Developing new urban water supplies: Investigating motivations and barriers to groundwater use in Cape Town, South Africa

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ABSTRACT

Many cities are experiencing increasing water resource stress. In Cape Town, South Africa, surface water supplies are at a record low due to a multi-year drought crisis which began in 2015. This paper analyzes the range of motivations, possibilities and obstacles related to diversifying Cape Town's water supply system through the upscaling of groundwater resources. Drawing on insights from local experts, it is maintained that uncertainty surrounding groundwater and drought management practices present significant barriers to Cape Town's ongoing water diversification efforts. This paper provides further insight and discussion for future water planning in Cape Town, as well as for other urban, water scarce, regions.

Keywords

Cape Town, groundwater, drought, water supply planning, resilience

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INTRODUCTION

Many cities are facing mounting stress on the water resources required for growing urban populations, in addition to other factors such as anticipated impacts of climate change (Vorosmarty et al. 2000). Urban water professionals and researchers are increasingly highlighting the imperative of sustainable management of urban water particularly as uncertainty and variability of water supplies becomes more pressing. This paper seeks to investigate the possibilities for water supply diversification using groundwater in Cape Town, South Africa as a specific case study. The case study is relevant for Cape Town, as well as for other cities that work to respond to ongoing and intensified water stress, while also seeking to build diverse and resilient water supply systems (Rijke et al. 2013).

While historically focus has been on technical and infrastructural responses to water supply augmentation, increasingly researchers and policy makers are moving to also consider concerns of resilience and sustainability of water management (Briassoulis 2004). “New” mechanisms 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”; and decentralization of water governance responsibilities and authority (Mitchell 2006). Specific examples of frameworks that have been created to use these concepts are Sustainable Urban Water Management (e.g. Medema et al. 2008), the Water Sensitive City (Wong & Brown, 2009), and Water Sensitive Urban Design (e.g. Armitage et al. 2014). These frameworks strive to align elements of water efficiency and re-use with urban planning mandates around sustainable water infrastructure development and design.

When discussing water supply management, one central argument in the literature is around water supply diversification and portfolio approaches to reduce water stress (Wada et al. 2014). While focused on infrastructure, this nonetheless represents a shift from past notions where augmenting supply had been a primary focus (e.g. the hydraulic paradigm) (Gleick 2000). Recent discussions emphasize the importance of diversification and portfolio approaches, which reduce the risk of critical water supply failures and ensure resiliency to future changes in water availability (Kaspryzk et al. 2009).

The literature also discusses the possibilities for barriers when integrating new water sources into an existing management framework. Issues that have been raised regarding possibilities and limitations include: conventional path dependencies (Brown & Farrelly 2009), entrenched and inflexible institutional structures (Young 2009), and governmental fragmentation (Bakker & Cook 2011). Historically, groundwater in particular has been associated with overexploitation, drawdown, and specific contamination threats in some areas (e.g. Gleeson et al. 2012a; Jakeman et al. 2016; Sorensen et al. 2015)—thus a note of particular concern must be emphasized when speaking to the development and augmentation of groundwater supply schemes.

Through a case study of Cape Town, South Africa, we address the notion of transitioning towards more sustainable management of urban water with the objective of providing additional insight into the possible obstacles associated with water supply diversification. We do so through a qualitative research design, relying primarily on interviews with local government officials, planners, and experts to evaluate possibilities for the upscaling of groundwater in the City of Cape Town’s (CCT) water supply. The timeliness of this research is evident as the current mix of water supply sources is dominated by surface water and is increasingly vulnerable, as evidenced by the ongoing regional drought. This drought is the most severe in living memory, necessitating a countdown clock to Day Zero (now pushed out to 2019 in the hopes of winter rains) with the eventuality that “the taps will be turned off” given supply and demand projections (CCT 2017a). As such, discussion has proliferated about how to avoid “Day Zero” and future crises—calling for a mix of responses, from supply augmentation to further restrictions and demand management approaches. Indeed starting in early 2018, the city of Cape Town has fast-tracked several supply augmentation schemes related to groundwater, water re-use and desalinization (CCT 2018).

The water scarcity situation is viewed as so dire at present that city planners and research analysts alike consider all options to be on the table—every possibility must be considered (Winter, 2017; Ziervogel, 2017). One of the focal efforts is to augment supply through groundwater sources. Cape Town’s Mayor Patricia de Lille has been quoted recently saying: “Groundwater is the key immediate, and cost-effective, option for navigating this crisis” (Davis 2018). We seek to critically assess the role of water supply diversification when discussing approaches to drought management and sustainable water management. We also seek to engage with debates related to water sensitive urban design and urban water resilience (Luker and Rodina 2017; Rodina et al. 2017; Armitage et al. 2014; Ziervogel et al. 2010)—again with specific focus on groundwater.

Our research question highlights the potential for a water supply portfolio approach that relies more heavily on groundwater, and what it would mean to integrate these sources into the existing water supply system in the CCT. We ask: What are the expert perceptions surrounding integrating new, large-scale groundwater sources into existing water supply systems? Although we focus on groundwater, we nonetheless aim to connect to broader conversations surrounding augmentation and diversification of urban water supplies and debates regarding concerns about other alternative and re-use sources, such as stormwater or wastewater.

BRIEF GLOBAL GROUNDWATER CONTEXT

Communities around the world rely heavily on groundwater resources. At present, it is estimated that groundwater provides safe potable water to approximately 2 billion people worldwide, and 40% of global food production relies primarily on irrigation from groundwater sources (Morris et al. 2003). However, groundwater has also been overexploited in many different global contexts (Gleeson et al. 2012a), with notable high-profile examples such as the Oglalla aquifer in the United States (Chaudhuri and Ale 2014), aquifers in the Indo-Gangetic Basin (Biswas and Hartley 2017), and the Murray-Darling Basin in Australia (Eamus 2015). Thus, among the most important considerations for groundwater management and governance is how to avoid unsustainable abstraction.

In response, there is a growing body of work related to best groundwater management practices (Gleeson et al. 2012b, Jakeman et al. 2016), and associated governance frameworks (Riemann et al. 2012). These discussions include concepts such as polycentricity when working at the local scale (Seward and Xu 2015) and collaborative decision-making for groundwater resources (Brown et al. 2016). There are also a number of specific principles discussed in the literature that are proposed as being important when seeking to avoid groundwater drawdown or overexploitation. These include: groundwater vulnerability mapping and delineation of protection zones to prevent aquifer deterioration (Adelana et al. 2010), monitoring and comprehensive aquifer knowledge (Custodio 2002), and setting long-term sustainability goals addressed through adaptive management (Gleeson et al. 2012b).

For countries such as South Africa, however, that have past and current legacies of "uneven development" (Bond 2006), it can difficult to find relevance in these principles when other governance priorities, such as poverty reduction, appear as paramount. Cape Town's story is also somewhat distinct given its historic lack of reliance on groundwater, making it stand out in the broader global context where groundwater reliance has often been considerable. We highlight several insights from this wider context before turning to the specifics of our study.

Among other notable examples, Perth, Australia (Turral & Fullagar 2007) and Phoenix, U.S.A, (Jacobs & Holway, 2004, White et al. 2008) are potentially instructive in that they are semi-arid urban areas that experience intense water stress and highly variable seasonal rainfall. These cities also offer cautionary tales. Both have experienced tumultuous social and environmental effects even with efforts to implement clear water management frameworks (Turral & Fullagar 2007, Jacobs & Holway, 2004, White et al. 2008). These two cities have had clear groundwater allocation and abstraction procedures in place for the last 20+ years, however they have both also experienced major disputes over water rights, overexploitation of groundwater resources, and water quality concerns, such as saltwater intrusion. Groundwater is evidently a complicated resource to manage effectively, and has been associated with numerous governance challenges in multiple different locations and circumstances in the past (Colvin & Saayman 2007).

Other cautionary tales exist in other parts of the world as well. 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 mismanagement, 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 often led to a drastic decline in groundwater levels, and this situation is currently threatening the livelihoods and food security of as many as 90 million households (Zaveri et al. 2016). This extreme groundwater drawdown has been attributed to groundwater usage outstripping natural aquifer recharge rates (Cook-Anderson 2009) and has been worsened by misguided groundwater policies, with an insufficient focus on groundwater rights and water conservation (Kumar 2018).

These examples make one point very clear: groundwater abstraction is highly complex and comes with a wide variety of difficult-to-predict externalities, both social and environmental. A key lesson learned relates to the need to protect groundwater from contamination (Sorensen et al. 2015), such as saltwater intrusion and agrochemicals - which is relevant for Cape Town as some aquifers are shallow and coastal (DWS 2015). A second lesson learned is to develop a comprehensive groundwater monitoring framework in order to build a sound body of knowledge and institutions from which to pursue groundwater management (Jacobs & Holway, 2004). Due to the high level of uncertainty associated with developing groundwater supply schemes, it is essential to emphasize the goal of ensuring sustainable long-term abstraction (Jakeman et al. 2016).

All told, a high dependence on groundwater has been highly problematic in the past, and there have been varied examples of groundwater mismanagement in different global contexts. However, as previously mentioned, groundwater in Cape Town has historically been a very small proportion of the overall supply, and the narrative to this point among planners and experts is largely one of potential regarding this relatively untapped resource. To date, the minimal groundwater use has mostly been in the nearby town of Atlantis, which uses 1.5% of Cape Town's water supply. Other groundwater users include Cape Town residents, and farmers from the local Philippi Horticultural Area farming collective, who retrieve groundwater from individual boreholes (Colvin & Saayman 2007). Larger users have been largely dependent on surface water. However, even with relatively minimal use at the household scale, groundwater drawdown can be a concern, and considerations related to broader monitoring, quality, and overall governance remain important.

The South Africa Water Allocation Reform Strategy (2008) defines the types of water uses permissible and their regulatory requirements. "Schedule 1" water use is for small volumes of water for household use, and requires no license or application to be made (DWAF 2008a). This Strategy does not reference groundwater specifically, however boreholes are used at the household scale and thus this definition means that there are no monitoring or regulatory requirements surrounding groundwater use at this scale. This is important because limited groundwater monitoring has been identified as a primary challenge to groundwater governance across the country (Riemann et al. 2015). Poor groundwater monitoring networks have also been identified as a risk to to the upscaling of groundwater resources elsewhere, including in the KwaZulu-Natal province of South Africa (DWAF 2008b). As the CCT continues to examine the role of groundwater in augmenting urban water supplies, it will be important to address these gaps in monitoring in order to have sufficient baseline data on which to base future decisions (Seward & Xu 2015), such as those to do with determining the use and risks of larger scale abstraction, as well as difficulties related to monitoring of smaller household users.

Increasingly, policy reports and news stories have emphasized groundwater potential in Cape Town as a major aspect of future solutions to the ongoing drought (CCT 2017b). In response, local academics and consultants have stressed that the groundwater plans for the City are unrealistic in their timelines for abstraction because of the large planned volumes of water and subsequent infrastructure requirements (de Villiers 2017). In this context of intensified focus on integrating groundwater into the city's supply we now turn to an analysis of key opportunities and challenges associated with water supply diversification.

SITE CONTEXT

Presently, 97.3% of Cape Town citizens have access to water provided by the regional 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 several surrounding municipalities and agricultural areas. The CCT makes up more than 80% of the whole Western Cape Province population (Western Cape Government 2013). At the time of this research in 2017, only 1.5% of the CCT's water comes from groundwater sources, while 98.5% comes from surface water sources, drawing primarily from five major dams in the region (CCT 2014a). The small town of Atlantis, an isolated, previous black township built during the apartheid-era, represents the small proportion (1.5%) where residents rely on groundwater. Atlantis is located within Cape Town's municipal boundary, approximately 60 km north of the central business district of Cape Town, and has a population of about 67,000 people (Statistics South Africa 2011b). Atlantis residents access water through an innovative Managed Aquifer Recharge (MAR) scheme (DWA 2010) that was developed in the early 1980s. This system blends high quality stormwater and wastewater from the residential areas of the town and recharges the aquifer through groundwater seepage ponds.

In 2007, the national Department of Water and Sanitation (DWS), in conjunction with Cape Town's municipal Water and Sanitation Department, 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). In South Africa, the national DWS is responsible for water policy development and governance, while municipalities serve as the water service authority and are generally responsible for provisoin of water locally. In the case of Cape Town, the municipality is both the water service authority and the water service provider (Beck et al. 2016). The DWS and CCT updated the Reconciltation Strategy most recently in 2014 (DWS 2014). The strategy update outlines four augmentation schemes: (1) river to dam inter-basin transfer, (2) deep aquifer groundwater for bulk water supply from the Table Mountain Group aquifer (TMG), (3) water reclamation or water re-use, which includes temporary aquifer storage in the Cape Flats aquifer (CFA), and (4) desalination.

Recently, water shortages associated with the ongoing drought have been declared a crisis, and has driven the municipal government to develop a City of Cape Town Critical Water Shortages Disaster Plan – the first of its kind in Cape Town (De Lille 2017). Other municipal responses include increased focus on strict residential and commercial water restrictions within the Cape Town municipal boundary. In the CCT, water restrictions are rolled out in stages, and increase in severity according to assessments of dam water storage levels and water demand projections. To date, demand-based approaches such as water restrictions have been a main focus of the City, and remain central to disaster response efforts at present. Prior to the onset of the drought, 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 and repairs; and installation of water management devices, such as smart meters. While the WDM/WC policy has been celebrated globally for its success through a C40 Award for Adaptation Implementation 2015, smart meters have been likened to "debt-recovery strategies in disguise" that critics note have unduly targeted poorer households (Wilson and Pereira 2012).

In terms of expected future changes to regional water availability, climate change is expected to further exacerbate existing water-related stressors, such as the prevalence of droughts, while also reducing stream flows and groundwater recharge rates (ADAM

2009). The coupling of increasing urban water demand, due mainly to population growth (Ziervogel et al. 2010), and climate change impacts is projected to significantly reduce the water resource capacity of the CCT over the next three decades (New 2002). Indeed, recent weather data indicates that 2015 was the driest year in South Africa in 112 years (South Africa Weather Service 2016). Other evidence from the Southern Africa region points to shorter rainy seasons and more extreme rainfall events in the future. This could intensify drought periods, exacerbate the risks of flooding and soil erosion, and put regional food security into question (Pohl et al. 2017). Furthermore, it is expected that the region will be characterized as "chronically water scarce" by 2025 (Herrfahrdt-Pähle 2010), and this prompts concern over water availability for surface runoff and discharge, infiltration, and deep percolation of infiltrated water into regional aquifers. These changes to the local hydrological regime expose citizens of Cape Town to a vulnerable bulk water supply that has been built on surface water infrastructure—inviting more explicit investigation into the potential for groundwater and other water sources.

METHODOLOGY

For the purposes of the research, the first author completed 15 in-depth interviews with experts and stakeholders in the water sector of Cape Town, some of which were conducted collaboratively with other members of the broader research team. 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 local groundwater conversations (see Table 1). It is important to note, that this research involves only considerations important for the local level in Cape Town and did not include national level experts, including those working for the South African government, who might have different perspectives and relevant expertise. Since groundwater has to date not been a focus for Cape Town, the number of local decision-makers, water managers and consultants involved in groundwater governance and planning in the CCT was limited at the time of this research. The 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 or mandate related to groundwater issues. When developing the specific interviewee sampling rationale, the first author worked with several academics from two local universities, which enabled introductions at the City and with relevant groundwater experts. All told, our sample can be understood as inclusive of the range of views and perspectives of these experts in the region.

Table 1. Detailed breakdown of the organizations interviewed for this paper, and their affiliation or relevance to the research.

Sector	Organization affiliation or topic 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
Consultancies and research organizations	Atlantis	1
	Table Mountain Group and Cape Flats aquifers	2
	Cape Flats aquifer	1
Non-governmental organizations	Broader community issues of water and climate change	1
	Cape Flats aquifer protection	2
Academia	Cape Flats aquifer	1

Note: The number of interviewees refers to the number of individuals interviewed (18), resulting in a total of 15 interviews

As there were several distinct categories of interviewees, three different interview questionnaire templates were developed: one each for Local Government, Experts, and NGO representatives, also with some tailoring to the expertise of the individual participant. The three templates covered perceptions of how the water future might look like in the CCT over the next 20 years, and how groundwater is integrated into that vision. In addition to focusing on the barriers and opportunities for large-scale groundwater use in the CCT, 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. The first author also conducted several supplementary research activities, namely: visits to four key water infrastructure sites, attending the National Groundwater Strategy Workshop for the Western Cape (2016), and organizing meetings with key scholars engaged in groundwater research. Additionally, both authors hosted a water resilience conference for scholars from the Southern Africa region.

Interview transcriptions were analyzed through NVivo qualitative analysis software using a combination of structural and descriptive coding techniques and a secondary cycle of coding for frequency counts (Saldana 2009). This methodology allowed for us to organize interview data according to the most prevalent themes that arose from expert perceptions related to upscaling groundwater supplies for the CCT. Document and policy reviews also made up a considerable portion of the methodology, as this informed the development of interview questionnaires and protocols, as well as overall research conceptualization, analysis, and fact-checking results.

RESULTS

The analysis revealed primary dualisms associated with groundwater potential. On the positive side, there were clear motivations for groundwater development related to the future potential of the resource. More cautiously, some narratives stressed key limitations of integrating groundwater into a surface water-centric supply system. Notably, the original language of "barriers" to groundwater development, as opposed to motivations, was revealed to constrain the analysis. This was because research participants did not speak directly about groundwater barriers; instead they focused on the existing surface water infrastructure that was making widespread water supply changes and groundwater integration difficult. Thus, any "barriers" to groundwater development were discussed in terms of the "conventional path dependencies" (Brown & Farelly 2009) that have limited, or are limiting, the capacity for upscaling groundwater use.

Some key considerations to keep in mind throughout this section involve both the incentives and disincentives for groundwater development. Clear emphasis was placed on the high potential for groundwater to contribute to the overall resilience and sustainability of the Western Cape Water Supply System. However, the historical influence of the difficulties with the past management of the Atlantis scheme was also mentioned. Hesitation in accepting the concept of non-stationarity in climate change modelling scenarios (see Milly et al. 2008), and limited institutional capacity for hydrogeological expertise, are also challenges associated with agumentation of groundwater sources that will be unpacked in the discussion that follows.

Motivations

With respect to positive considerations and motivations related to supply diversification and augmentation of groundwater sources, we identified two primary themes: to strengthen the resilience of the water system and to broaden public acceptance of alternative water sources by countering negative perceptions.

Water Supply System Resilience

Groundwater is thought to provide a buffer against hydrological extremes, such as droughts, which the city could potentially face: "there's obviously benefits for when you go into a drought situation because then you could use your groundwater scheme" (Interview #5, CCT bulk water manager). In research interviews aquifers were likened to underground reservoirs that could function as extra supply during dry periods, thus increasing water supply system resilience in times of surface water shortages. One water manager from the CCT summed up this perception about the contribution of groundwater to overall system resilience in a statement: "I think diversifying our resources mix, putting more emphasis on groundwater surely can help us in terms of resilience" (Interview #10). Using groundwater sources was also associated with a decrease in water quality risks. Participants discussed this idea in terms of the CCT using groundwater in times of surface water contamination, or when dam levels got too low to effectively dilute contaminants and adhere to potable water quality standards. The CCT will not use the last 10% of water stored in dams for this reason. The literature also views groundwater sources as important for future drought periods (MacDonald et al. 2012). For example, references specific to Cape Town likened the Cape Flats aquifer scheme to a “survival strategy” due to the chronic water shortages that Cape Town is currently experiencing (Sorenson 2017).

Aquifer use was also an obvious choice for promoting water resilience from the stakeholder perspective. A farmer from the Philippi Horticultural Area (PHA) who uses groundwater to irrigate 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 illustrates that current farmers, who are the largest group of groundwater users in the area at present (albeit outside the municipal network), benefit from their use of the Cape Flats aquifer. While many echoed this sentiment, this doesn't necessarily address the issue of upscaling to the entire water system—indeed, there could be threats to small scale users if groundwater is integrated more fully into the city-wide scheme to any considerable degree.

Related to the above, participants also noted that groundwater could act as redundant, or back-up, water supply infrastructure. One participant cited an example from Cape Town’s 2015 summer when there was a water contamination issue in the Voëlvlei Dam in the northern suburbs of Cape Town, and it needed to be cut off from the water supply system. Additionally, if a pipe connecting a major dam to the Western Cape Water Supply System (WCWSS) was blocked or damaged, groundwater could provide back-up infrastructure until the issue was fixed.

Research participants associated groundwater with heightened water resilience in times of water availability extremes, and with water system resilience for scenarios where water quality or equipment malfunctions were of concern. These findings point to the need to think broadly about how integrating groundwater into the WCWSS can complement the goals for the system over the long-term. Given that research participants emphasized the resilience benefits of groundwater, a key goal could be to keep system resilience in the foreground of the design and management of future groundwater schemes.

Addressing Negative Perceptions of Alternative Water Sources

An unexpected result from discussions about groundwater opportunities was the potential to dispel negative perceptions of non-surface water sources. This is particularly salient for treated stormwater and wastewater (recall that the current artificial groundwater recharge scheme in Atlantis uses a mix of residential stormwater and wastewater). In addition to being relevant for Atlantis, these perceptions are also tied to the ongoing design of the Cape Flats aquifer scheme. For this scheme, the idea is again to use treated stormwater and wastewater to recharge the aquifer, building on the experience and example of aquifer development in Atlantis (DWS 2015). While the design of this scheme is still being developed, the integration of groundwater, stormwater and wastewater was a clear theme in the discussions of future uses of groundwater for the City. When discussing water scarcity, one CCT water manager said:

> *“I mean the other thing that is making us look at it differently is how we integrate the wastewater [and] effluent re-use and how do we make that work and manage perceptions around it…we haven’t really gone public and we are still busy*

> *formulating a communications strategy because there's been a lot of failure of things even in Durban, in eThekweni, where you get to a point and then suddenly people raise a lot of objections. So, it is a very sensitive issue. And* ***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 among both the City management team and the public. In reference to the example of eThekweni: this municipality in KwaZulu-Natal province adopted a direct potable re-use strategy for wastewater that has not been implemented yet. As awareness spreads regarding this future water strategy, public perceptions regarding reclaimed water in this region are mainly negative due to skepticism and fear surrounding water quality risks and uncertainty in the water treatment process (Owen 2016). Within the CCT, this research found that the perception about alternative water sources was largely uncertain due to the backlash expected to come from the public and the new management and technical aspects that would come along with of using treated wastewater at a large scale.

Branching out to groundwater may be the next step towards shifting water supply definitions and notions of acceptability to include groundwater, stormwater and wastewater for the City. Using the suite of water supply and re-use options that these three new sources could provide has the potential to embed notions of best management practices into the Cape Flats aquifer scheme. Examples of these practices could be water sensitive design and the concept of "fit-for-purpose." As a large component of the Cape Flats aquifer scheme could involve using treated stormwater, one participant emphasized this as an opportunity to shift the perception of stormwater towards that of a usable and beneficial resource. In the past stormwater has been largely thought of as a burden on the urban system. When discussing desired changes to the public image of stormwater and groundwater, 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). This quote exemplifies a key opportunity for future water supply development to use stormwater as a resource and extend its benefits to the overall CCT water system, in ways that are consistent with broader discussions regarding WSUD (e.g Armitage et al. 2014). Additionally, this shows a clear motivation in groundwater development – it is a potential catalyst in expanding additional opportunities for diversifying the supply mix in the WCWSS.

Conventional Path Dependencies

In addition to the overarching themes noted above, a number of the experts and stakeholders interviewed also emphasized the need to consider path dependencies in any efforts to upscale groundwater resources in Cape Town, South Africa. The first dependency, building on the issues noted above, involves historical influences surrounding groundwater perceptions, the second is linked to drought management and climate change modelling, and the third involves the inherent uncertainty associated with groundwater resources.

Groundwater Management Perceptions

> *"[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." – CCT water manager (Participant #5)*

This quote exemplifies that historical considerations influence perceptions surrounding groundwater – in that it has been viewed in the past as an emergency resource, or only used in rural and small systems. While interviewees spoke positively about the groundwater benefits regarding resilience and water resource attitudes, there is limited understanding about how to effectively manage groundwater resources because it has not been utilised at a large scale by the CCT in the past. One potential reason for this path dependency is the difficulties seen with groundwater scheme design and infrastructure stewardship in Atlantis, which are hindering any structural changes to the Western Cape Water Supply System.

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. 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. These types of monitoring capacity issues have also been seen elsewhere in South Africa, such as the KwaZulu-Natal province (DWAF 2008b). 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?" The City is clearly aware that groundwater requires different management practices when to compared to those of surface water, however these practices are not yet fully understood.

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. Surface water management is seen as easier due to significant investment in infrastructure and institutional knowledge, which is an evident path dependency challenging the transition towards enhanced groundwater use.

Drought Management and Climate Modelling

A second interesting finding from this research is that there is hesitation from the City of Cape Town water managers in using water models that take climate change effects into account. The Reconciliation Strategy for the Western Cape illustrates 11 different water supply diversification model scenarios, and three scenarios include a climate change factor. This research found that these future scenarios, which incorporate climate change impacts, 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). Additionally, in a recent report outlining her approach to Cape Town’s water crisis, Mayor Patricia de Lille shared a similar sense in early 2017: “many City officials did not see that climate change was introducing more uncertainty into our water supply planning and models” (Davis 2018).

Using conventional water modelling approaches is an interesting path dependency because it supports one of the larger arguments in the urban water management literature that water managers are slow to take up the projected timelines or effects of climate change. This is discussed as being mainly due to a lack of evidence or high uncertainty, and the implications of inaccuracy when drawing water planning conclusions (White et al. 2008, Tribbia et al. 2008, Beck & Krueger 2016). However, in the case Of Cape Town where groundwater has been seen as a resource to be used only in times of extreme water scarcity this perspective is limiting capacity for strategic planning that acknowledges the impacts of climate change. Encapsulating these future real impacts is now necessary in the field of water resource management in order to update the methods of water infrastructure planning that traditionally have considered climate variability to be small enough to be negligible (Milly et al. 2008).

There is also a hesitation in revising approaches to drought management in Cape Town. One CCT water manager stated that: “[y]ou don’t manage drought by building new resources. You manage drought with restrictions” (Interview #10). This approach to drought management has been the foundation of the CCT’s approach to the ongoing drought, as evidenced by the city’s unprecedented water restriction targets, currently at less than 50 litres per day per person (Level 6B) (CCT 2017c). For reference, during the time of field research in 2016, there were three levels of water restrictions outlined by the CCT, thus Levels 4-6B are a new outcome of the ongoing drought crisis.

Another factor cited by multiple research partcipants as a barrier to revising the drought management approach, was the perception that droughts are temporary events. A frequently cited example came from Melbourne, Australia, where during the “2000s Drought”, the municipal government invested in a desalination operation to augment supply that became obsolete when the rains returned. The operation then became a large financial burden to maintain, as opposed to an infrastructure asset (Interviews #7, #10 and #15). This chosen example is important because it demonstrates the reason behind the hesitation in investing in permanent infrastructure: because drought is perceived to be a temporary problem. However, droughts may be increasing in terms of frequency and intensity at the global scale (Sheffield & Wood 2008) and in South Africa (ADAM 2009, Pohl et al 2017). Indeed this ongoing drought was highly unpredictable in its length and intensity (Ziervogel 2017) and this has shed light onto how a temporary drought can become a water crisis. The conventional perspective of focusing mainly on water restrictions and building new supplies only when demand outstrips supply is not capturing the bigger picture in Cape Town where water scarcity and climate variability are serious, long-term considerations.

Uncertainty and Knowledge Barriers

Lack of groundwater knowledge and uncertainty were frequently mentioned by CCT water managers and consultants as a barrier to sustainable groundwater development. These knowledge barriers centered around the uncertainty that exists when planning for the environmental impacts that come as a result of a groundwater abstraction scheme:

> *"The thing with groundwater that is uncertain is its effect on the environment. So while…we've spent a significant amount of money putting monitoring infrastructure in place and collecting background information on the broader environment in the areas we'll be abstracting water from… And theoretically while we think we can anticipate what the impact will be, we still don't know and of course there is some… Obviously there's some environmental sectors that are worried about [it]." (Interview #5)*

From this quote, it is evident that the sustainability of abstraction is a concern to both the CCT and local environmental stewardship organisations. Other participants echoed this sentiment, adding that "in groundwater, it has so many unknowns. So much easier in surface water, because…you can see it, and it behaves in a very predictable way, whereas with groundwater there's so many unknowns" (Interview #6). This quote exemplifies the opinion that managing a resource with high institutional understanding is an attractive option because there are less unknowns and less uncertainty.

Another factor exacerbating uncertainty in groundwater development at a larger scale is the reduction of employed groundwater experts at the national level. 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 also had the outcome of "limiting functions and operations" (National Groundwater Strategy Workshop 2016). Without people both knowledgeable and passionate about groundwater in specified roles of groundwater planning leadership, the perception is that the responsibilities for groundwater planning is falling through the cracks. This perspective was repeated several times at the National Groundwater Strategy Workshop for the Western Cape, held in August 2016 . 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. This suggests that a path dependency could be the large amount of institutional understanding linked to surface water management, in contrast to the fundamental uncertainty connected to future groundwater development and use.

This is not to say that there is no work being done on building institutional knowledge around groundwater. One participant outlined the feasibility work underway in 2016: "we've spent a significant amount of money putting monitoring infrastructure in place and collecting background information on the broader environment in the areas we'll be abstracting water from. So that when we eventually start pumping, we can compare to a set of background data or baseline data" (Interview #5). It is important to note here that creating a baseline dataset for the sites of future groundwater schemes is an important step in building sound understanding about future groundwater use (Riemann et al. 2012, Riemann et al. 2015, Gleeson et al. 2012b). This feasibility work will also shed light on the many unknowns associated with groundwater use, such as new management best practices, sustainable abstraction rates, and environmental impacts.

DISCUSSION

In this section, connections are drawn between the motivations for, and path dependencies hindering groundwater integration, by identifying two main priorities in relation to our specific results and discussions of water governance and water supply diversification more broadly.

Building Resilience to Drought

Drought episodes are no longer functioning under an envelope of predictable probability. The local hydrological regime changes that have been realised in Cape Town, such as increased frequency and intensity of droughts and changing water availability patterns (New 2002), argue clearly for developing new water supplies to meet demand. In the case of Cape Town, current drought management processes focus on water conservation policies, which include strict water rationing with the ultimate potential of cutting off supplies to homes with Day Zero. With the ongoing drought and the creation of the Critical Water Shortages Disaster Plan, there is an opportunity for Cape Town to practically build drought resilience. An essential consideration here provided by research partcipants is ensuring that groundwater be used as a drought buffer in addition to augmenting bulk water supply. Water experts in Cape Town agree that using groundwater as a drought buffer could ensure that emergency water supplies are available to use throughout future drought periods.

Using groundwater as a bulk water source and drought buffer is now being taken much more seriously due to the current drought, and new projects are underway which include abstracting 100 million litres per day from the TMG and CFA aquifers (CCT 2018) – a target stated to be “impossible” by the proposed deadline, according to local groundwater experts (de Villiers 2017). Clearly groundwater resources are being realised as a key intervention to managing the current drought, however these will be long-term projects. Including context surrounding changing hydrological regimes and increasingly variable surface water availability will be an important step in building water system resilience in Cape Town. An insight here would be to also increase coordination between the CCT and external consultant organisations that are conducting the hydrological models and other technical water supply studies for the City. This would also strengthen the existing limited groundwater monitoring networks, as they have been identified as a key obstacle to groundwater governance (Riemann et al. 2015). As there is limited institutional knowledge surrounding groundwater management at the City, beyond operations in Atlantis, the input of local hydrogeologists or other groundwater experts will be essential moving forward. This input would also be relevant for larger drought management, water demand management and stormwater management plans for the City.

Groundwater can serve as a drought buffer; this was a prevalent motivation for future groundwater use from research interviews. Building on this insight, there is a clear need to focus on proactive approaches to water scarcity through a portfolio of water sources. This acknowledges the role that groundwater could play, already appreciated by Cape

Town water experts, and could perhaps better equip the CCT to handle unexpected changes in surface water availability and increase the resilience of the WCWSS to future droughts.

Water Supply Source Definitions

A second policy direction identified by this research to be a future priority is to reevaluate the current water sources that are perceived as being safe, useful or preferred supply sources. Due to the historic focus on surface water and dam development, other water sources have gone unused. Groundwater has been viewed as a water source for emergencies and rural areas, such as Atlantis, that have no other water supply options. In Cape Town and beyond, stormwater and wastewater been perceived as an urban burden or byproduct. These water sources are increasingly being used in new and innovative ways around the world to build water resource capacity for water scarce areas, and in regions that are interested in conserving water and becoming more water aware. For example, the American National Association of City Transportation Officials recently released the Urban Street Stormwater guide (2017), which is based on stormwater infrastructure practices for public streets, learned and tested in cities across the United States. Elsewhere, the city of Rotterdam in the Netherlands, is emphasizing the usefulness of stormwater with their “Room for River” campaign which has made significant strides in creating new spaces for urban rivers (Kimmelman 2017).

These types of innovative ideas and practices fall under the umbrella of Water Sensitive Urban Design (WSUD), which uses themes of green infrastructure broadly in new development projects. A shift such as this in Cape Town could extend definitions of useful water resources beyond conventional surface water approaches, and instead move towards increasing the efficiency of how urban water flows and is used throughout the CCT system. This notion has already started through the proposed plan for the CFA to use harvested stormwater and treated wastewater, which would build on the innovative scheme that began in Atlantis. 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, permeable pavement and bioswales, in new development projects (Armitage et al. 2014). Other lessons learned from past WSUD research for the City of Cape Town includes developing simple tools for consultants to value the benefits of water sensitive design, and the need for long-term monitoring of sustainable drainage system projects (Armitage et al. 2013).

Identifying WSUD as a future policy priority builds on the foundation that has already started to take shape by the growing support for these concepts and practices in Cape Town (Armitage et al. 2014). It would benefit Cape Town in the long-term to encourage and invest in the WSUD movement in order to improve water monitoring networks and to coordinate efforts with the research and consultancy communities to push for a water supply system built on diversified water sources. Progress is being made in these directions (see Ziervogel 2017), but further effort is required.

CONCLUSION

Expert perspectives surrounding the use of alternative water sources are meaningful when it comes to urban water management, because their perceptions shape the policies and strategies that guide the mechanisms for long-term water demand and supply planning (Ziervogel et al. 2010). While the challenges for integrating groundwater sources into the WCWSS are significant, the Table Mountain Group aquifer and Cape Flats aquifer schemes make up a sizeable portion of the Western Cape Water Reconciliation Strategy and are an inevitable addition to the WCWSS. These two supply augmentations schemes that use alternative water sources have high potential for increasing the resilience of the WCWSS to drought. We argue that reconciling the motivations and barriers to groundwater governance is a goal that has thus far been largely underrepresented in the planning procedures responsible for upscaling groundwater development in Cape Town. These research findings continue to be relevant in the water management sector of Cape Town, however it should be noted that the research landscape concerning groundwater is changing rapidly as plans for future supply augmentation become realised.

The goal of the recommendations for building drought resilience and broadening water supply source definitions is to provide tangible ideas for strengthening future water supply diversification schemes in water stressed cities. Based on our research, this would involve focusing on the high potential of new sources to alleviate the water constraints associated with insufficient supplies, and in the case of Cape Town, to help address severe ongoing drought in the Western Cape province of South Africa. We believe identifying and addressing the challenges associated with alternative water source development has the potential to provide the foundations of a more portfolio based approach to water supply. The research contribution from this paper is two-fold: to reinforce the messaging around how institutions can use portfolio-based approaches to water supply; and address path dependencies which may be keeping them “locked-in” to less resilient approaches to urban water management.

This paper provides insight into some of the possible challenges associated with urban water supply diversification, while in pursuit of greater security and resilience in times of regional water stress. The main argument is for stronger acknowledgement of the motivations and barriers to sustainable integration of groundwater as a bulk water source into the existing urban supply system. From our case study, the shift to water supply diversification is pivotal to increase the resilience of an already water scarce region likely to face increasing water stress and drought periods.

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