urbanization surrounding groundwater recharge zones, experiences in Atlantis are relevant for the Cape Flats. Urban development (both formal and informal) has especially been an issue in the Philippi area of the Cape Flats because farmers in the Philippi Horticultural Area (PHA) use groundwater for irrigation. For comparison, the TMG is a secondary, fractured-rock aquifer in a much more isolated and mountainous area and the scheme will not be artificially recharged.

The following results synthesize my research findings regarding lessons learned from Atlantis that were stated as applicable for the CFA; a unique approach to understanding institutional memory surrounding groundwater in Cape Town. The lessons learned approach has been frequently used in the groundwater best management practices literature in order to inform other emerging urban groundwater management strategies (Ex. Jacobs et al. 2004). This chapter provides context for the tools borne out of Atlantis scheme institutional memory, supplemented by other pieces of institutional knowledge beyond Atlantis, and how they could be relevant for the design of the Cape Flats aquifer scheme. Furthermore, it provides a nested case study within the larger Cape Town case study by examining the water supply diversification motivations and path dependencies outlined in Chapter 2, in an applied sense. Lessons learned are separated into the main three categories found from interview data analysis, those to do with water quality and aquifer protection; borehole operation and management; and groundwater champions.

3.4.1 Lessons Learned #1: Aquifer Protection to Preserve Water Quality

The most frequently cited concern of the future Cape Flats aquifer scheme from interview participants was that of water quality. Concerns about water quality were in response to the heavily urbanized nature of the Cape Flats region, mostly due to poor drainage and sanitation services provided in the township areas. This has been well documented by local water researchers, and several long-term projects are underway to explore solutions to this complex socio-political problem (see Winter et al. 2008). This perspective was evident in my research interviews: “You have farming activities on the Cape Flats aquifer, where you’ve got bad stormwater drainage, where you’ve got bad sewers. All that sort of stuff’s going to leak into the aquifer” (Interview #9). This is notable because of the contrast to the dominant global perception around groundwater being of high quality, for example borehole water was declared as an “improved water source” by the WHO/UNICEF Joint Monitoring Programme in 2011. However, the same report also highlighted how the increase in global dependence on groundwater sources is prompting concerns surrounding groundwater contamination and sustainability (WHO/UNICEF 2011).

When asked about these types of water quality concerns, a local groundwater expert from the University of the Western Cape emphasized the lack of any water or soil sampling evidence from the CFA area that indicates any significant contamination issues. Empirical studies on this topic returned a variety of findings on water quality in the CFA. An early 1989 study explained that there was no evidence of contamination from coastal saltwater and that the water was safe for potable use (Vandoolaeghe 1989). A study done in 2011 however, found that groundwater in the Philippi Horticultural Area was considered brackish due to a high dissolved salt content, and while agricultural activities were still possible, some vegetables may no longer grow (Aza-Gnandji et al. 2011). Additionally, there has been evidence showing the landfill sites in the Cape Flats are leaching toxins into the aquifer (Swilling 2006). The fact that water quality issues have arisen in the last 20 years in the CFA is unsurprising. However, when coupled with the lack of consensus with experts in the field, this points to evidence that water quality in the CFA may be a perception issue, in addition to being grounded in local hydrogeological knowledge.

According to my research, a more specific issue is actually inconsistent water quality coming out of the CFA and how to best equip the Cape Flats Wastewater Treatment Works for inconsistencies in water treatment requirements to ensure potable water standards. One interviewee from the consultancy industry stated that: “what you don’t want, in a treatment works, is every day a different quality coming in. And I think this is one of the challenges on the Cape Flats, how to deal with that aspect.” (Interview #14).

Inconsistencies in water quality are still rooted in the urbanization happening around the CFA. Due to this finding, the first potential lesson for the CFA relates to the lack of pollution problems in Atlantis because of the purposeful land management system implemented around groundwater seepage. One research participant stated that “the Cape Flats Aquifer has got pollution problem because the most productive parts of the aquifer have been built over. At least in Atlantis the aquifer is not built on; it’s in a nature reserve” (Interview #9). In the 1992, professionals from both the government and consultancies collaborated to form the Witzands Aquifer Nature Reserve: a protected nature reserve around the recharge areas of the Witzands aquifer to areas to maintain groundwater quality from encroaching urbanization (Interview #9). This nature reserve consists of the Silwerstroomstrand Conservation Area and the Atlantis Dunefields, and the latter has become a major tourist destination because of its views of Table Mountain. In addition to protecting groundwater seepage ponds from industrial effluent runoff, this reserve has also successfully protected many different types of vegetation and species of mammals, birds, amphibians and reptiles (West Coast Way 2017). Atlantis effectively implemented an aquifer protection policy while simultaneously protecting regional ecosystem health and biodiversity.

This aquifer protection policy is relevant for the future CFA because of the water quality concerns surrounding this scheme and the lack of aquifer protection policy in the main water policies relevant to groundwater at both the municipal and national level. This finding stems from several discussions about aquifer protection not being included yet in groundwater management discussions and policy. For example: “[W]e have to examine policy and the extent to which policy protects the aquifer. Because it doesn't” (Interview #13). Groundwater protection and conservation was frequently discussed by my research participants from the CCT, but following interviews with hydrogeologists it seems like aquifers, or the water-bearing layers holding this groundwater, are not as readily understood as the valuable groundwater resource itself. This feeling of groundwater and aquifers being viewed differently, and policy protecting the resource but not the supporting environment was mentioned by several participants. In response, participants listed the National Groundwater Strategy as an opportunity to address this gap of knowledge, the feasibility of which will be discussed in the following policy recommendation section.

The Atlantis artificial recharge scheme is seen as a success because those involved innovated a method of providing sufficient potable water in an area with little freshwater. Due to this success, I suggest that the CFA scheme could benefit from being accompanied by aquifer recharge zone protection legislation in order to properly address water quality concerns incited by the high density of urbanization in the Cape Flats. Not only that, but this zone protection policy might be most beneficial if implemented as soon as possible, instead of when the scheme has been fully explored and designed. One interviewee discussed the importance of fully understanding the aquifer system as early as possible: “[O]bviously opportunities for recharge of aquifers and things like that, they should be identified right from the start even if it’s not going to happen for another 20 years or so” (Interview #7). This relates back to the literature surrounding long-term understanding and baseline data for aquifer management. An aquifer recharge zone protection policy for the CFA will require full understanding of the hydrogeological system in order to best mitigate point and non-point sources of pollution that could contaminate the aquifer, in addition to the social system above the aquifer. One important thing to note, which is outside the scope of this research, is that any land use regulation in response to aquifer recharge zone protection has the potential to impact the residents living in high densities above these recharge zones in multiple townships, most notably Philippi and the PHA. Addressing any land use change outcomes on the people living nearby any identified CFA recharge zones will be essential once plans for the CFA scheme become clear. One Section 3.6 details other groundwater successes around the world that could provide examples of what this has looked like practice.

3.4.2 Lessons Learned #2: Field Training for Borehole Operation and Management

A second lesson that could be learned from Atlantis is that involving levels of investment into borehole Operation and Management (O&M). Research participants from operational and technical disciplines, such as those that had actually worked in designing and maintaining the wellfields in Atlantis, frequently mentioned biofouling problems with Atlantis' boreholes, mostly to do with iron-related clogging. This process significantly limits the ability to pump a borehole, and resulted in several rounds of mandatory borehole rehabilitation. I found that this process is linked to a lack of sufficient investment into field staff training and equipment:

> *"We are currently doing rehabilitation of those boreholes at Atlantis. And to be honest with you, the management are not on board properly about how you… And I'm not talking about upper management; I'm talking about on-the-ground management. Because the on-the-ground functionaries have got to be trained, and there isn't any official sort of training in this sort of field." (Interviewee #9, hydrogeologist)*

Additionally, another interviewee cited "funding" and "staff issues" as the main reasons behind the present "neglect" that the Atlantis groundwater scheme is experiencing (Interview #11). Evidently, the productivity and operations of the Atlantis Water Treatment and Recharge Works are suffering from a lack of training and capacity building for field technicians. Notably, participants referenced that they had responded to these issues in Atlantis through collaborations by a team of CCT employees and consultants submitting a report to the City reporting on recommendations to promote efficiency after 30 years of artificial recharge (DWS 2010). At the time of interviewing, six years after the report was published by the national DWS, it was the impression of participants that no action had been taken by the City in response to these recommendations.

This can potentially be a lesson learned for the CFA, and ensure that a specific proportion of funds for the scheme be devoted to training field staff, as well as consistently maintaining boreholes. This lesson learned is important for the ongoing design and budgeting of the CFA, because as there was no pilot scheme yet designed at the time of my fieldwork, this type of broad motivation still can be captured in the writing process. Learning from the Atlantis example, and implementing a framework for an official borehole O&M training program, could benefit the CFA design and allow for more efficient allocation of human and financial resources across the new wellfield.

One way that institutional memory regarding borehole O&M from Atlantis, but also the other groundwater projects that have been happening in South Africa over the last 20 years, is through the new National Groundwater Strategy. In 2014, the Water Research Commission released a Groundwater Management Framework to guide the DWS in writing the new strategy, and it includes a "Wellfield O&M" section, specified to be implemented under local government responsibilities (WRC 2014). This is hopeful because it was highly recommended that this framework be adopted by the DWS as an official strategy, thus it is likely that an emphasis on local resources for borehole O&M will be incorporated into the new National Groundwater Strategy.

Ultimately, my research found that boreholes are not easily maintained and present new water management challenges, and this is a sentiment that has been experienced by a very large number of failing water points installed across sub-Saharan Africa in the last four decades (Liddle & Fenner 2017). However, tools building on institutional memory, such as investing in field staff training, and emphasizing borehole O&M frameworks in groundwater policy, could provide some guidance for more successful boreholes, as well as the ongoing design of the CFA scheme.

3.5.3 Lesson Learned #3: Institutional Support for Groundwater Champions

The third lesson learned from Atlantis from my expert interviews was the need for a core group of groundwater champions, and also maintaining consistent support for these agents of change.

> *I believe you need like a core of people that have a…. How shall I say, a passion for groundwater … [I]f there's a lone guy here and a lone guy there, you know … Water pollution, or whatever, then I don't know whether they have the same clout. (Interview #11, hydrogeology consultant)*

This quote comes from a discussion of the key elements of success for a groundwater project. In the case of the MAR scheme in Atlantis, two people involved with the feasibility and design of the scheme were cited by multiple participants as the key actors responsible for the groundwater supply project. These two major groundwater leaders worked in collaboration, and were mentioned as being the reason behind the successes of Atlantis in providing potable groundwater to an area where no other source was sufficient; a significant achievement. Individuals being regarded as key drivers behind project successes is notable because leadership has been discussed as significantly influencing more organized collective action around natural resource regimes (Ostrom 2009). Additionally, knowledge leaders, also known as "champions," have been shown to have a strong positive impact on environmental management responses to do with resource sustainability, ecosystem services and biodiversity (Kenward et al. 2011). Building on this literature: for the development of diversified water supplies generally, there are strong benefits associated with champions leading and directing the process for integrating alternative sources into systems such as the WCWSS, which have been traditionally managed for one source of bulk water supply.

As shown in Chapter 1, additional support for groundwater champions could lead to a clarified structure of roles and responsibilities for groundwater governance. Thus, there is an additional need on top of identifying groundwater champions: clarify who is responsible for supporting those champions that are identified. This could perhaps enable capacity within the water planning departments, to set future water planning goals for the CFA scheme.

Institutional support regarding groundwater champions is also related to the loss of knowledge linked to the disbanding the Directorate of Geohydrology. When discussing the implications for groundwater governance due to this disbanding, one interviewee said: “there was no voice anymore for it. There was no champion” (Interview #15). Evidently, having no institutional support for hydrogeological knowledge limited the ability of people passionate about groundwater to have a voice within water institutions, perhaps even on a national scale. This provides further evidence that it is not solely about the presence of groundwater champions as stakeholders within the water sector, but also the need for platforms on which these champions can act.

3.5. Institutional Memory and Groundwater Leaders

Chapter 2 of this work emphasized a loss of hydrogeological knowledge due to past jurisdiction transitions and the disbanding of the National Directorate of Geohydrology. I also discussed how these factors limited the integration of groundwater knowledge at the CCT level. Capitalizing on institutional memory from Atlantis now is related to supplementing some of this lost hydrogeological understanding and presenting new ways of framing future groundwater supply ideas. Luckily, there are existing outlets for applying these ideas. The National Groundwater Strategy writing and stakeholder engagement process was a platform for professional hydrogeologists, government officials, NGOs and other stakeholders to present their insights on what future successful groundwater management and governance might look like in South Africa. This process was also cited on multiple occasions as an opportunity to bring attention to the existing policy gap between groundwater protection and aquifer protection. Here is where the recommendation of aquifer protection policy being required with urban groundwater development projects is grounded.

A holistic aquifer and groundwater protection policy is essential to address water quality issues for the CFA. However, as this area is significantly built up, this presents a new challenge that the Atlantis development never needed to address. Ultimately, proactive surface and sub-surface land protection is a lesson that can learned from the success of the design of the Atlantis scheme. As the Atlantis scheme was developed from the beginning of the town planning phase, the creation of the Witzands Aquifer Nature Reserve was relatively straightforward. In the Cape Flats, land is already densely used and is becoming an increasingly valuable commodity with growing population rates: new innovation will be required to satisfy current Cape Flats land users and owners, as well as the Philippi Horticultural Area groundwater users, led by the Food and Farm campaign.

Fortunately, a large number of mechanisms and past examples of how aquifer protection and land use policies were rolled out in urban settings all over the world. A sample of these specific policy and management tools include: initial aquifer recharge zone identification and mapping in southeastern Australia (Tweed et al. 2006), encouraging more open green spaces in Jaipur, India (Singh et al. 2010), land use rezoning and limiting the lot size of land parcels on vulnerable aquifer areas in California, U.S.A (Sutton 2011), and zoning land according to direct indicators of groundwater vulnerability and resilience to anthropogenic contaminants and climate change effects in the U.K (Lerner & Harris 2009). Multiple approaches for aquifer protection are being developed for the express intent on maintaining sustainable groundwater quality and quantity, which presents the CCT with a large opportunity when ensuring the success of large-scale groundwater use in the next several years.

Protection mechanisms could be designed for the CFA scheme now, guided both by global examples and that of Atlantis, but also according to aquifer protection goals laid out in the new Groundwater Strategy. This is timely because of the connections between artificial recharge best practices, and the water quality concerns related to the ever-growing urbanization in the Cape Flats. From my research, this aquifer protection recommendation sees potential due to the success that Atlantis saw in maintaining potable water quality due to the creation of a nature reserve, even with increasing urban encroachment, as well as the growing body of global literature concerning the management of land uses in groundwater recharge areas.

Presently, perceptions of large-scale groundwater use are that any water sector shifts are locked in conventional path dependencies and associated with hesitation. One interviewee spoke about alternative water supply sources with a significant amount of fear, stating that “when people’s backs are to the wall things can change” (Interview #10). This mentality of reactive water supply planning has reportedly clouded the roles and responsibilities related to groundwater governance and limited the support for groundwater champions and leaders. An important consideration on this point is that institutional support for future championship requires sufficient capacity within the technical and engineering communities at the City. Following the South African democratic transition, “transformation” within governmental institutions took place in order to better reflect the racial components of South African society and many civil engineers lost their influence across the water sector (Bourblanc 2017). This may have left a capacity gap in which groundwater champions would have previously stood, but are constrained given the historical legacies within South African governmental institutions, as well as by current efforts to rectify past injustices through more demographically representative governmental institutions.

The champion phenomenon is one that has been recognized as a larger movement towards individuals acting as agents of change to promote more sustainable and water sensitive urban practices. Knowledge leadership has been shown to be a major positive driver behind effective resource governance regimes (Kenward et al. 2011) and building this type of leadership capacity has been identified as a key strategy in promoting sustainable forms of urban water management (Taylor 2008). Project champions in sustainable urban water management (SUWM) have shown leadership capacity in many different ways, such as influential executive champions "transforming" or inspiring others to become leaders as well, or providing for "safe havens" where leadership could occur without the dominant organizational culture (Taylor et al. 2011). Indeed, "champions" make up a pillar of Water Sensitive Urban Design framework (Lloyd et al. 2002), which, while having Australian roots, has recently seen significant uptake in South Africa (Armitage et al. 2014).

These effective leaders are viewed as catalysts in leading new sustainable water initiatives through taking new leadership roles upon themselves based on their personal values in SUWM (Taylor 2010). This is mirrored in one of the recommendations borne out of the document written about 30 years of the Atlantis MAR scheme history: "For the City of Cape Town, groundwater as a water supply source is a new venture, and "ownership" has to be embedded into all the administrative avenues." (DWA 2010, pg. 45). Interestingly, notions of "community ownership" are a key theme in the water champion movement regarding urban waterways, and thus this need for champions can be linked to the third lesson learned from Atlantis to do with more consistent support for groundwater knowledge leadership.

Due to the frequent discussion of groundwater champions in my research interviews, as well as significant emphasis in the urban water management literature, I suggest re-integrating hydrogeological knowledge into the toolkit of the City by investing in more support for groundwater leaders. A suggestion relating to this recommendation comes from the National

Groundwater Strategy Workshop, where participants suggested developing a Groundwater Committee that could be responsible for creating local groundwater governance guidelines. Participants suggested this committee with the hope that such local guidelines could be built on those to be provided in the National Groundwater Strategy. This suggestion brings together the concepts of institutional knowledge and groundwater leadership because such a committee could provide a platform for hydrogeologists, engineers and local groundwater stakeholders, such as the Philippi Horticultural Area Farm and Food Campaign, who were interested in pushing groundwater projects forward and ensuring governance best practices.

3.6. Conclusions

Building knowledge pathways between these groups responsible for groundwater use in Cape Town is especially relevant now as groundwater motivations are clear due to the current drought and long-term water planning objectives, but also because the plans for the two future large-scale groundwater schemes are still in the design phase. This flexibility allows for increased scholarly and stakeholder input, and can also be an opportunity for setting a precedent for future collaboration between different branches within the CCT Department of Water and Sanitation who will be responsible for groundwater governance in the future.

The research findings provided in this chapter show how learning from past successes and failures can be applied to future projects in related circumstances. Because of the unique situation presented by the groundwater scheme in Atlantis, there is an opportunity to take advantage of institutional memory and gain resources for the CFA scheme, and general groundwater governance and management best practices, by learning from this example. Furthermore, this promotes and encourages future collaboration between CCT water managers, who are responsible for the future TMG and CFA schemes, and Atlantis groundwater operators and technicians. My approach shows how the tools of institutional and social learning can be usefully applied to promote increasingly collaborative water governance frameworks. A collaborative governance model also discourages conventional hierarchical natural resource regimes, as well as technical path dependencies to do with urban water management.

Chapter 4: Thesis Conclusions

4.1 Thesis Conclusions

Ultimately this thesis work acts as an example of how the governance and management of an emerging water resource might look in the future, given increasing regional water scarcity and long-term policy and planning objectives. While it is important to note that both demand side and supply side interventions are necessary for sustainable bulk water systems, Cape Town has achieved a globally recognized threshold of efficiency in water demand, thus the supply narrative should now be prioritized. The case of Cape Town also differs from most other groundwater narratives because of its largely untapped groundwater sources, historically surface water centric infrastructure for all sectors, and the significant investment being made into innovative schemes of combining harvested stormwater, treated wastewater and groundwater. Integrating alternative sources are inevitable for the regional Western Cape Water Supply System, and so the goal of this research is influence the ongoing plans and designs in order to highlight the possibilities for the sustainability and efficiency of groundwater integration.

Chapter 1 connected the conceptual foundations of this work to the context of Cape Town, and water scarce, urban areas in general. Using the basis of water governance transitions, I demonstrated the timeliness of this type of water supply planning research with the emerging discussions of water institutions prioritizing water sustainability above conventional technical and built approaches (Medema et al. 2008). Out of these discussions have come multiple urban water management frameworks that are useful to communicate the shifting priorities in sustainable water management, and how best to translate the literature consensus into institutional action (Wong & Brown 2009). As groundwater requires different management techniques and research than conventional approaches to surface water and dam management, it must be acknowledged that alternative sources require thoughtful approaches to supply integration. I argue that the frameworks of Sustainable Urban Water Management (SUWM) and Water Sensitive Urban Design hold high value in promoting the effective groundwater governance and management principles required to avoid historical and current global examples of groundwater overexploitation and drawdown. This narrative is one that has been associated with groundwater resources around the world for decades (ex. Turral & Fullagar 2007, White et al. 2008, Shah et al. 2008) and this thesis offers a specific look at the possibilities for groundwater in Cape Town, while seeking to avoid these negative impacts of groundwater overexploitation.

With extensive water supply planning presently happening in South Africa, Cape Town is in the spotlight due to past unconventional and innovative approaches to water management, such as widespread Water Demand Management and early development of Managed Aquifer Recharge in the town of Atlantis. Chapter 2 reviewed the water planning history of Cape Town, and contributed to the discussion behind the hurdles involved in SUWM. I used terms from the urban water management literature that described three SUWM barrier typologies, namely: technocratic path dependencies, unclear roles and responsibility and an uncoordinated institutional framework (Brown & Farrelly 2009). My work provides a case study where these barriers have been observed, and are accompanied by significant motivations for overcoming these hurdles and achieving water security, resilience, and more positive water resource attitudes. This chapter further emphasized the importance of incorporating climate change factors into municipal water models, as well as promoting broader definitions of water sources, such as groundwater, stormwater and wastewater, as water resources as opposed to burdens on the urban environment.

I emphasize the importance of individual actors and their leadership influences in Chapter 3 by drawing on the institutional and social learning literature. My research found that water sector champions were frequently associated with water supply planning successes, and this theme is echoed in the work done around institutional learning and knowledge leadership (Pahl-Wostl et al. 2007, Ostrom 2009). Groundwater management best practices such as long-term aquifer baseline studies and relevant policy horizons to groundwater dynamics (Gleeson et al. 2012b), offered context into the narratives behind successful groundwater management elsewhere, and acted as examples of alternative ways of integrating old and new water sources together to prepare for more variable temperature and precipitation regimes in the Western Cape. I highlighted aquifer protection, increased operational staff field training, and institutional support for groundwater leaders, as the contributions and lessons learned from the nearby Atlantis scheme which could be useful to the design of the Cape Flats aquifer scheme. This research contribution was grounded in the value of institutional memory and the global movement towards recognizing individual leaders as reasons behind successful cases of sustainable urban water management.

This research provides several avenues for future work to be done on some of the aspects that were mentioned in this thesis but not fully explored. One suggestion for future research would be to examine the equity and social justice implications of any of the land use and zoning changes associated with the Cape Flats Aquifer development. The Cape Flats houses densely packed township areas and informal settlements, thus any negotiations around displacement for the purposes of aquifer recharge zone protection will have to be mindful of the high social vulnerability in the area. This line of thinking will require substantial future research and community outreach. A second avenue for potential research that came out of my work, but

I did not discuss in detail, is that of any flood risks associated with the CFA scheme. Participants mentioned the scheme was proposed to lower the naturally high water table through groundwater abstraction in order to mitigate flood risks, however it would be interesting to study how if this scheme indeed performs in this way. Additionally, any pollution issues associated with the CFA, such as surface contamination, wastewater reuse and saltwater intrusion, will be important themes for future research when discussing the public perceptions surrounding the CFA scheme. Lastly, it will be essential to monitor the two proposed groundwater schemes when they are integrated into the WCWSS in order to avoid groundwater drawdown or overexploitation. An interesting note here might be how the widespread use of private boreholes will impact any future borehole water regulations, which would be unprecedented in the Cape Town groundwater conversation.

As this conversation around groundwater is emerging, I look forward to the research that will build upon this thesis, a key focus of which has been to provide detailed insight into the complex water planning landscape of Cape Town, South Africa. In this work, Chapter 2 and 3 together act as two lines of thinking regarding helpful tools for discussing the water future of Cape Town, and other semi-arid urban locations experiencing hydrological and institutional change. Generally, the goal of this work is to connect any climate change effects on water supply availability, with water sector transitions and the increasing recognition of models of collaborative water governance and learning. Specifically, with the ongoing drought in the Western Cape reaching an alarming state of severity, I hope this work, when combined in its entirety, fully emphasizes the need for a portfolio-approach to water supplies to promote greater water security for Cape Town in the summer of 2018.

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Appendix

Appendix A: Interview Questionnaire Templates

Academic Groundwater Governance Questionnaire

Goal: To find out the academic perceptions on groundwater in Cape Town, and the conversations currently going on surrounding groundwater governance
Reason: To find out what types of topics would be the most relevant to bring up in City official interviews (Not get bogged down in old or irrelevant research)

Introductions

Research Overview

Background

1. Can you tell me a bit about your role at your institution?
2. What does your research look at broadly?
3. When did you become involved with water-related questions?
    a. Why?

Groundwater Governance/Boreholes

4. What are some of the major conversations concerning groundwater and governance in Cape Town right now?
5. What are the general perceptions surrounding groundwater as a water supply resource?
6. What do you think about private boreholes lessening demand on municipal supply?
7. What is your sense of the reasons behind private borehole construction?
8. Have you heard about the Keep Saving Water campaign?
9. What is your take on the organization of the 19 Water Management Areas?

Drought

10. How would you say the current drought compares to droughts you have seen in the past, such as the one in 2004?
11. Would you say people feel the effects of the four stages of water restrictions?

Future

12. Can you recommend any sources or contacts that may be helpful for providing any other information on any of these topics?

Expert Groundwater Governance Questionnaire

Goal: To better understand institutional responsibilities of each water department, see how groundwater is currently being managed and how decisions are being made for the future
Reason: To see what the institutional barriers to groundwater governance are in terms of Cape Town's urban water system and when/where they are located (ex. feasibility studies into the TMG are ongoing but unclear as to its end goal or timeline)

Introduction

Research Overview

Atlantis:

1. How are current groundwater extraction operations monitored in Albion springs and the Atlantis wellfield?
2. Can you explain the process of artificial groundwater recharge currently under operation at the Atlantis wellfield?
    a. Has this process changed since it began in 2000?
    b. Do you have a sense of how much impact managed recharge has had on sustainable extraction and extraction yields since 2000?

TMG Aquifer:

1. What are the decision-making criteria surrounding using the Table Mountain Group aquifer as a potential new water source?
2. Will the addition of the TMG aquifer change the hydrological boundaries defining the Berg Water Management Area?
3. How is uncertainty in recharge and extraction being dealt with throughout the feasibility studies being done on the TMG aquifer?
4. When do you see the shift to the aquifer use happening?
    a. What would be the tipping point?

Keep Saving Water:

5. How are boreholes built under the Keep Saving Water campaign regulated?
6. Has the uptake of the Keep Saving Water increased with the ongoing drought?

Drought

7. Given the record low rainfall in 2015, how has the drought changed current operations?
8. Can you explain the stages of urban water restrictions in response to water scarcity?
    a. How have these played during past droughts versus this one?
9. What has to happen for the city to shift into stage 3 restrictions?

Surface Water Integration?

10. What is your understanding of how surface water and groundwater sources are integrated within the Berg WMA?

Groundwater/Borehole User Questionnaire

Goal: To find out why and how people are constructing their own boreholes, and understand better how and why people are using groundwater
Reason: To see if any aspects of private borehole construction factor into the larger issues of institutional barriers to groundwater governance (short-term vs. long-term planning, demand management focus (cheaper, easier) rather than supply shift reorganization (expensive, complicated))

Introductions

Research Overview

Logistics

1. When did you install your borehole?
2. Where is it located?

Motivation/Uses

3. For what purposes do you use borehole water?
4. What made you decide to build your own borehole?
5. At what times of year do you use borehole water the most?
6. At what times of day do you use borehole water the most?

Registration/Eligibility

7. What was the registration process like when you decided to build a borehole?
    a. Were there any criteria that you had to have to be eligible?

Costs

8. Who paid for the installation?
9. Were there any other associated costs with the construction?
    a. What were they?
    b. Who paid for them?
10. Were there any costs covered by the City of Cape Town?

Government Intervention

11. Have you had any communication with the government about your borehole since construction?
12. Did they ever follow-up with you about satisfaction from borehole water?
13. Do you follow the city's water restriction schedule for borehole water?
14. Are you told or encouraged to follow the schedule?

Appendix B: Example of a Tailored Interview Questionnaire

Date

Name of Interviewee

Current Position with the CCT

Past Position with the CCT

Introduction & Research Overview

Questions:

1. Can you give us a brief description of your current role in Bulk Water and your past responsibilities in the City?

2. Given the record low rainfall in 2015, how has the drought changed current operations?

3. Are there issues with supply right now? This year? Last year? Projected for next year?

4. How are current current dam levels affecting decision-making?

5. What are the biggest challenges to deciding on a supply side augmentation?

6. What are the biggest opportunities for groundwater abstraction in Cape Town?

7. What are the biggest challenges facing groundwater management plans for Cape Town right now?

8. What are the decision-making criteria surrounding using the Table Mountain Group aquifer as a potential new water source?

9. How is uncertainty in recharge and extraction being dealt with throughout the feasibility studies being done on the TMG aquifer?

10. What is the realistic time frame for the Newlands, West Coast, TMG and Cape Flats aquifers to come online?

11. What levels of authority are guiding the assessments of the Cape Flats and TMG aquifers?

12. Are their scenarios built for flood management in Cape Town?
    i. How does groundwater planning factor into those scenarios?

13. What would an integrated urban water management plan look like to you?
    i. What are they key obstacles preventing this from happening?