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Water Literacy in Drought-Prone Regions: Case Studies from Aurora, Colorado, USA and Cape Town, Western Cape, South Africa

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Abstract

Water managers around the world must reevaluate their approach to water security as challenges continue to grow. Supply-focused paradigms that aimed to capture, control, and commodify water resources are increasingly unreliable and often depend on environmentally and socially damaging practices. Of particular concern are regions experiencing climate shocks and aridification from rising global temperatures. In order to stretch limited water resources using equitable water policies, conservation programs, and alternative water sourcing, water managers must invest in a water literate citizenry. Water literacy is the culmination of water-related knowledge, attitudes, and behaviors. The benefits of a water literate citizenry abound, including increased transparency and trustworthiness around water management decisions, an uptake in water conservation and collective action, and a focus on community justice and water equity. However, the relative newness of water literacy research means our understanding of this concept, including what it entails and how its formed, is limited. Within this dissertation, I draw on theories of political ecology and planned behavior to respond to calls for an increased understanding of water literacy and its application within diverse case studies. First, I conduct a systematic literature review of water literacy and synthesize available definitions into an organizational framework. Then, I seek to apply this framework within the case studies of Cape Town, Western Cape (South Africa) and Aurora, Colorado (USA). These cities represent rapidly growing urban contexts that experience recurring drought seasonally and also experienced severe droughts within the last two decades. They also offer vast differences in geographic, sociopolitical, and economic contexts. The results of this research provides each city with a baseline understanding of community water literacy, which can be used to improve water management processes. Additionally, the results expose how lived experiences and sociopolitical structures can both help and hinder the formation of community water literacy.

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Table of Contents

List of Figures

List of Tables

Chapter One: Introduction, Theory, and Study Context

1.1 Introduction

The task of water managers has always been a complex balancing act, weighing the quantity of water demanded by regional agricultural, industrial, and urban consumers against available water supplies collected in rivers, lakes, reservoirs, and groundwater aquifers. Such a balance requires a firm understanding of hydrologic watersheds, the built environment, and competing human and environmental needs, as well as the legal and institutional systems in which they operate (Baker, 2009). However, the ability to achieve a water balance model is increasingly difficult due to shifting factors on either side of the equation. On the water demand side, rapid global urbanization is inflating the quantity of water needed (Niemets et al., 2021). Additionally, environmental flows and indigenous water needs are increasingly being recognized as important water demands that have not historically been recognized (Arthington et al., 2018; Finn & Jackson, 2011; Richter et al., 2012). Meanwhile, the water supply side is marred by the environmental degradation and resource depletion emerged from a history of large infrastructural development (Bakker & Morinville, 2013; Gleick, 2000; Joy et al., 2014; Loftus, 2015). Increasing global temperatures also introduce increasing vulnerability to water balances through shifting hydrologic regimes (Jiménez Cisneros et al., 2014). Earth's drylands, which cover 41% of land area and are home to over a third of the world's populations, are particularly affected by trends of aridification and increased risk of intensified droughts

(Falkenmark, 2013; Kimura, 2020; Li et al., 2021; Overpeck & Udall, 2020; Seager et al., 2014). Research suggests that the combination of climate change and urbanization will increase the number of urban centers experiencing water scarcity will increase from 193 to a maximum of 284 by 2050 (He et al., 2021).

Collectively, these challenges produce imbalanced water models, where the quantity of water supplies amounts to less than the quantity needed by consumers. Rebalancing the system requires water managers to boost the quantity of available water supplies through supply-focused adaptations or reduce the amount of water that is needed through demand-focused adaptations. The options to boost water supplies in arid regions, where water resources are limited and highly contested, is increasingly difficult. Instead, supply-focused adaptations lean more and more on treating formerly unusable water to potable standards using technologies like recycled wastewater or desalination. Importantly, these projects carry large price tags and take years to complete, making them less viable during climate shocks (Australian Aid, 2021). Alternatively, water managers can target demand-focused adaptations. These utilize smaller efficiency upgrades or behavior changes on the behalf of water consumers to reduce the amount of water needed. Demand-focused projects carry price tags that are three to ten times less than supply-focused adaptations, and can often be implemented quicker than infrastructural supply-focused projects (Richter, 2014). However, they are inextricably tied to the water consumers themselves. As such, water managers have limited direct control over the success of these projects and are relegated to engaging stakeholders, raising awareness and financially incentivizing upgrades (Australian Aid, 2021).

Both supply-focused and demand-focused adaptations are important components to balancing a water system. But the successful implementation of either hinges upon the public. Supply-focused augmentation schemes that utilize alternative sources are steeped in opposition and controversy, emerging from the relative newness of these technologies and the stigmatism of their sources. Public fear and a lack of understanding has brought numerous projects to the point of failure in drought-prone regions in the United States and Australia (Caball & Malekpour, 2019; Kosovac et al., 2017). Demand-focused projects have also failed when the public lacks knowledge of how or why to change their behaviors, or the willingness to do so (Howarth & Butler, 2004; Mulwafu et al., 2003). The lack of water-related knowledge, attitudes and behaviors among the public, or community water literacy, hinders the ability to of water managers to adapt their water systems.

In much the same way, then, a strong community water literacy can be leveraged as a tool to assure the success of both supply-focused and demand-focused adaptations. Indeed, scholars increasingly correlate increased support for alternative water sources and a willingness to pay for water supply investments with water literate communities (Attari et al., 2017; Giurco et al., 2010; Stoutenborough & Vedlitz, 2014). Additionally, higher levels of conservation and behavior change have been correlated with higher water knowledges and attitudes (Dean et al., 2016). Adaptation pathways that actively engage communities with water literacy are more likely to succeed, while also fostering trust in water managers (Attari et al., 2017; Cooper & Cockerill, 2015; Dean et al., 2016; Jorgensen et al., 2009). Simultaneously, community water literacy leads to more engagement in formal and informal dialogues about water (Dean et al., 2016), which scholars suggest as a mechanism to expose and correct water-related injustices (Bergquist et al., 2020; Rusca & Di Baldassarre, 2019).

Despite these widespread benefits and growing importance within sustainable water management, the concept of water literacy is a relatively new field of study. Its definition and use vary widely across existing literature, suggesting its highly contextual nature (i.e. Giurco et al., 2010; Gilbertson et al., 2011; Sammel, 2014; Dean et al., 2016). Scholars have repeatedly called for more studies that investigate how social and political contexts influence water literacy, how to maximize community water literacy and how to mobilize it into action (Giurco et al., 2010; Wood, 2014; AWC, 2016). Thus, my research seeks to contribute to the growing field of water literacy with the goals of improving demand management strategies while empowering community members to advocate for their water needs. First, I analyze the concept of water literacy as it has been used and applied in existing literature. Then, I investigate water literacy within the cities of Cape Town, Western Cape (South Africa) and Aurora, Colorado (USA). These research sites exist within vastly different sociopolitical contexts but have both relied on demand management techniques in the recent past to survive extreme droughts. Using a mixed-methods approach, I investigate the water literacies of Cape Town and Aurora communities, and how they relate to local water management and experiences of drought.

1.1.1 Research questions

The specific research questions (RQ) guiding this dissertation include:

1. How has the concept of water literacy been understood and applied in the literature and in practice?

2. What are the water literacies of communities in Cape Town and Aurora, measured by water-related knowledges, attitudes, and behaviors?
    b. Are there correlations or relationships between these elements of water literacy?
3. How do water literacies of communities in Cape Town and Aurora relate to their geographic, sociopolitical, and economic contexts? How do they relate to lived experiences of drought?
    b. How was water literacy used to engage tourists in Cape Town during the Day Zero drought?

1.2 Theoretical Frameworks: Political Ecology & Theory of Planned Behavior

My research into water literacy is framed first and foremost by political ecology, an established framework grounded in the understanding that natural resource management is fundamentally a political act, impacted by surrounding social, cultural, and economic powers (Blaikie, 1999; Islar & Boda, 2014; Robbins, 2020). Applied to water management, the framework of political ecology reveals how instances of drought and water scarcity are complex phenomena shaped by the combination of environmental instabilities, societal power differentials (Loftus, 2009; Swyngedouw, 1997), and uneven distribution of water resources (Harris, 2020; Johnston, 2003; LaVanchy, 2017; Mehta, 2003).

Political ecology is an ideal framework for this research because the concept of water literacy is intimately tied to a community's social, political, and economic contexts. For example, water literacy includes an awareness of one's local water system, from the water sources to the water uses, and the infrastructure and distribution system used in between. But water resources are managed along political boundaries rather than hydrologic boundaries. The division of water sources between competing communities are bound in compacts and treaties, and water uses are generated by economic activities. In this way, water literacy is knowing how political and economic structures are influencing what water sources are available.

Perhaps most importantly, knowledge is itself political, a concept which has been widely recognized through the old adage “knowledge is power.” Scientific knowledge is often construed as objective, despite being continuously used to shape hegemonic powers and reinforce decisions of access. Similarly, ignorance or the cultivation of the unknown also boosts political powers (Aubriot et al., 2018). Those with knowledge have power, and that gives them the ability to choose how, when, and with whom they share that knowledge. Further, even what we deem as “knowledge” is political. The field of water management is dominated by western knowledge, based on compartmentalized, quantifiable data and the scientific method. In contrast, indigenous knowledge that emphasizes holistic, experiential, and connected understandings of water, are largely absent from water management techniques (Hawke, 2012). In this way, political power decides what type of water knowledge is valuable and therefore utilized in decision-making processes.

However, water literacy encompasses more than just water knowledge. Water-related attitudes and behaviors are just as important for shaping successful demand management. As such, the theory of planned behavior is a secondary framework to my research design. This theory postulates that behaviors are the result of the following three factors (Ajzen, 1991):

- The individual's *attitude* toward the behavior, whether it is viewed favorably or not;
- The social pressure to perform (or not perform) the behavior, known as the *subjective norm*; and
- The individual's perception of the level of difficulty to perform the behavior, known as the *perceived behavioral control*, which is based on available resources, opportunities, and confidence that the behavior can be done.

According to this theory, knowledge alone is not sufficient to generate behaviors like water conservation. Indeed, numerous studies have demonstrated the importance of information about water conservation and access to the right resources to conserve (Chaudhary et al., 2017; Kilic & Dervisoglu, 2013; Montano & Kaspryzk, 2015). While less central to my research than political ecology, the theory of planned behavior was a central tenant within the design of my methods. Specifically, I targeted the three factors of planned behavior within the content of my water literacy surveys and focus groups.

1.3 Research Sites

My research focuses on two different geographic locations whose experiences and characteristics contribute broadly to the research questions. The first research site is Cape Town in the Western Cape Province of South Africa, and the second is more local at Aurora, Colorado in the United States. Both cities exist in drought-prone climates that are projected to experience droughts of increasing magnitude and duration because of climate change. They have also both experienced multi-year severe droughts since the turn of the century that nearly caused water system failure and had widespread socioeconomic impacts. And while my research is not a direct comparison, the vastly different in cultural, social, and political contexts of these cities also provides insight into how context influences the development of community water literacy. The following section provides more contextualization and details of both research sites.

1.3.1 Research Site 1: Cape Town, Western Cape (South Africa)

Cape Town is located in the Western Cape province in the southwest corner of South Africa (Figure 1.1). The regional landscape is physically dynamic moving east from the Atlantic coastline, immediately rising 1000-m at the Table Mountain formation, then sinking down to the barren and low-lying Cape Flats, which sit in the shadows of the towering Cape Fold Mountains in the distance. The city enjoys a Mediterranean climate, a product of its location at 33.9°S and it's positioning between the cold South Atlantic Ocean to the west and the warm Indian Ocean to the southeast. As a result, Cape Town experiences cool, wet winters and hot, dry summers with recurring droughts.

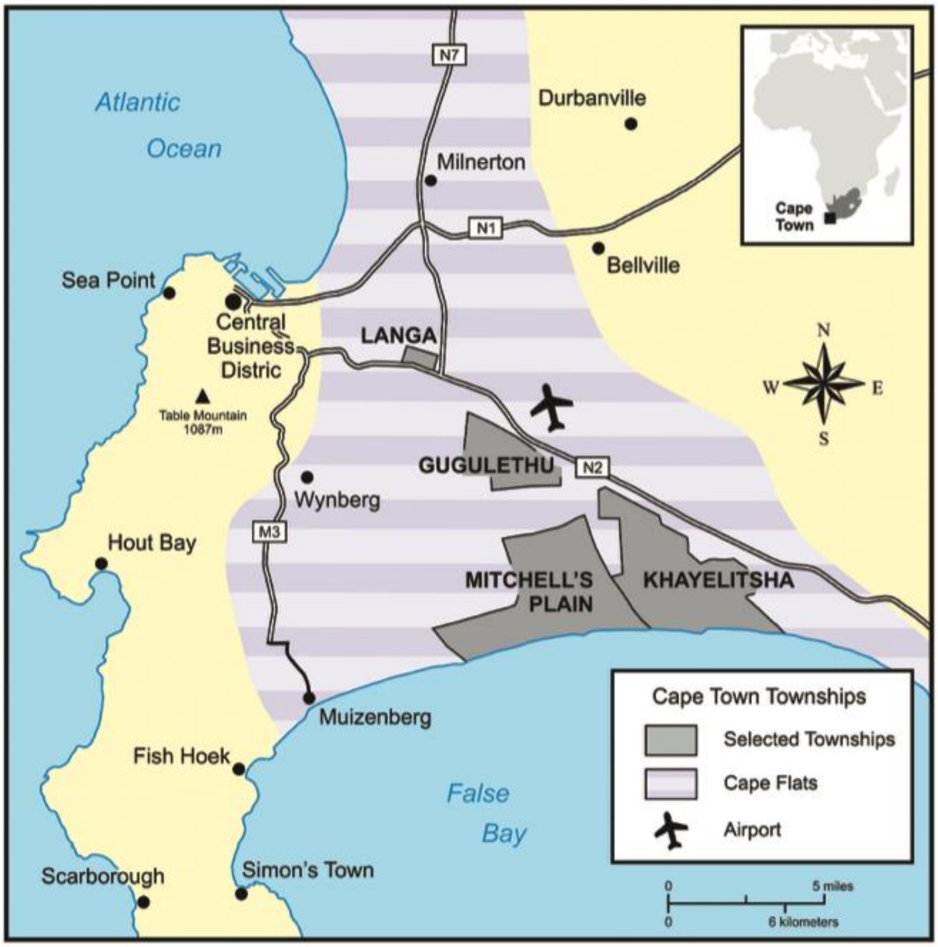

Figure 1.1: Location of Cape Town and Langa township within South Africa. Cartography from Michael Larson.

Cape Town is home to over 4.75 million people, a population that is expected to grow past 5 million by 2025 (WCG, 2021). It is regarded as one of the world's most multicultural cities with high levels of diversity, and yet it is also a city of stark contrast where large, affluent homes are built alongside sprawling informal settlements and extreme poverty (Goodness & Anderson, 2013). Cape Town is also an important tourist destination for both the region and the country, consistently accruing both the largest numbers of visitors and the highest levels of tourism receipts annually (Signé, 2022; UNWTO, 2021). Attractions include the Cape Floristic Region, one of the most biodiverse ecosystems in the world (Goodness & Anderson, 2013), Table Mountain, one of the seven natural wonders of the world (New 7 Wonder, 2021), and the Cape Winelands in the surrounding countryside.

Cape Town's water is sourced from the Western Cape Water Supply System (WCWSS), which collects winter precipitation in six interconnected reservoirs for treatment before distribution to the city and surrounding regions. The largest demand is urban domestic consumption (Stafford et al., 2018), fueled by increasing populations, rural-urban migration, and tourism. Decades before 2018, this system was deemed insufficient to meet growing water needs (Luker & Rodina, 2017). The inner-city distribution system is also insufficient as it furthers water inequity through a physical manifestation of the country's history with colonialism, apartheid, and racial segregation (Enqvist & Ziervogel, 2019; Rodina & Harris, 2016; Smith, 2012; Smith & Hanson, 2003). The history of Cape Town's water system is discussed in detail in Chapter 3.

Past water literacy research in South Africa is limited, suggesting only that South Africans do not understand their roles in water management and water conservation, and frequently view water managers with distrust (Cameron & Katzschner, 2017; Meissner et al., 2018; Sershen et al 2016; Wolski 2018; Ziervogel, Shale and Du 2010). This is also discussed in greater detail in Chapter 3. However, Cape Town's recent experience with drought and near system-failure may have contributed to the formation of community water literacy. From 2015 to 2017, the Western Cape region received below average rainfall that led to extreme drought. As reservoir levels continued to drop (Figure 1.2), city officials began the countdown to Day Zero, the day when low reservoir levels would force them to turn off city taps. An ambitious water conservation program was implemented, utilizing a combination of education and fear to reduce water demands and avoid Day Zero.

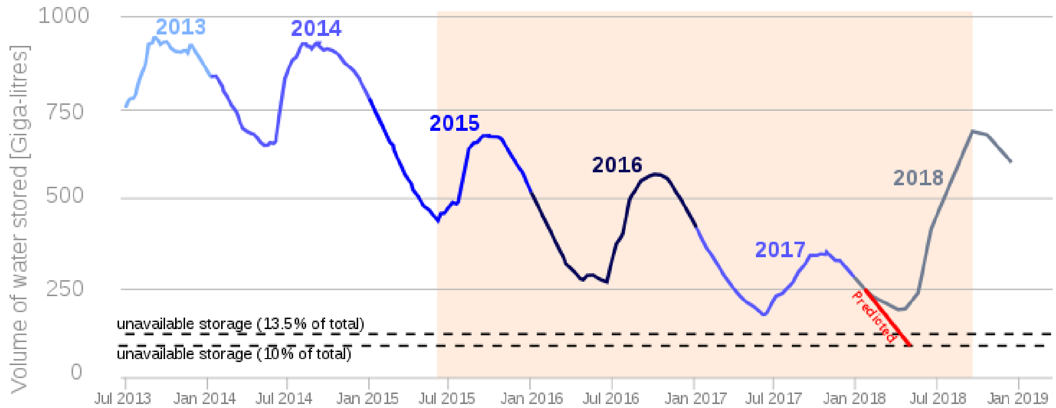

Figure 1.2: Declining dam capacity in WCWSS leading up to Day Zero (from Discott, 2018). CC BY-SA 4.0

Active adoption of restrictive conservation guidelines initially lagged while the public vocally blamed management failures for the drought, requiring city officials to further tighten restrictions (Newkirk II, 2018). In contrast to the level 1 restrictions (10% water savings) typical for an average dry summer, the threat of Day Zero forced the city to escalate restrictions to level 6B, limiting residents to a mere 50 liters per person per day (LaVanchy et al., 2019). For comparison, this restriction coincides with the lowest end of the 50-100 liters per person per day range that the World Health Organization (WHO) states as required to meet basic needs (UN-Water, 2014).

In the end, Cape Town avoided the arrival of Day Zero thanks to conservation, forced rationing, and a timely 2018 rain season. Yet the threat of extreme drought is far from gone. A trend of increasing air and sea surface temperatures has already been identified for the region (Boko et al. 2007; Cazanave et al. 2019; Niang et al 2014). Warmer ocean waters contribute to a weakened circumpolar vortex and an extension of the Hadley Cell poleward, which subsequently decreases the upslope wind conditions that drive winter precipitation patterns (Niang et al 2014; Burls et al 2019). Climatologists predict these collective impacts of climate change will increase the likelihood of severe droughts by a factor of 3.3 (Otto et al., 2018). Thus, Cape Town provides a prime opportunity to understand the immediate impacts to community water literacy following a historic drought, but one that is likely to reoccur.

1.3.2 Research Site 2: Aurora, Colorado (USA)

Aurora is the third largest city in the southwestern state of Colorado, behind Denver, immediately to the east, and Colorado Springs, to the south (Figure 1.3). It is located in the Colorado Front Range, a corridor of semiarid high plains environment to the east of the dynamic Rocky Mountains. The city enjoys a warm and temperate climate that shape cold, snowy winters and hot, dry summers with recurring drought. Precipitation is fairly limited at an average of 413 mm per year (Climate-Data, 2022).

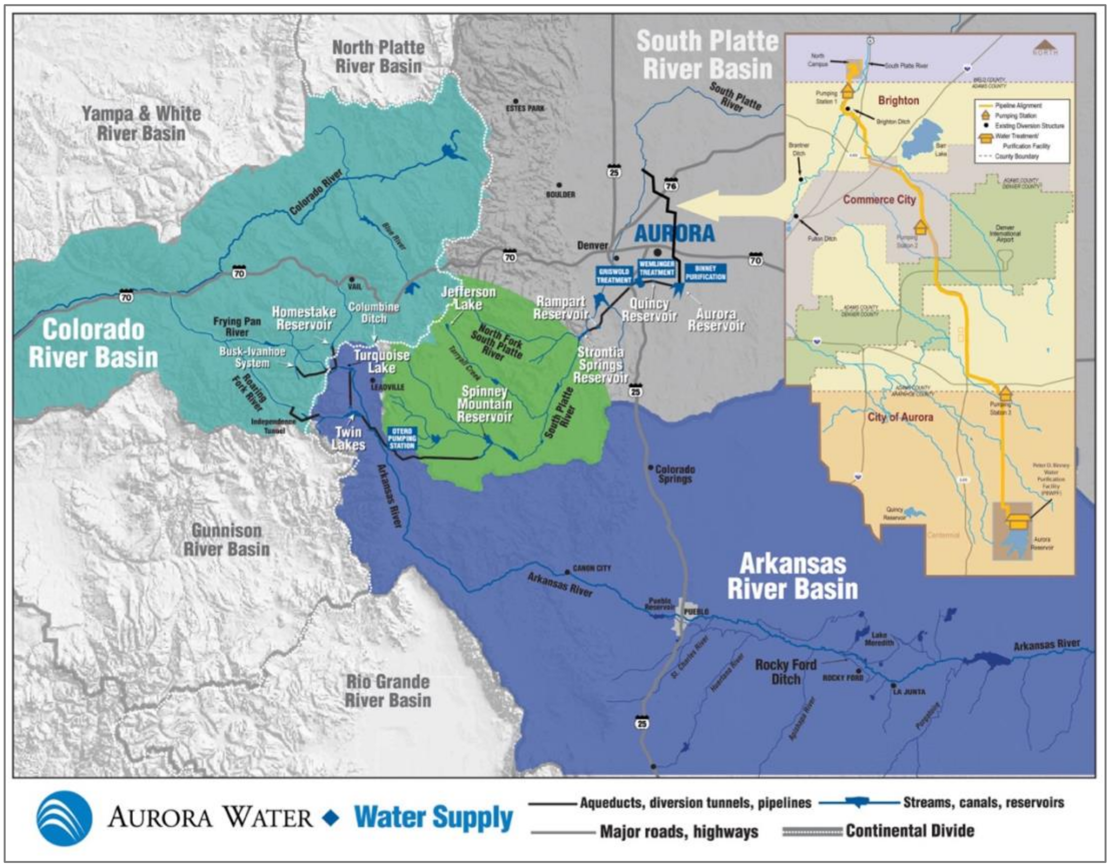

Figure 1.3: Location of Aurora along Colorado Front Range and the three watersheds from which it sources water supplies (from CoA, 2023b).

The entire Front Range region is experiencing rapid population growth, but while cities like Denver are increasingly "landlocked" by surrounding suburbs, Aurora still has large amounts of undeveloped land and is expanding residential developments into the East. The most recent population estimates from the city show a 2.9% increase in population from 2021 to a total of 398,018 individuals in 2022 (CoA, 2023a). Aurora is also uniquely diverse compared to other Colorado cities, wavering in its status as a minority-majority city from year to year. Data from the 2017-2021 American Community Survey report populations of 44% non-white, 29% of Hispanic or Latinx origins, and 22% foreign-born (CoA, 2023a).

The City of Aurora (CoA) was originally supplied water through the Denver Water Union Company (now Denver Water). Aurora Water (AW) was created in 1949 and the municipality become entirely self-sufficient in 1967 after the construction of the Homestake Reservoir. AW now manages a system of 12 reservoirs throughout the mountains and eastern Front Range (Figure 1.3), which are primarily sourced by spring snowmelt (COA, 2023b). However, the delay in securing water resources means that AW holds more junior water rights compared to other Front Range cities and therefore runs a greater risk of failure during periods of prolonged drought (Kho, 2013). One example of near failure can be found at the turn of the 21st century, when abnormally dry conditions starting in 1999 reached disaster proportions by 2002.

Cities across the Colorado Front Range were all hit hard by drought in 2002, but Aurora was hit especially hard because of its junior water rights. The reliance on surface water and lack of preparation for drought quickly dropped AW's reservoir capacity to 25% (CWCB, 2013). AW responded quickly and aggressively to avoid system failure, and implemented a range of city-wide water restrictions and conservation strategies that have since developed into a suite of permanent offerings. The experience of the 2002 drought also acted as an impetus for innovation, inspiring AW to creatively augment their water supplies with a reclaimed wastewater project called Prairie Waters, and more recently with the purchase of the London Mine water rights. These are outlined in greater detail in chapter 5. Collectively, this work has shaped AW's reputation as a state leader in innovation and water sustainability.

Increasing global temperatures are producing patterns of aridification across the southwestern United States, driven by increased evapotranspiration, shifting precipitation patterns, reduced river flows and drying soil conditions (Kimura, 2020; Overpeck & Udall, 2020; Seager et al., 2007). Climatologists predict this will cause occurrences of droughts that worsen in frequency and intensity (Jenkins & Warren, 2015; Kimura, 2020; Naumann et al., 2018). Combined with growing populations and urban water demands, water managers like AW are facing increasing vulnerability to water shortages and failures. This makes it essential to understand how AW has contributed to community water literacy in the face of drought with the goal of preparing for an increasingly arid future.

1.4 Research Methodology

Theoretically, the concept of water literacy inherently involves objective, quantitative knowledge (i.e. water flows, water treatment, water usage) as well as constructivist, qualitative knowledge (i.e. attitudes and values about water resources, perceptions of water managers, hydrosocial relationships). To capture the diverse components of water literacy, I utilized a similarly diverse mixed-methods approach with the goal of revealing both quantitative and qualitative knowledge generation. Specifically, I paired a quantitative literature review and surveys with qualitative focus groups and interviews. The combination of these methods varies across manuscripts, and so more detailed descriptions of applied methods are provided within each manuscript chapter. However, the following section introduces the methods used to answer each research question.

1.4.1 Methods for RQ1: How has the concept of water literacy been understood and applied thus far in academic and governmental settings?

This question emerges from calls among scholars to better understand the theory of water literacy (i.e. Giurco et al., 2010; Gilbertson et al., 2011; Sammel, 2014; Dean et al., 2016). Given the relative newness, water literacy has been defined in a wide diversity of ways and across various disciplines that relate to water management. Thus, the method used to analyze Research Question #1 was a systematic literature review, which is ideal for synthesizing interdisciplinary research with the goal of facilitating theory development (Snyder, 2019). This is a necessary starting point for my research that was then used as a theoretical foundation for following questions.

Research Question #1 can be broken down into two different parts. The first part investigates how water literacy been understood in academic and governmental settings, while the second investigates existing applications and dominant trends in water literacy across populations. To answer the first part, I first gathered all available scholarly and grey literature that provided a definition or detailed understanding of "water literacy" or "watershed literacy". Using an iterative qualitative thematic text analysis, I then inductively identified themes among the existing definitions and uses of water literacy. Eight themes, or "knowledge sets", were identified and shaped into an emergent framework.

To answer the second part, I sought to apply the emergent framework to surveys of water literacy knowledge sets across adult and student populations. This allowed me to evaluate key the general strengths and weaknesses of water literacy across public populations and identify best methods of improving water literacy for the benefit of sustainable water management.

1.4.2 Methods for RQ2: What are the water literacies of communities in Cape Town and Aurora, measured by water-related factors like knowledges, attitudes, and behaviors?

Research Question #2 emerges from a lack of systematic analysis of the current water literacy within the two chosen case studies. In order to answer this question, I needed a to inquire about water-related factors across large audiences. Thus, I started with surveys, which are highly structured tools that quantify the same set of variables across large groups of people to generate comparable data (de Vaus, 2014). Surveys are both the most frequently used method for quantitative analysis in social research (Philip, 1998), as well as the tool of choice across existing water literacy research (i.e. AWC, 2015; Cooper & Cockerill, 2015;Dean et al., 2016; Duda et al., 2015; He, 2018). However, my approaches to surveying varied between case studies because of important contextual differences that required different attentions.

As mentioned before, Cape Town is a very diverse city. There are 11 national languages and although English is the lingua franca, Langa township in which we worked was primarily isiXhosa. This necessitated some form of survey translation. Additionally, research among marginalized African communities has often been conducted in exploitative ways, leading to distrust of outsiders (Teixeria da Silva, 2022). Langa township is no exception to this pattern. Thus, I approached the survey process using inclusive and collaborative strategies, including: an exploratory community focus group to both discern key water issues for community members and include them in the process of survey development; a review of the survey draft with local community leaders before finalization; and the hiring of a team of local Langa residents as survey administrators, who were familiar with the whole community and could translate in-person during data collection. These strategies were chosen as ways to build community involvement and ownership of the process, with the goal of building trust in the research. The results were then analyzed for patterns using a combination of Xcel and SPSS.

Aurora was chosen as the second case study for several reasons, including my previous work relationship with AW that provided insider status within the community. A similar process of community inclusion was utilized for survey development, including AW input in survey design and the piloting of the draft survey with a small group of Aurora residents, whose feedback was used to refine the survey content and design. While the Langa survey was administered in-person, the Aurora survey was administered online via Qualtrics both because AW has a well-developed online presence and because the COVID-19 pandemic necessitated the minimization of in-person contact. The results from this survey were also analyzed for patterns using a combination of Xcel and SPSS.

1.4.2.1 Research sub-question: Are there correlations or relationships between water-related factors?

After identifying patterns regarding water-related knowledges, attitudes, and behaviors, I sought to identify correlations between these factors. Here it is important to note that the Langa survey was developed and administered before the water literacy framework was complete, while the Aurora survey was developed and administered after. Thus, this statistical analysis was applied mainly to the Aurora context because it was built into the survey structure. Survey questions were scaled and combined to create aggregated variables for water knowledge, water sensitivity (attitudes), water conservation behaviors, and AW engagement. SPSS was used to identify bivariate correlations between these factors, and then a series of ANOVA tests were conducted to identify variation in factor means across demographic groups.

1.4.3 Methods for RQ3: How do water literacies of communities in Cape Town and Aurora relate to the geographic, sociopolitical, and economic contexts of Cape Town and Aurora?

In contrast to surveys, focus groups offer a way to understand how and why people feel or react to certain topics, as well as how social interactions affect responses to topics (Hennink, 2020). The social and permissive environment generates conversation with the pressure of voting or reaching consensus (Krueger & Casey, 2015). Although the nature of focus groups restricts participation size, they present an opportunity to investigate details and explanations that a survey alone cannot. Thus, focus groups were an ideal method for my research because they allowed me to expand on interesting survey results digging deeper into the socially influenced characteristics of water literacy, such as social norms about water use and opinions about water management strategies.

In Cape Town, the plan was to conduct a series of focus groups with both the survey administrators and the broader Langa community. However, the onset of the COVID-19 pandemic limited this possibility to the former because of travel restrictions, risks associated with in-person meetings, and the technical and cultural difficulties of switching to virtual focus groups. Thus, a slightly more informal focus group was conducted just with the survey administrators and two community leaders. Discussion prompts included community reactions to the survey, verification of the survey results, and the influence of sociopolitical factors surrounding the Day Zero drought. The focus group was not recorded but the team of three researchers (myself included) took extensive notes and wrote down notable quotations from participants. These were then aggregated and analyzed by hand using constant comparative and critical incident methods (Krueger & Casey, 2015).

In Aurora, a series of three focus groups with survey participants were conducted virtually over Zoom. Discussion prompts were similar to those in the Langa focus group, focusing on community reactions to the survey, explanation of some survey results, and the influence of sociopolitical factors surrounding AW water and drought management. These focus groups were audio-recorded and transcribed, and then analyzed in Dedoose using a constant comparative method.

1.4.3.1 Research sub-question: How was water literacy used to engage tourists in Cape Town during the Day Zero drought?

Given the importance of tourism to Cape Town's local economy, and the unprecedented conservation campaigns utilized within Cape Town hotels during Day Zero, a sub-research question emerged to better understand how and why water literacy was used to engage Cape Town tourists during Day Zero. To this end, I utilized semi-structured interviews. Like focus groups, interviews provide a smaller sample size than surveys, but also results in collection of intensive details, meanings, and motives (Johnston et al 2000; Hennink et al., 2020).

Given the difficulty of reaching tourists well after their visits to Cape Town had ended, I decided to interview members of the local tourism industry involved with water conservation campaigns and consistent contact tourists. Interview transcriptions and notes were then coded and analyzed deductively along the guiding interview questions, as well as inductively along instances of repetition, consensus, and/or emphasis within data. The codebook was also tested for inter-coder agreement (ICA).

1.5 Positionality

The generation of knowledge is socially constructed around one's positionality, or the combination of one's identities and their interaction with one's physical and social surroundings (Rose, 1997; England, 2017). Our identities influence the way we come to understand and interpret the world. Importantly, though, identities are also socially constructed to mean different things in different places at different times (Harvey, 2010). Thus, positionality and the generation of knowledge are both changing and variable over space and time.

My own positionality has shifted numerous times over the course of the research presented within this dissertation. For example, before pursuing my doctoral degree, I held various positions within the field of water management, two of which placed me firmly within the power structures of different water utilities and trained me to see water issues from the perspective of water managers. Particularly with Aurora Water, I was considered a content expert that shared my expertise to influence community knowledge and behaviors for the better. However, literature has shown the existence of various hydrosocial perspectives that are not typically present within dominant water management structures. Additionally, one of the main goals of water literacy is to empower citizens to engage with water managers and hold them accountable. Thus, my research on community water literacy required that I continually reframed my thinking to center on the community. This was particularly important when partnering with Aurora Water, so as not to let them override the survey content or focus group conversations.

My research also hinged on my identity as an insider or outsider within the two chosen research sites. Although I do not live in Aurora, my job with Aurora Water and long-term residency in Colorado provides me with an insider perspective to the Aurora community. Aurora Water treated me like a team member, and participants didn't question my lead role in the project. However, this also created the risk of conflation between participants' perspectives and my own (Kerstetter, 2012). However, in Cape Town I have an obvious status as an outsider at numerous levels. I am a white American, relatively new to the cultural context of South Africa. And although many South Africans share a white identity, the township in which I conducted much of my research is a black isiXhosa community. Thus, my research required critical reflection on the histories of imperialism and exploitative research practices that sought to 'civilize' savages and natives for the greater good of science (Roy, 2018). Indeed, I was quickly confronted with this reality during our first exploratory community meeting with Langa residents, when a local isiXhosa man asked how we were different than the other foreigners who conducted research on members of his community like they were lab rats. In that moment, I had never felt so much like an outsider. I could not relate to the Langa experience of collecting water from a community tap or getting my water shut off regularly, and I would ultimately be returning to my comfortable life with reliable water access in the US. As a result, I made a conscious effort to connect with Langa residents and learn about their lived experiences in the township. I repositioned the power dynamics of my research where possible by seeking community input in survey designs and collecting data with community participation. Finally, I shared survey findings with community members to verify that the results made sense with them and also build ownership of the data. I also intend to provide the community with the final paper in person, so I can genuinely thank them and answer any lingering questions. In this way, I have tried my best to bring the community into the research structure and give them ownership of the data and results.

1.6 Outline of the Dissertation and Key Arguments

The bulk of this dissertation is comprised of four published or publishable manuscript that collectively answer the guiding research questions. Chapter 2 is a systematic literature review that investigates the current understandings and applications of water literacy as a concept (research question 1). This paper synthesizes water literacy definitions from 26 scholarly and grey literature sources and describes the emergent framework of eight knowledge sets. Importantly, this emergent framework is the foundation for the following chapters within this dissertation. The framework is then applied to existing water literacy surveys to glean common strengths and weaknesses from communities around the world. This paper was published in October 2020 in *Water*.

Chapter 3 introduces my first case study site in Langa township of Cape Town, South Africa. Specifically, it investigates the current water literacy in Langa township (research question 2), and how it relates to both the lived experience of Day Zero and the sociopolitical context of Cape Town (research question 3). It utilizes a combination of a survey and focus group to argue that Langa's current water literacy reflects its historic marginalization and exclusion from Cape Town's water management system. It also demonstrates that the experience of Day Zero both contributed to community water literacy, and also revealed a great need for more intentional water literacy engagement within the township to build community resilience to future droughts. This manuscript is intended for submission to the *International Journal of Water Resources Development*.

Chapter 4 answers research sub-question 3a, which relates to Cape Town's economic dependency on tourism and the subsequent tourism demand management enacted during Day Zero. Interviews of tourism industry members are analyzed to demonstrate that the political, social, and economic drivers of water conservation are just as important as the need to reduce water demands during drought. Additionally, I argue that tourist water conservation campaigns are generally well-received by tourists and offer opportunities to build customer loyalty and spread conservation knowledge and practices elsewhere. This manuscript is intended for submission to the *Annals of Tourism Research*.

Chapter 5 investigates community water literacy in Aurora, Colorado (USA). Here, the water literacy framework is applied to investigate the current water literacy of Aurora (research question 2) and how it relates to both lived experiences of drought and the sociopolitical context of Aurora (research question 3). I reveal key strengths of community water literacy, which connect to AW engagement and experiences of drought, and acknowledge substantial gaps in outreach and engagement of Aurora's diverse population. This manuscript is intended for submission to *Water Resources Management*.

Finally, Chapter 6 provides a summary of the dissertation as a whole, synthesizing the key findings from each individual chapter. I discuss the theoretical and practical contributions of this dissertation, reflect on the policy implications, and suggest avenues for future research.

This dissertation utilizes an integrated-article format, where each interior chapter is a self-standing article, designed to provide unique contributions to the growing field of water literacy both by themselves as well as together. Please note though that this inevitably creates a risk of redundancy when reading the dissertation as a whole.

Chapter Two: What We Know about Water: A Water Literacy Review

Meghan McCarroll and Hillary Hamann

Published: *Water (Switzerland)*

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Author Contributions

Order of Authorship	Name of Author	Contribution to Paper	Overall Percentage
1	Meghan McCarroll (Candidate)	Conceptualization, visualization, methodology, data collection, analysis, writing of drafts, editing, and submission for publication	75%
2	Hillary Hamann	Conceptualization, data collection, supervision, writing of drafts, critical review and feedback, editing,	25%

By signing the Statement of Authorship, each author certifies that:

i. The candidate's stated contribution to the publication is accurate (as detailed above);
ii. Permission is granted for the candidate to include the publication in the thesis; and
iii. The sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

[signature] 4/27/23

Author 1 Signature *Date*

[signature] 4/27/23

Author 2 Signature *Date*

2.0 Abstract

Water literacy, or the culmination of water-related knowledge, attitudes and behaviors, is a relatively new field of study with growing importance for sustainable water management and social water equity. However, its definition and use across existing literature are varied and often inconsistent. This paper seeks to synthesize and streamline the conception of water literacy. We conducted a systematic review of literature that defines or describes in detail either "water literacy" or "watershed literacy". From this, we suggest a new holistic framework for water literacy to guide a more inclusive, relevant use of the concept. We utilized the framework to examine existing surveys and studies of water knowledge, attitudes and behaviors in both student and adult populations, and summarized water literacy levels and knowledge gaps that exist around the world. To address knowledge gaps, we suggest using a suite of approaches drawn from the published literature, including enhanced visuals, place-based learning, interdisciplinary curricula, and reflective and iterative development of future water literacy initiatives.

2.1 Introduction

Water is a key component for a sustainable future as a human, industrial, and ecological resource. Indeed, the United Nations' Sustainable Development Goals (SDGs) for 2030 have expanded in SDG to "ensure availability and sustainable management of water and sanitation for all" (2020). However, recent scholarship has demonstrated that a large contributing factor to unsustainable water management and use is the poor understanding of water resources and systems. This includes depictions of water systems as isolated and separate systems from human activities, and the treatment of water systems as constant and self-regulating rather than dynamic and complex (Defries & Nagendra, 2017). Additionally, water management practices often neglect the increasing globalization of water resources, where international water flows and virtual water extend beyond geographical boundaries and water scarcity issues stem from interjurisdictional (Defries & Nagendra, 2017, Hoekstra & Mekonnen, 2012). Such research demonstrates that water sustainability must be founded on clear knowledge and understandings of our water resources and their relationships with humans and global systems. Moreover, the need for such knowledge is not confined to water managers, researchers, and decision makers, but also includes every citizen and user of water. Scholars have advocated for environmental efforts that mobilize widespread public support and action, even from those who "may not consider themselves 'environmentalists'" (Bergquist et al., 2020, p. 2). Sustainable water management is no exception to this idea and thus requires broad understanding and engagement across the masses.

There are several other important reasons why knowledge is a critical factor when it comes to sustainable water management and use. Water managers who engage their customers with knowledge and information are believed to be more transparent and trustworthy (Attari et al., 2017; Cooper & Cockerill, 2015; Dean et al., 2016a). Additionally, public support for water management decisions is greatly increased when people understand the various issues and risks associated with options for action, or lack thereof (Attari et al., 2017; Dean et al., 2016a; Giurco et al., 2010). Particularly in democratic countries, this can lead to political will (Stoutenborough & Vedlitz, 2014), public willingness to "pick up the tab" for new water projects (Harvey, 2015, p. 7), and even correlation with uptake of water conserving behaviors (Dean et al., 2016a).

Sustainability also extends beyond this westernized approach of managing water as a good on which to capitalize. Mustafa and Halvorson (2020) highlight how water resources and their various hydrologic features are as much social elements as they are physical. Water knowledge is multiplicitous, emerging from not just western science but also historical hydrologies, cultural traditions, and spiritual knowledges (Hawke, 2012). Additionally, water resources are inherently tied to economic and social processes. Water sustainability must therefore acknowledge all types of water knowledge and their connections within and across sectors and cultures. Indeed, such approaches in similar fields have been found to boost public support for environmental policies, particularly within communities of color (Bergquist et al., 2020). Moreover, they can lead to opportunities to contribute to social justice surrounding water resources. For example, Dean, Fielding and Newton (2016a) posit that higher levels of water-related knowledge among the public leads to more numerous and productive discussions and public engagement in both informal and formal processes. Such conversations can expose and work to overcome the structures of power, culture, and cognitive biases that ultimately shape how people engage with modern water governance (Rusca & Di Baldassarre, 2019).

A strong, interdisciplinary, and widespread foundation of water knowledge among all water users is therefore a pivotal goal towards achieving water sustainability and social equity. Some of this foundation, particularly scientific knowledge, is included in most K-12 educational systems, as well as in college curricula. The specificity of water education, though, varies from requiring a "basic knowledge of the hydrosphere" (Pan & Liu, 2018, p. 574) to an overall scarcity of water topics (Xiong et al., 2016) and is rarely addressed across the curriculum in systematic or multidisciplinary ways (Sadler et al., 2017; Zint et al., 2012). Additionally, Dean et al. (2016b) draw on the field of educational psychology to state that efforts to build a water-sensitive and engaged citizenry must include cognitive, emotional, and behavioral domains. This approach mirrors the learning goals set forth by the United Nation's Education for the Sustainable Development Goals (ESDGs) (Rieckmann et al., 2017). Yet current K-16 curricula tend to focus on the cognitive learning domain, often neglecting other learning domains that are necessary for achieving true sustainability (Buckley & Michel, 2020). Finally, though water knowledge emerges from experiences and interactions with water throughout childhood and adulthood (Dean et al., 2016a), this experiential knowledge is often treated as separate from traditional classroom and textbook curricula. The disconnect results in important gaps in both water knowledge and the translation of water knowledge to actions that support sustainability.

Out of the increasing recognition of the importance of water knowledge emerges the field of water literacy. It is the culmination of water-related knowledge, attitudes, and behaviors, setting apart its importance and uniqueness from other more commonly used labels such as ecological or environmental literacy. The use of the term “water literacy” is increasingly popular, mirroring the growth of water issues and conflicts around the world. It is utilized by academic scholars (e.g., Cooper & Cockerill, 2015), governmental departments and municipalities (e.g., AWC, 2016), and community organizations and non-profits alike, (e.g., Project WET, 2011; Ripple Effect, 2020). However, among these groups there appears no consensus on how to define, apply and assess water literacy as a concept. If we hope to develop a common framework to improve water knowledge and achieve water sustainability, a more comprehensive analysis of the water literacy concept is needed. To this end, we conducted a systematic review of the available literature to define, assess the state of, and describe efforts to improve water literacy.

2.2 Methods

The scholarly and grey literature surrounding water knowledge is broad and multi-disciplinary. We focused our search of the literature in four main areas: efforts to define water literacy, efforts to describe K-16 student water knowledge, efforts to describe adult water knowledge, and approaches to improve water literacy.

Our initial sources were found by searching three primary scientific databases (Google Scholar, ProQuest, and Jstor). Given the similar connotations of the phrases “water literacy” and “watershed literacy”, both were used as key terms for our initial search of water literacy definitions. This resulted in 55 sources that provided a focus on water literacy rather than a passing mention. We next excluded any sources in which water or watershed literacy was not clearly defined or described. In total, this left us with the collection of 26 definitions listed in Table 1, which we then subjected to a qualitative thematic text analysis (Kuckartz, 2019) to understand how the terms are commonly defined and applied. This approach involved first identifying terms and phrases and interpreting the intent of their use in each definition. We then generated themes using an inductive approach. We reviewed these themes within the context of other learning and knowledge frameworks and led to our final grouping and naming of eight unique themes.

Our searches also revealed a plethora of sources that draw on the concept of water knowledge and perceptions without explicitly using the phrase water literacy. While these papers do not provide an understanding of the definition of water literacy, they do still contribute to our knowledge of what people know or believe regarding water. Thus, in order to review the current levels of water literacy among student and adult populations, we searched any formally published or publicly available literature that also included the key terms "water knowledge", "water education", "water perceptions" and/or "water attitudes". We started with these key terms, and then expanded our collection by reviewing the reference lists of the primary sources. When recent and comprehensive reviews of water knowledge elements were available, we referred to these in place of additional primary sources. We also obtained several surveys from www.waterpolls.org (Tobin, n.d.), a website that aggregates, analyzes and shares data from public surveys about water.

We recognize that some very specific aspects of water literacy have been investigated in great depth. For example, there is a large body of work that investigates attitudes and knowledge of alternative water resources, like recycled wastewater or desalination. As our focus is on water literacy as a whole, a full review of the literature in these specific areas was viewed as beyond the scope of this review and thus excluded.

This search brought us to our final count of 35 student and 35 adult water knowledge studies and surveys, authored by academic scholars, nonprofit organizations, water utilities, and local governments. This collection included journal articles, white papers, reports, and websites. We acknowledge that this review cannot possibly include every piece of literature that has been written about water knowledge and perceptions. For example, we are confident that there have been numerous, small-scale surveys completed by local municipalities of their customers' water knowledge and behaviors, which have not been published or made easily accessible. Additionally, most of this collection details water literacy among the westernized regions of the world, with very little data emerging from developing countries.

Table 2.1: Definitions of water literacy from the 26 identified sources.

Authors	Definition provided in source
Ewing & Mills, 1994 (p. 37)	"Roth (1991) suggests that functional literacy includes the ability to communicate the substance of an account to another person. In the case of water knowledge, we believe functional literacy entails ability to communicate an accurate understanding of processes such as condensation and evaporation as phase changes of water."
Covitt et al., 2009 (p. 37)	"Possessing an understanding of water in environmental systems is a necessary, though not sufficient, component of environmental water literacy. Understanding how water moves through environmental systems and interacts with other substances is critical for making informed decisions about water at an individual or societal level."
Dolman, 2010 (pp. 99-100)	"In 1878, Thomas Henry Huxley involved watershed as a landscape entity or catchment basin, stating it is 'all that part of a river basin from which rain is collected, and from which therefore the river is fed.' This definition encapsulates the basic physical definition of a watershed in common parlance today. Our challenge is to move beyond a static, hydrologic definition toward a dynamic understanding of the wholeness of watersheds and how they literally underlie all human endeavors."
Eldridge-Fox et al., 2010	"level of water-related knowledge… on a local and global scale" and includes things like, where does Ann Arbor water come from, do you drink bottled water, do you conserve, access to water in different countries.
Project WET[1], 2011 (p. xiii)	Seven Essential Principles of Water Literacy: "(1) Water has unique physical and chemical characteristics; (2) Water is essential for all life to exist; (3) Water connects all earth systems; (4) Water is a natural resource; (5) Water resources are managed; (6) Water resources exist within social constructs; (7) Water resources exist within cultural constructs."
Su et al., 2011 (p. 518)	"It is suggested that understanding the usage of water, the health implication of water quality, and the overall impacts as a result of water shortage or extreme precipitation should all be part of the curriculum delivered effectively to students of all levels and the general society"
Laporte et al., 2013 (p. 3)	"a water literate citizen understands essential principles and concepts about the Great Lakes' functions and value and can accurately communicate about the Great Lakes' influence on people and systems. However, what truly makes a person water literate is application of such concepts; making informed and responsible decisions regarding the Great Lakes."
Wood, 2014 (p. 7)	"I suggest that a water literate citizen is someone who is informed and knowledgeable about water use and issues, and is applying this knowledge to their values and their actions, whether that is achieved actively or subconsciously"
Hensley, 2014 (p. 29)	"Watershed literacy is the ability to understand the hydrological systems that make life possible within, and beyond, our water basin. Watershed literacy necessitates the ability to comprehend what a watershed is and "connect the dots" by recognizing the impact that human choices have on local, regional, and global water systems (Hensley 2011). A watershed-literate person can tell you in which watershed he or she lives and articulate the forms of point source and non-point source pollution that affect its integrity, balance, and

	health. Furthermore, a watershed-literate individual can articulate the opportunities to revitalize, protect, and restore water quality within his or her watershed while knowing how to reduce individual and collective impact.”
Duda et al., 2015 (p. *i*)	“knowledge of and attitudes toward watershed health, knowledge of basic watershed concepts, and activities or behaviors that may impact the watershed’s environment.”
Fielding et al., 2015 (p. 6)	"In the current report we will use the term ‘water literacy’ to refer to Australians’ water-related knowledge."
Reenberg, 2015 (p. 185)	“In the Global North (www.allianceforwatereducation.org), the notion of water literacy has been developed and defined to mean 'knowing where your water comes from and how you use it'. This includes but is not limited to, a basic understanding of water footprints, virtual water, groundwater recharge and consequences of over-drafting, how to move and control surface water, competing demands for water, and water conservation... broader notion of literacy is thus perceived as the capacity to assess (a) the impact of spatial and temporal rainfall patterns on the comparative advantage of different agricultural micro-strategies, (b) alternative ways of maneuvering to adapt to site-specific production potentials defined by water, and (c) long-term consequences of contemporary water use strategies”
Zint et al., 2012 (p. i)	“a watershed literate individual should be able to: 1) define the term “watershed”, 2) identify their local watershed(s), 3) identify how watersheds are connected to the ocean via streams, rivers, and human-made structures, 4) identify the functions that occur in a watershed (transport, store, and cycle water), 5) recognize that both natural processes and human activities affect water flow and water quality in watersheds, 6) identify connections between human welfare and water flow and quality, 7) identify possible point and non-point sources of water pollution, 8) identify actions individuals can engage in to protect/restore water quality in watersheds, and 9) identify how humans seek to manage watersheds”
Otaki et al., 2015 (p. 36)	“we define water literacy as the ability to feel familiar with water, get actively involved in water and face the issue of water as one’s own issue. Being water literate means understanding how the water we use daily is delivered and treated, as well as knowing the quality and safety of that water, how much water we use daily and exactly what we use it for.”
AWC, 2016 (pp. 6-7)	“Being 'water literate' means having an understanding of the significance of water in life, and understanding where water comes from and how to use it sustainably… Water literacy can include aspects of air, water, land and/or biodiversity, which are inter-connected; it can also relate to discussions around sustainable development.”
Dean et al., 2016a (pp. 2-3)	“The concept of ‘water literacy’, and other forms of literacy such as health literacy, integrate topic knowledge and the capacity to apply this knowledge to decisions [20, 21]. The literature has not identified specific areas of knowledge considered necessary for adequate water literacy. The emerging emphasis on sustainable water management suggests that key areas of individual-level water knowledge include the urban water cycle and impacts of urbanisation on waterway health via stormwater pollution, in addition to issues related to water demand, supply and treatment”

Sherchan et al., 2016 (p. 173)	"we see a need for a general education course that focuses on strengthening every student's understanding of water literacy: its properties, sources, uses, issues, and the implications of these factors for informed decision making in the 21st century."
Huxhold, 2016 (p. 2)	"Water literacy… refers to the amount of knowledge one has about the water system; it encompasses knowledge ranging from the state of water system infrastructure, the availability of water in an area, the quality and cleanliness of the water, the types of treatment used, the environmental impact, and what source the water comes from and/or where water goes when the individual is finished using it."
Febriani, 2017 (p. 15)	"Water literacy covers basic knowledge of water sources and other aspects that interconnected with it (management and related issues), and being water literate means having a basic understanding of how to use or manage the water sustainably as a manifest of understanding the importance and significance role of water in life"
Mackenzie, 2017 (p. 18)	"Water literacy is the knowledge one has about the earth's water sources: how they are used and how to use them"
Singh et al., 2017 (p. 153)	"Water literacy is having an understanding of where the water that we consume or use comes from and how we use it."
He, 2018 (p. 486)	"water literacy is a composition of necessary water knowledge, scientific water attitude, and normative water behavior... Water literacy, composed of water knowledge, water attitude and water behavior, is related to social economics, living habits, water ecological environment, water conservancy propaganda and education"
Roncoli et al., 2018 (p. 575)	"Defined as knowing where your water comes from and how to use it, it denotes an analytical capacity unrelated to formal education or technoscientific expertise, being rather grounded in farmers' understanding of the interconnectedness of water, natural landscapes, and human practices (Hastrup and Hastrup 2015: 19). Specifically, water literacy entails the ability to assess the impacts of climate variability on water supplies and use, to identify place-specific adaptive options, and to consider their effects on environment and community"
Ternes, 2018 (p. 349)	"the understanding of water supplies and how water is used"
Ripple Effect, 2019	"A water literate person recognizes the impacts of climate change on real people and real communities, understands the role of water in shaping those impacts, and has a strong sense of civic responsibility to help redesign our relations to a changing environment."
Wang et al., 2019	"Water literacy should include variables such as water knowledge, attitude, and appropriate water behavior."

[1] Project WET principles were developed in 1991 but were more recently renamed as "water literacy" principles.

2.3 Defining Water Literacy

Our first goal for this review was to provide a deeper understanding of how water literacy has been defined and applied up to the present moment. To this end, we conducted a thematic text analysis of 26 sources that either explicitly defined or very clearly described water or watershed literacy. The analysis resulted in the identification of eight unique and overarching themes that were mentioned within at least two different definitions, with the most frequent theme present in 17 different definitions. The emergent themes, hereby referred to as knowledge sets, are visually depicted and grouped in Figure 1 by both the level of detail and the learning domains present in each knowledge set. From the cognitive domain, we identified four separate knowledge sets: science and systems knowledge, hydrosocial knowledge, local knowledge, and functional knowledge. From the behavioral domain, we identified two knowledge sets: individual action and collective action. From the affective domain, we identified one knowledge set: attitudes and values. The unequal division between these three learning domains reflects a common issue among sustainability education literature, which emphasize cognitive learning over behavioral and affective learning (Buckley & Michel, 2020). Yet, our analysis indicates that water literacy practitioners still acknowledge the importance of the latter two domains.

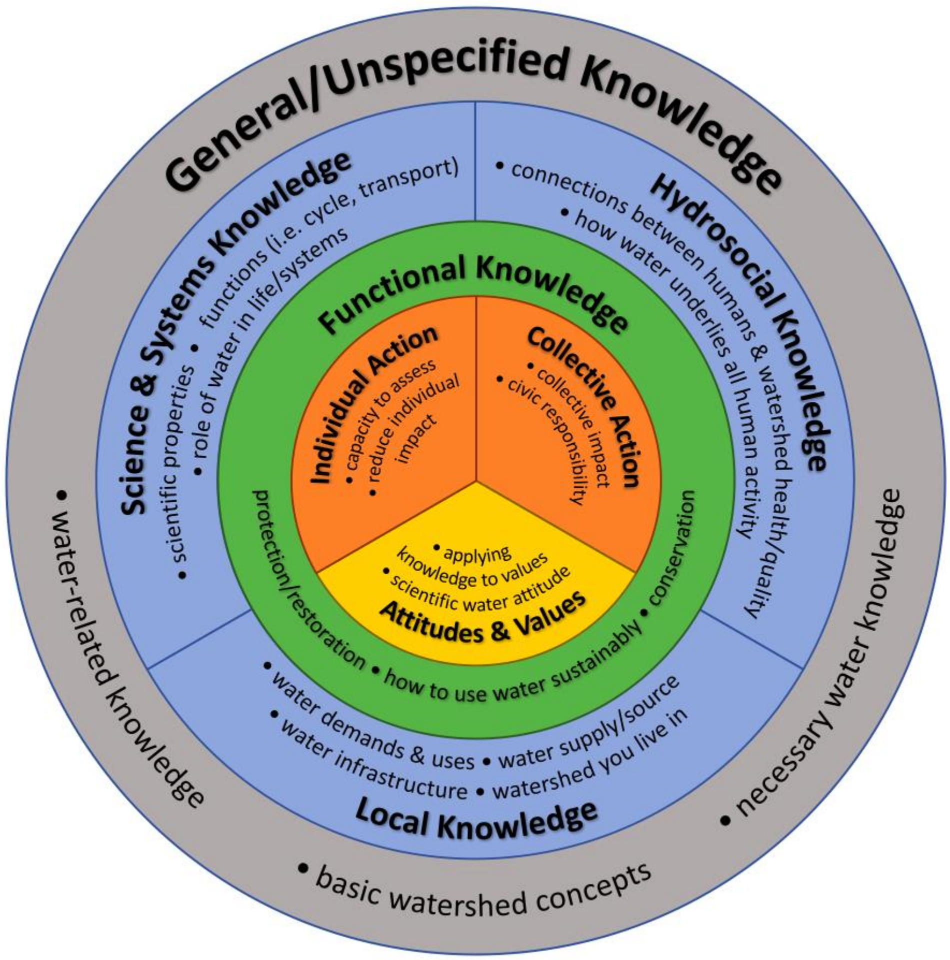

Figure 2.1: Key knowledge sets of water literacy. This figure highlights the level of agreement regarding specific topics or requirements for water literacy within available definitions. More complete conceptions of water literacy draw on all or most of these.

In the gray, outermost ring of Figure 1 are the definitions that evoke simplicity and conciseness. For example, one of the broadest and most thorough water literacy surveys to date was conducted by Fielding et al. (2015) in Australia, and yet they define water literacy as “water-related knowledge” (p. 6). This is one of the shortest and vaguest definitions we found, with little indication of what learning domains are included. Fielding et al. (2015) are not alone in a preference for simplicity, though. In total, nearly half of the sources reviewed mention general and un-specified knowledge as central to water literacy, including “basic watershed concepts” (Duda et al., p. i) and “necessary water knowledge” (He, 2018, p. 486). The draw of such definitions is obvious. As water intersects in so many ways with both the natural and human world, water literacy encompasses a vast array of topics. It is difficult to select which are most important, particularly when considering the wider public who may not have much experience nor interest in water. By being vague, water literacy acts as an umbrella for all of these water topics.

However, such vagueness also sacrifices the ability to easily compare water literacy among locations and populations. Thus, most authors expand upon the details and information that should constitute water literacy, particularly within the cognitive domain. Three cognitive knowledge sets are depicted in Figure 1 by the second ring of blue circle segments. The first we termed science and systems knowledge, which is based on water’s unique scientific properties and its significance for living systems, including the water cycle and water’s ability to transport dissolved and solid materials. This category encompasses ecosystem needs and flows, with five definitions (AWC, 2016; Covitt et al., 2009; Eldridge-Fox et al., 2010; Hensley, 2014; Project WET, 2020) mentioning the role of water in life and one explicitly advocating for knowledge of interconnected aspects like “air, water, and/or biodiversity” (AWC, 2016, p. 7). In addition, six definitions address hydrological processes, cycles and functions (Covitt et al., 2009; Dean et al., 2016a; Laporte et al., 2013; Project WET, 2020; Reenberg, 2015; Zint et al., 2012), but only three specify that water literacy includes knowledge at the level of water’s chemical and physical properties (Ewing & Mills, 1994; Project WET, 2020; Sherchan et al., 2016). Interestingly, four definitions call specifically for an understanding of "watershed concepts" (Duda et al., 2015, p. i) or ability to define watersheds (Dolman, 2010; Hensley, 2014; Zint et al., 2012). Sources emphasizing science and systems knowledge imply that a base understanding of hydrologic and ecologic science along with systems thinking is needed for application within broader, overarching water issues (Ewing & Mills, 1994).

In contrast to this idea is a popular push for a *local knowledge.* This category encompasses an understanding of local water sources (Febriani, 2017; Sherchan et al., 2016), water infrastructure (Dean et al., 2016, Huxhold, 2016; Reenberg, 2015; Otaki et al., 2015; Zint et al., 2012) and current water demands and uses (Huxhold, 2016; Mackenzie, 2017; Reenberg, 2015; Roncoli et al., 2019; Singh et al., 2017; Ternes, 2018; Otaki et al., 2015). The definitions emphasizing local knowledge do not often overlap with the definitions emphasizing science knowledge, which highlights a key divergence in the literature. Instead, these sources suggest that such technical scientific understanding of the minute complexities of water systems may actually be perceived as burdensome and discouraging (Huxhold, 2016). A local knowledge is deemed more inviting to the general public because it highlights the more relatable and simplified water topics as they pertain to day-to-day life. Within the category of local knowledge, there is a particular focus on knowing where one's water comes from (AWC, 2016; Eldridge-Fox et al., 2010; Huxhold, 2016; Reenberg, 2015; Roncoli et al., 2019), with two definitions honing in on the need for familiarity with the watershed one lives in (Hensley, 2014; Zint et al., 2012). Examples like these convey the importance of context within water literacy.

Indeed, water is itself an extremely contextual resource, and what might be important for someone living in a rural setting to know is inherently different from what is important for someone living in an urban setting to know.

The third set of detailed cognitive knowledge we have termed as *hydrosocial knowledge* because it refers to the bi-directional and continuous interactions between society and water resources. Definitions that fell within this category emphasized how human actions impact water quality and health of water resources, and at the same time, how the health and quality of water resources directly impact human health and welfare (Dean et al., 2016a; Hensley, 2014; Laporte et al., 2013; Otaki et al., 2015; Reenberg, 2015; Roncoli et al., 2019; Su et al., 2011; Zint et al., 2012). Like local knowledge, these topics were also presented in a contextual manner, with authors emphasizing the hydrosocial setting within built environments (Dean et al., 2016a) or the watersheds like those of the Great Lakes (Laporte et al., 2013). However, it is this knowledge set that really reveals why it might be so difficult to agree on one definition. Rather than a static and self-contained natural system, scholars are increasingly recognizing and emphasizing the hydrologic cycle as intricately intertwined within and around social processes (Abbott et al., 2019; AWC, 2015; Swyngedouw, 2009). Water fuels economic growth, and economic and political systems simultaneously influence the generation of pollution. Social and cultural structures are the backbone of how water resources are valued and maintained, while the cleanliness and health of water resources often creates social value. Thus, what we know about water, and what we should know about water, depend heavily on the complex and iterative relationships between water resources and their political, economic, social, and cultural contexts.

While these three cognitive knowledge sets are often (but not always) mentioned separately from one another, it is obvious that they all offer something different to the concept of water literacy. Knowing the science of a water molecule is important, but not enough to create water stewardship. Local knowledge creates personal ties to water resources, but it also confines water knowledge to a very specific region. Moreover, understanding the hydrosocial context to water reveals the layered complexity of water issues, but without the scientific knowledge of how to address an issue and the local knowledge of whom it most directly affects. Together though, these knowledge sets create a complex understanding of water literacy that revolves around geographic and social contexts.

In addition to these three knowledge sets, we identified one more cognitive set that we called *functional knowledge*. It is represented as the inner green ring in Figure 1, separately from the first three, because it is fundamentally different. We consider this as a bridging knowledge set that connects water-related knowledge to real world applications by underscoring the difference between how water is used currently, and how water should be used. It is a conative element that highlights knowledge about how to act or use water with a long-term perspective of water resources such that there is still adequate quality and quantity to supply future generations. This includes awareness of how to use water sustainably (Febriani, 2017; Mackenzie, 2017; Roncoli et al., 2019), how to conserve (Eldridge-Fox et al., 2010; He, 2018; Reenberg, 2015), and how to protect and/or restore watersheds (Duda et al., 2015; Hensley, 2014).This knowledge set was the least mentioned among the cognitive domain, with explicit inclusion in only nine of the 26 sources. However, we suggest that functional knowledge is indirectly implied in more definitions that require a translation of water-related knowledge into water ideologies and behaviors. Either way, the functional knowledge set is unique because one generally has to understand how to act before action can actually occur.

The final three categories in Figure 1, depicted in the center circle, introduce the other two learning domains of water literacy. First, is the affective application of water-related knowledge to one's *attitudes and values*, represented by the yellow wedge in the center of Figure 1. Water attitudes refer to the way one thinks or feels about water resources, and several definitions specifically say that the application of water-related knowledge should be reflected in one's "attitudes toward watershed health" (Duda et al., 2015, p. *i*) or "scientific water attitude" (He, 2018, p. 486). In a discussion of environmental literacy, Elder (2003) refers to the shifting of attitudes as a subtle and difficult process, but also emphasizes how important they are for shaping behaviors. Along a similar line are water values, which center around assigning importance to water resources. For example, one definition ties water literacy to the ability to value the role and function of the Great Lakes in the U.S. (Laporte et al., 2013). In total, seven of the 26 reviewed definitions refer to attitudes or values as a necessary component of water literacy.

Finally, we identified two behavioral domains of water literacy, including *individual action* and *collective action*. These are shown by the two orange wedges in the center of Figure 1. Individual action refers to "informed and responsible" (Laporte et al., 2013, p.

3) decisions about water resources, which have the capacity to “reduce individual . . . impact” (Hensley, 2014, p. 29) on water quality and water quantity. Reenberg (2015) extends this category to local farmers, who assess water application based on productivity requirements and long-term consequences. Either way, it is typically a single person or single household that is responsible for action. This is the most common application of water literacy mentioned in 11 of the 26 definitions. In contrast to this is collective action, which refers to the water-conscious actions of a large group of people. It is the act of making informed decisions not just as an individual, but also at a “societal level” (Covitt et al., 2009, p. 37), in order to reduce the “collective impact” of humans (Hensley, 2014, p. 29). This is by far the least mentioned application of water literacy, with only two of the 26 definitions explicitly calling for collective action (Covitt et al., 2009; Hensley, 2014; Ripple Effect, 2020). Yet, it is important to distinguish this from individual action because it recognizes both the shared nature of water resources and the public responsibility to proper management and use. Collective action, like participation in a watershed group or pushing a water-conscious political agenda, is usually a long, complex process with numerous moving parts, and the resulting impacts are often delayed (Linton & Budds, 2014). As it can be hard to convince ourselves that it is worthwhile to change our lives for some future benefit, collective action is difficult to achieve. Yet, it is a crucial step towards achieving sustainability for our water resources.

Collectively, these definitions and knowledge sets highlight that the concept of water literacy is multi-faceted and complex. The development of the emergent framework from this literature review utilized a bottom-up approach to determine how water literacy is being defined and used. This approach points to a strong anthropocentric bias for the concept, where water literacy efforts tend to focus largely on human actions and relation to water resources. While the emergent framework still depicts the importance of water for the environment in its own right, existing literature emphasizes a human-centric approach to water literacy that could be placing the environment second to societies and human development. Additionally, the unequal weighting of the three learning domains within the emergent framework demonstrates that water literacy efforts reflect the same overemphasis on cognitive knowledge that exists through sustainability education literature [21]. While Dean, Fielding and Newton (2016a) suggested no clear identification of a knowledge body necessary for water literacy, our review sheds light on several commonly agreed-upon elements that constitute the emergent framework.

It is worthwhile to compare this emergent framework to others within environmental and sustainability education. For example, in 2016 the Alberta Water Council (AWC) proposed a water literacy ladder (2016), adapted from the environmental literacy ladder (Elder, 2003), which details five essential steps to move citizens to water literacy: awareness of water, knowledge, attitudes, skills, and finally actions towards water stewardship. While the water literacy ladder highlights all three learning domains more equally than Figure 1, it does not elaborate well on the specific topics and details of each step, as the emergent framework does. Thus, interpretation of the water literacy ladder may differ substantially between contexts. Additionally, even though the AWC acknowledges that water literacy is not always such a linear development (2016), the depiction of a ladder with specific steps implies a set progression of water literacy that rarely occurs in practice. A second framework is one developed by Project WET. Since its creation in 1984, Project WET (Water Education for Teachers, rebranded in 2020 as Water Education Today) has provided water education and resources to teachers, educators, and the public across the United States and 70 other countries. Their work is centered around seven core water literacy principles that explicitly detail all of the cognitive knowledge sets depicted in Figure 1 (Project WET, 2011; Project WET, 2020). However, the Project WET framework provides little-to-no acknowledgement of the affective and behavioral domains. More recent efforts have expanded the Project WET core mission (2020) to include local engagement and action through their Action Education efforts, which apply water knowledge to local community projects, but such a behavioral effort is not yet evident within the framework. Additionally, the Project WET framework lacks anything resembling functional knowledge.

The third framework worth considering is that provided by the United Nations (UN) in the ESDG. It is not specific to water literacy, but rather frames sustainability education more broadly. As mentioned, the framework is built on a combination of cognitive, socio-emotional, and behavioral learning objectives (Rieckmann et al., 2017), colloquially known as “know, feel, act”. Compared to our emergent framework, the ESDG is more simplified and equally distributed across the three learning domains. However, the level of detail provided in the emergent framework provides greater specification about the range of topics within water literacy efforts, particularly within the cognitive domain. For example, the science and systems knowledge set, the local knowledge set, and the hydrosocial knowledge set are all cognitively based themes that would be lumped into the first learning objective of the ESDG. Breaking down these categories as we have in Figure 1 may enhance water literacy efforts by providing stronger guidance about what details to include. Additionally, a recent critique of the ESDG highlights a problematic emphasis on anthropogenic activities (Kopnina, 2020). The emergent framework from our review presents a similar issue, although perhaps recognizes non-anthropogenic ethics marginally better within the science and systems knowledge set.

2.4 What we know about water literacy from surveys

Understanding how we define water literacy provides a standard by which we can evaluate the current water literacy levels and knowledge gaps of the public. Of course, there is no one survey or even a standard set of surveys that breaks down water literacy as we have, but there are many studies and surveys that have investigated sections of our water literacy framework for specific populations. Synthesizing this information allows us to see broadly the general strengths and weaknesses of current public water literacy, which can then guide us on how to move forward. Thus, we attempted to summarize water literacy levels through two additional reviews of water-related surveys. The first focused on students, from children in kindergarten to young adults in college, and the second focused on adults aged 18 years or older. The following sections detail the key findings of these reviews, divided into the knowledge sets identified in our water literacy definition review and summarized at the end.

2.4.1 Student water literacy

Students across the educational spectrum are considered the next decision makers, and their public and private civic engagement around water will be integral in developing a sustainable future for water resources. An understanding of their water literacy and conceptions, as well as their alternate, limited, naïve or misconceptions, is a critical basis for designing effective educational programs and interventions. In 1993, Brody reviewed the literature on student understanding of water and water resources. This review helped set the foundation for the development of the Project WET learning goals and curriculum. His primary conclusions indicated that biological, chemical, physical, and earth system knowledge related to water was poor and misconceptions abounded. While advanced students who had taken science courses utilized scientific terminology, their conceptions remained linked to personal experience and perpetuated past misconceptions. Brody (1993) suggested that for students, water concepts were abstract and disconnected from everyday life and experience. Additionally, complex and interdisciplinary topics related to water resources were found to have the lowest levels of understanding. Brody's (1993) review highlighted a lack of longitudinal studies as well as a lack of breadth in research outside of physics and chemistry. In subsequent work, Brody (1994) also critiqued the lack of geographical and cultural diversity in studies of student water knowledge.

Since 1993, studies of student (K-16) water literacy/knowledge have continued and diversified, particularly in geographic representation. The breadth of topics addressed in the literature has also expanded, though most studies remain focused on distinct scientific and systems aspects of water knowledge, such as groundwater or the water cycle. Fewer student studies address hydrosocial knowledge, local knowledge, or functional knowledge topics. Comprehensive or broad survey data remain rare. Mills (1983) developed a Water Resource Knowledge Assessment for high school graduates, but it was not broadly adopted by others. Additionally, though pre/post learning intervention studies were common, there is a marked absence of longitudinal studies in conceptual water knowledge. What follows is a summary of the current standing of student water literacy, as determined from a review and synthesis of 35 different student surveys and research studies, broken down by the knowledge sets identified in Figure 1 (excluding general/unspecified knowledge).

2.4.1.1 Student Science and Systems Knowledge

Two recent efforts to develop learning progressions and frameworks around water for K-12 science education in the U.S. have synthesized many of the more recent studies of science and systems knowledge, particularly as they relate to environmental science literacy and science education standards (Gunckel et al., 2012; Sadler et al., 2017). Gunckel and others (2012) reviewed the naïve conceptions of upper elementary to high school students related to the science and systems of the water cycle (including atmospheric and groundwater elements along with processes such as evaporation, condensation, and movement), watersheds (including links to the water cycle and biotic systems), and water properties (including chemical processes and pollution). They highlight the challenges documented in understanding the cyclical systems and the invisible or unseen elements of water. Some progressions of learning are documented, such as students moving from conceptualizing pollution as visible trash in younger grades to recognizing invisible chemical pollutants and some of the broader complexities, hydrosocial drivers and impacts of pollution (e.g., economic effects) in upper grades (Brody, 1993; Brody, 1994; Rodriguez et al., 2014). Without naming it as such, the authors also recognize in the literature the disconnect between water and local contexts such as students envisioning rivers as existing in rural areas (Dove, 1997) or watersheds in mountainous areas (Shepardson et al., 2007) and more representative of textbook figures than their own watershed, e.g., Vinisha & Ramadas (2013). Finally, they highlight that learning interventions and instruction have been shown to "develop more connected, sophisticated, and systems-oriented ideas about water" (Gunckel et al., 2012, p. 846).

Sadler, Nguyen and Lankford (2017) conducted a review of research on student's (K-12) missing- and mis-conceptions within four natural water systems (surface water, groundwater, atmospheric water, and water in biotic systems) and water in engineered systems. They note that although water is an interdisciplinary topic, it is most commonly addressed in science classes, and that the treatment across U.S. science curriculum and standards is in no way systematic. Difficulties and misconceptions begin with the most common curricular aspect of water, the water cycle. Their review reiterates that students struggle to grasp the abstract and invisible aspects of energy and matter exchanges, as well as both water and chemical fluxes between atmospheric water, surface water, ground water and biotic systems.

Together, these two reviews summarize well the recent science and systems knowledge of students. To build on these reviews in the context of diverse definitions of water literacy, we looked explicitly for studies related to local, hydrosocial, and functional knowledge among K-16 students. Though somewhat limited in the literature, both of these represent key progressions of understanding that can link the natural/physical science and systems of water to human actions in a reflexive way. For example, Sabel et al. (2017) suggest that college students' difficulties with core hydrological concepts may contribute to findings that students are challenged to provide scientific support for decisions about socio-hydrological issues and to link these to hypothetical voting scenarios.

2.4.1.2. Student Local Knowledge

A final topic taken up by Sadler, Nguyen and Lankford (2017) in their review is "water in engineered systems". Several of these research themes fall under our local knowledge set. Research highlights that most students do not know where their drinking water comes from or the treatment processes it undergoes before and after use, e.g., (Assaraf et al., 2012; Sammel & McMartin, 2014; Schwartz et al., 2011). Middlestadt et al. (2001) found that high school students in Jordan recognized rainfall as a source of water, but even after a curricular intervention they remain deficient in a number of knowledge aspects, such as knowing that treated sewage is a source of water in Jordan. In some cases, life experience and observations may lead to better understanding. High school students in Ecuador showed a relatively good recognition of their local water sources, treatment and transport, however, they lacked the correct vocabulary to identify all of these elements (Liefländer et al., 2016).

A study of German undergraduates found that although most students were aware that in the urban water cycle used water is sent to a wastewater treatment plant, many held incorrect conceptions that waste was treated to drinking water quality standards and cycled directly back for distribution and use without discharging into natural systems (Schmid & Bogner, 2018). Attari, Poinsatte-Jones and Hinton (2017) asked U.S. college students to draw a diagram showing how clean water reaches a home and returns to the environment. They found that the majority of both environmental science majors and non-majors drew sources, water treatment, distribution and household use. However, the majority of non-majors did not show elements of wastewater collection, treatment or return to the environment.

The term “virtual water” refers to an important hydrologic concept that identifies how water is used in indirect ways. Two studies of German high school and college students found that only between 2% and 22% could identify or explain virtual water, even as linked to production (Benninghaus et al., 2018; Fremerey et al., 2014). A number conceptualized virtual water as associated with computers or the internet, as in virtual worlds or data, or as somehow fake or not existing. Most provided no answer. Given that virtual water is not addressed in the German school curriculum, the authors (Benninghaus et al., 2018) attribute the correct, limited and alternate conceptions to exposure and experience outside of school. Most students incorrectly estimated that their direct to indirect ratio of water uses were essentially equal. When asked to list water-intensive products, the majority of responses focused on textiles and clothing (96%) followed by plant-based foods (88%). Animal foods was also a frequent response, though surprisingly, less common than vegetable foods in 75% of responses. Interestingly, while products associated with cattle/beef/burgers appeared in student responses, there were no mentions of other forms of animal products (e.g., poultry or pork) (Benninghaus et al., 2018).

2.4.1.3. Student Hydrosocial Knowledge

The hydrosocial knowledge set is one of the least addressed among student surveys. While systems thinking about water is often included in science curricula and within the science and system knowledge set, hydrosocial knowledge highlights the importance of the reflexive and integral nature of humans within water systems. Shepardson et al. (2007) found that when prompted to draw and explain the water cycle, human activities and impacts and human landscapes were largely absent and suggest that "students do not make the connection to their everyday world, where human activity alters the hydrologic cycle" (p. 1465). An important link between humans and their water systems involves water quality. Students in India could identify some human impacts on water quality such as chemical fertilizers, deforestation and sewage, but they missed others including thermal pollution from power plants and atmospheric pollution (Mohapatra & Bhadauria, 2009). These same students identified a number of impacts of pollution on biodiversity and ecological systems, but only a third recognized that pollution could enter the food chain. Similarly, Jordanian students did not link actions such as dumping oil or groundwater overdraft to water quality and salinity (Middlestadt et al., 2001).

2.4.1.4. Student Functional Knowledge

While student knowledge of how to sustainably use, conserve and protect water resources is not always studied explicitly as we have defined it, some themes can be pulled from the literature. Overall understanding of water resources management and decision-making processes is found to be low among a range of ages (Brody, 1991; Mills 1983). Gill, Marcum-Dietrick and Becker-Klein (2014) utilized the Model-My-

Watershed web and problem-based learning application to evaluate student knowledge related to management decisions in a watershed. While students showed improvements, most did not reach the highest levels of conceptual understanding. Benninghaus, Kremer and Spregner (2018) asked students to define their conceptions of sustainable development within a broader survey of global water consumption knowledge. Half of the high school students surveyed were able to identify the long-term conservation of a resource and responsible use to avoid depletion as elements of sustainability. Specific conservation knowledge was shown to vary in one study as three quarters of students recognized that compost preserved soil water, but only half knew that overuse depleted a local water source.

2.4.1.5. Student Attitudes, Values, and Actions

As noted, studies of water-related attitudes and values among students tend to be sparse. Two studies surveyed college students in contrast to members of the public and provide some insights. Cooper and Cockerill (2015) found, as compared to the public, students were less concerned about future household water supply and thought less about water conservation. Conversely, Eck and others (2019) found that of 27 water issues in Oklahoma, USA, two of the most important issues identified by students, the public, and professionals alike were clean drinking water and clean rivers and lakes. However, students diverged from the other groups in assigning particularly high importance to agricultural water and land preservation and practices.

Perceptions related to drinking water quality among students is also a topic that has been surveyed with some breadth. Students often show a high trust in the safety of drinking water (Eck et al., 2019; Fremerey et al., 2014), though high school students may still prefer to drink bottled water (Fremerey et al., 2014). Either due to or regardless of misconceptions, German undergraduates accepted the idea of using recycled water, particularly for non-consumptive uses (Schmid & Bogner 2018). The majority (>50%) of surveyed college students in Oklahoma, USA, supported the use of recycled produced water from oil and gas for industrial or agricultural purposes unrelated to consumption, but only the minority supported the use for improving stream flows or for drinking water (Eck et al., 2019).

Several studies addressed affective and behavioral aspects related to water. Work by Pan and Liu (2010) found a positive correlation between students' groundwater systems understanding and concern about conservation and use of groundwater. Middlestadt et al. (2001) found that a high school curriculum aimed at teaching water conservation knowledge and behaviors was effective at improving both of these in the experimental group of Jordanian students as well as improving certain water conservation practices by their parents (e.g., watering gardens in the evening instead of during the day). Their study also found that even among the control group, certain water conservation behaviors were more common, such as shutting off the tap while brushing teeth or drinking refrigerated water. What might be perceived as more challenging tasks, such as collecting running tap water until it heats to the desired temperature or taking a shower rather than a bath, were less likely to be impacted by intervention. Keramisoglou and Tsagarakis (2011) had similar findings with high school students in Greece regarding both the impact of educational program on parents and the low adoption rates of high-effort conservation activities, in their case primarily related to body hygiene. They infer that teenagers, specifically, may be influenced by social factors that override conservation knowledge. Additionally, Middlestadt et al. (2001, p. 43) note that “our results indicate that providing students with specific behavioral knowledge can lead to behavioral change before the development of concrete attitudes about the efficacy of those actions” highlighting the importance of teaching not just about water, but teaching the tools, actions, and behaviors needed to conserve.

2.4.1.6. Student Water Literacy Summary

Water is a particularly challenging topic due to its systems complexity as well as its interdisciplinary nature. While much of the hydrologic basis of water systems represents scientific literacy, the global water crisis also involves impacts and actions by both individuals and societies and requires cross-disciplinary literacy to promote a knowledgeable citizenry. There is a call for greater focus in education on hydrosocial aspects of water and a push to emphasize the economic and social aspects of sustainability in addition to the environmental (Benninghaus et al., 2018). The studies reviewed here help to identify knowledge gaps and misconceptions in student populations. However, our emergent framework also highlights that there are elements of water literacy that are in need of further study, particularly hydrosocial and functional knowledge as well as student attitudes, values, and behaviors regarding water.

Based on the literature, attention needs to be paid to helping students to better understand and conceptualize the unseen elements of hydrologic systems (e.g., groundwater) and hydrosocial systems (e.g., water pollution). More emphasis should also be placed on the systems nature of water that includes both ecological systems and human or hydrosocial systems. Finally, knowledge gaps must be filled for students to have a more complete understanding of water management systems such as addressing the fate of wastewater and investigating virtual water use.

The research reminds us that without curricular intervention and formal education, student conceptions and mental models are dependent on prior experience and substitute observed phenomena for the unobserved or unknown hydrologic processes. However, care must be taken in the education system to link with prior knowledge and local experience so as not to overgeneralize. As noted, a number of authors have drawn attention to textbook figures and representations of water topics that may create or reinforce simplified conceptions, misconceptions and alternate conceptions in students (Abbott et al., 2019; Gill et al., 2014; Pan & Liu, 2018; Reinfried et al., 2012; Shepardson et al., 2009; Vinisha & Ramadas, 2013). These include an absence of diversity in landscapes (e.g., mountainous terrain rather than plains), the lack of built environments, preferential depiction of natural environments, limited pathways and storage examples (e.g., lakes, but not groundwater), and highly abstract representations. Even the typical arrows in diagrams may mislead students (Gill et al., 2014; Reinfried et al., 2012; Unterbruner et al., 2016). When these static visuals are used as a primary teaching tool, such as in a lecture, students may learn and reproduce the representation rather than necessarily learning the concept (Henriques, 2002; Reinfried et al., 2012). Topics and case studies in textbooks may skew or limit student recognition of water scarcity and use topics(Benninghaus et al., 2018). In some cases, teachers themselves may lack the training and understanding to significantly impact conceptual change in their students (Bieswenger et al., 1991; Unterbruner et al., 2016).

Finally, an important point is made in several studies that there may be further disconnect when disciplinary water education occurs in isolation. Fremerey, Liefländer and Bogner (2014) make the observation that although German college students graduate with the chemical background to understand hard water, many still describe hard water as harmful to humans (while the same ions in bottled water may be regarded as healthy). Outside influences such as commercial media for bottled water or personal experience with calcification of washing machines can also skew conceptions of learned knowledge. Similarly, isolating cognitive knowledge from development of values, attitudes, and behavioral knowledge misses a key opportunity to set foundations, mindsets, and habits that can carry into adulthood.

2.4.2. Adult Water Literacy

As much as children and students represent the next generation of water users, adults represent the current generation of water users and decision-makers. Adults are responsible for paying water bills and managing household water use. Adults read the news, which highlights stories of drought, pollution, and various water crises around the world. Adults also have the opportunity to vote on new water measures and projects, including price hikes in water tariffs, construction of new dams, recycled wastewater facilities or desalination plants. In these ways, water literacy is of critical importance for adult populations because it informs and directs water-related attitudes and behaviors that make an immediate impact.

While much of the data describing student water literacy emerged from academia, data and surveys of adult water knowledge more frequently come from municipal and governmental organizations. The focus of these surveys tends to be on attitudes and behaviors rather than knowledge. Additionally, there is a lack of longitudinal studies that monitor water knowledge levels over time. What follows is a summary of the current understanding of adult water literacy, as determined from a review and synthesis of 35 different adult surveys and research studies, broken down by the knowledge sets identified in Figure 2.1 (excluding general/unspecified knowledge).

2.4.2.1. Adult Science and Systems Knowledge

While the science and systems knowledge set is well represented within student surveys and education, it is not the primary focus for adult populations. Moreover, the majority of survey data that fall within this knowledge set addresses systems knowledge rather than science knowledge. For example, some surveys demonstrate that certain water system terms are less well known than others. Surveyed Albertans were mostly aware of bogs, marshes and swamps, but knew little about fens (AWC, 2015). Similarly, surveyed Americans were widely unfamiliar with river system terms like riparian, watershed, and floodplain (NGS, 2001). Beyond basic vocabulary identification, surveys also demonstrate that adult populations have difficulty understanding concepts of water transport, particularly in regard to groundwater. For example, while the majority of surveyed Albertans understood that groundwater fills the pores and fractures of rocks and soils, most also believed that groundwater exists in underground rivers and lakes (AWC, 2015). Another survey indicated that respondents are not aware of groundwater quality or challenges with contamination (Neibauer et al, 2018). This points to an inability to connect surface water systems with groundwater or to understand the invisible or unseen water elements.

Certain adult populations, however, demonstrate higher understanding of specific topics within science and systems knowledge, which appears to be a result of contextual factors. For example, McDuff et al. (2008) found that consumptive resource users (i.e., anglers and hunters) in the Orange Creek Basin in Florida were more aware of water flow patterns and connectivity of streams and lakes than were non-consumptive water users (i.e., boaters and picnickers). Reenberg (2015) found that local farmers in a village in Burkina Faso were extremely knowledgeable about how soil types respond to different rainfall regimes. Ternes (2018) found that well owners in Kansas were more knowledgeable about groundwater movement and contamination issues than those on municipal supply. All three of these examples demonstrate how water-related science and systems knowledge are tied to life experiences and interactions with water systems.

2.4.2.2. Adult Local Knowledge

While less prominent within student surveys, local knowledge is by far the most commonly surveyed knowledge category among adult populations. The literature frequently emphasizes the importance of adults knowing facts like the source of one's water (Huxhold, 2016) and the structure of one's local water system (Schall, 2015). Interestingly, it is a common finding that adults believe they know where their water comes from (AWC, 2015; Dean et al., 2016a; Metz et al., 2017). However, most surveys do not actually confirm that participants are correct, and in fact many municipal water outreach campaigns find that most people do not know the source of their drinking water (Ternes, 2018).

Similarly, the average adult is unfamiliar with the concept of a watershed (CWP, 1999). The overwhelming majority cannot correctly define watershed, even when choosing from a list of choices (Dean et al., 2016a; Giacalone et al., 2010). In fact, several surveys from both Canada and the USA have indicated that many adults do not even know that they live within a watershed (AWC, 2015; Duda et al., 2015; Thompson et al., 2011). This is only possible because many do not understand that all land drains to somewhere, and thus inherently must be included within a watershed. Even those who know that they live within a watershed are generally unable to provide the name of that watershed (AWC, 2015; Dean et al., 2016a; McDuff et al., 2018)

Several surveys also depict widespread unawareness about municipal water systems. A poll of voters in western USA found that only half were able to provide a name of their local water agency, and of those who could, only 44% were actually correct (WF, 2017). Another survey revealed that only 57% of American respondents were able to recall their yearly water bill (VWC, 2016) which, when combined with an inability to name a water provider, indicates that most people do not pay attention to their water bills or may not pay a water provider directly. Finally, several other studies found that participants in both western USA and Alberta, Canada incorrectly identified another water user other than agriculture as the largest water user in the region (AWC, 2015; Pritchett et al., 2009; CWCB, 2013).

One topic that adult survey respondents tend to know slightly more about is physical water infrastructure. Several nationwide surveys in the USA found that Americans are typically aware of the broad importance of water infrastructure, as well as current infrastructural issues like aging and contamination (Nestle Waters, 2017; VWC, 2016; WF, 2017). That said, the actual treatment and distribution system is often misunderstood. Two surveys, one in Colorado, USA, and the second in Texas, USA, revealed a significant gap in knowledge concerning the fate of water sent down the drain (CWCB, 2011; Thompson et al., 2011). Similar results emerged out of a nationwide survey in Australia, where 26% of participants believed that wastewater was discharged into waterways with little-to-no treatment (Dean et al., 2016a).

Finally, one last local knowledge topic that is fairly unique to adult populations is water laws and water rights. These topics typically do not appear within school curricula until college-level, and even then, they are not considered a standard component of curricula. Correspondingly, surveys indicate that adults tend to know very little regarding water laws. For example, survey participants in the western states of the USA were largely unfamiliar with legal terms like riparian right, prior appropriation, interstate compact, river call, conjunctive use, water decree, beneficial use, and more (Pritchett et al., 2009). Another smaller study finds similar results in Alberta, Canada, where 62% of polled residents were aware that natural water resources are property of the Crown, but only 37% were aware of the existence of independent non-profit organizations called Watershed Planning and Advisory Councils (WPACs) (AWC, 2015). Overall, there is a broad lack of familiarity among adult populations with the legal processes governing their water systems. This is partially understandable given that municipalities and water utilities generally handle these processes on behalf of their urban, suburban, and sometimes rural customers. Yet, even just a minimal understanding of such knowledge is beneficial for both day-to-day behaviors (e.g., in Colorado, USA, where residential rain barrels were illegal until 2016) and broader understandings of water movements (e.g., why the city of Denver is in a drought when there is water flowing through the local South Platte River).

2.4.2.3. Adult Hydrosocial Knowledge

As in student studies, hydrosocial knowledge is a less common topic emphasized in adult surveys. Still, those that cover it demonstrate that adults often have difficulty with thinking of water and society as interconnected systems. For example, one study found the average American citizen was unaware of the connections between streams and developments, which increase pollutants and shift runoff patterns (CWP, 1999). More recent studies indicate that this may be shifting, with the majority of participants in both Canadian and American surveys exhibiting awareness that human activities can impact the quality of nearby surface water (AWC, 2015; CWA, 2014; CWCB, 2011). However, the ability to connect one's own actions with water quality is still often lacking. In Nevada, USA, the majority of respondents said their personal actions affected water quality either only a little bit or not at all (Duda et al., 2015). Similarly, residents in Colorado, USA, were mostly aware that their actions would impact water quality of nearby streams, but also often chose to leave grass clippings and dog waste on lawns as fertilizer, despite the risk of nutrient pollution (CWA, 2014).

Hydrosocial knowledge also extends beyond water quality. The connections between human water withdrawals, drought, and watershed health are well understood by scientific communities. Many adults are able to associate drought with increased water and food prices, increased fire risks, and increased water conflicts (Stoutenborough & Vedlitz, 2014). Yet, the more complex and less visible connections are far less understood, like how drought impacts water quality, or what the causes of water shortages are beyond meteorological drought (CWCB, 2011; Stoutenborough & Vedlitz, 2014). Still, the ability to tie a climatic event like drought to societal costs and conflicts is promising. It implies that perhaps it is easiest for people to recognize the aspects of hydrosocial relationships that most directly impact them. Indeed, other surveys have documented a growing recognition among the public of the key role water plays within economic systems and our public health (Nestle Waters, 2017; SDCWA, 2019; VWC, 2016).

2.4.2.4. Adult Functional Knowledge

Around the world, the public is increasingly recognizing burgeoning water crises. Adults tend to harbor a significant level of concern for water issues, which is often higher than the level of concern for many other environmental issues (CWA, 2014; Stoutenborough & Vedlitz 2014). International surveys of adults indicated that the public places water quality and water shortages as the top two current problems (Globescan, 2009). Newer research indicates even more growth in this public concern (CWA, 2014;Moshtagh & Mosenpour, 2018; NSB, 2018). However, recognizing an issue and understanding how to fix that issue are two very different sets of knowledge.

That is not to say that adults know nothing about how to use water. In Alberta, Canada, more than 80% of survey respondents are aware that they can protect their watershed by reducing or eliminating lawn chemicals, or by using a certified carwash rather than washing a car themselves (AWC, 2015). Across the USA, surveys indicate awareness of household-level water conservation, like installing water saving fixtures or operating sprinklers in cooler hours to limit loss from evaporation (Duda et al., 2015; Neibauer et al., 2018; NGS, 2001). However, much of adult functional knowledge appears to be contextually dependent. For example, He (2018) found that survey participants living in drought-prone regions of China had better conservation knowledge than those living in more water-rich regions. Similarly, well owners in Kansas, USA, knew more about sustainability of groundwater than those on municipal supply (Ternes, 2018). Experience plays a critical role within functional knowledge because understanding how to better manage water resources tends to follow after times of water crises.

Still, there is an acknowledged gap among adult populations in understanding how best to utilize and protect water resources. In addition, it is not just scholars and water managers emphasizing this gap; the public themselves are among the first to admit they need more information. Surveys indicate that people are aware that they could be doing more to protect water resources, but simultaneously feel as though they do not know enough to do so (AMNH, 2008; Globescan 2009). Some survey data indicate that the public perceives a lack of easily available information regarding water resources (AWC, 2015; Duda et al., 2015). Time and time again, survey participants express a desire to learn more about how to use water sustainably, whether it is about water conservation (NGS, 2001) or the “true cost of water” (CWCB, 2011, p. 15). Adults in Iran expressed the need for more educational programs about conservation and the cultural barriers of reuse and gray water (Moshtagh & Mohsenpour, 2019). Thus, it is clear that functional knowledge could most definitely be improved for students and adults alike.

2.4.2.5. Adult Attitudes, Values, and Actions

Within adult populations, the attitudes, values and actions categories of water literacy are a stronger focus than with students, who are not yet the primary decision makers in their households. In contrast to students, adults represent an age group that is not only capable of making many water-related decisions, but also expected to do just that. Their behaviors directly influence the success of initiatives like water conservation, pollution prevention, and the funding of large infrastructural projects. Thus, the translation of water knowledge to attitudes, values and actions is a very important process to understand.

Given the high levels of concern for water issues, it is no surprise that attitudes about water are emotional. Surveys indicate a reoccurring fear among adult populations about the ability of current water systems to meet the needs of the future (Cooper & Cockerill, 2015; CWCB, 2013; Nestle Waters, 2017; SDCWA, 2019). Only one survey indicated a substantial amount of optimism about future water supplies, but then went on to say that participants worry that urban centers will struggle more with water supplies than rural areas (WF, 2017). Furthermore, while many believe that conservation is the responsibility of everyone (AWC, 2015; Gilbertson et al., 2011), an even larger number indicate that some level of government ultimately needs to take charge (Cooper & Cockerill, 2015;

Globescan 2009). Even so, Cooper and Cockerill (2015) found that adults strongly prefer that water resources are controlled and managed by local governments rather than state governments.

Adult public opinions regarding the efficiency and success of current systems are fairly mixed. Some surveys demonstrate an even split between critique of and support for current water management strategies (AWC, 2015; CWCB 2013), while several others document dissatisfaction and a desire to see changes to water laws and practices (Pritchett et al., 2009). Such division is evident in the public's concern surrounding the quality of tap water. One survey demonstrates that more than one third of American participants believe tap water is unsafe to drink (Nestle Waters, 2017). Other surveys indicate that although tap water is perceived as safe, respondents still choose to filter or boil before drinking, or even choose to purchase bottled water instead (NEEF, 2015; Neibauer et al., 2018). Water managers and local government are not the only targets of such distrust. Surveys reveal that members of the public also tend to blame each other. For example, one survey indicates people think that that new residents are to blame for increased water demand and subsequent water shortages (Thorvaldson et al., 2010). Additionally, while the public often shows willingness to conserve and get involved, surveys often find that there is also a preference for mandatory conservation through government restrictions (Pritchett et al., 2009; Stoutenborough & Vedlitz, 2013), revealing a lack of trust in one's neighbors' ability or willingness to conserve.

In terms of behaviors, adult surveys mirror what is found in student surveys with a strong preference for individual actions over collective actions, especially those that require the least costs or lifestyle changes. For example, 90% of surveyed Americans (NGS, 2001) and Australians (Dolnicar & Hurlimann, 2010), as well as 70% of surveyed adults across the world (SDCWA, 2019) turned off their taps while brushing their teeth or doing dishes. Another 85% of surveyed Americans (NGS, 2001), 89% of surveyed Australians (Dolnicar & Hurlimann, 2010), and 64% of surveyed adults in San Diego, USA (SDCWA, 2019) only ran full loads of laundry and dishes. These are small changes with no price tags, that actually can save households money. Meanwhile, actions that are more pertinent to adults and homeowners, like installing water saving fixtures indoors or eliminating lawn chemicals are much less common (AWC, 2015; Dolnicar & Hurlimann, 2010; Duda et al., 2015; Neibauer et al., 2018). The price tags of water saving fixtures can be hundreds to thousands of dollars including installation, not to mention that eliminating lawn chemicals may mean a less green lawn with more maintenance.

Collective actions, however, are by far the least common applications of water literacy. While 40% of survey participants in Alberta, Canada, had discussed water issues with their friends at some point, less than 13% had extended that conversation to include municipalities, government officials, or watershed groups (AWC, 2015). A survey across the USA found that 32% of participants were involved with watershed conservation or protection groups (NGS, 2001).

2.4.2.6. Adult Water Literacy Summary

The water-related research and surveys conducted on adult populations provide a clear contrast to those conducted among student populations. Perhaps because science and systems knowledge is often the primary focus within conventional school programs, it is assumed (or at least hoped) that such knowledge will be retained through adulthood. The adult surveys suggest, however, that student misconceptions or knowledge gaps, like those surrounding groundwater, are carried through to adulthood (AWC, 2015; Metz et al., 2017). However, systems knowledge may also emerge more prominently out of contextual and experiential learning moments (McDuff et al., 2008; Reenberg, 2015; Ternes, 2018). Along those lines, local knowledge is a much stronger focal point for adult populations, likely because it is the category of knowledge that most directly applies to household decision-making and local voting initiatives.

As suggested for student populations, there is also a need among adults for a greater focus on hydrosocial knowledge. While adults indicate some awareness of the economic and social importance of water, they clearly show room for improvement. There is also a lack of surveys that emphasize culturally indigenous water knowledge as opposed to western knowledge, upon which most modern water management systems are based (Hawke, 2012). Additionally, the gap in students' functional knowledge extends into adult populations. This is acknowledged not just by surveyors, scholars and water managers, but also by the public themselves. There is a desire to learn how to become more engaged with water-conscious behaviors and governance processes (CWCB, 2011; NGS, 2001). Interestingly though, this is paired with an apparent disregard for one's water bill, which often includes educational articles, helpful information, or answers to frequently asked questions. Perhaps such passive attempts to enhance functional knowledge among adults should be more active and engaging.

Finally, it is clear that water knowledge among students is vastly different from that among adults. These two populations are typically educated and engaged in isolation from one another. This creates substantial gaps in water literacy knowledge sets. Achieving sustainable water governance may require more reflective and iterative approaches to water literacy, such that acknowledging gaps in water knowledge among adults results in a shift in educational programs among youth, and vice versa.

2.5. Approaches to Improving Water Literacy

A goal in identifying water knowledge and gaps is to find ways to improve and develop a more complete water literacy among the populace. Our review of water knowledge studies of students and adults reveals several key areas in need of improvement. These include the generation of misconceptions and misunderstandings among students that carry through to adulthood; the uneven emphasis of local knowledge; the widespread lack of hydrosocial and functional knowledge; the treatment of student and adult education as isolated and separate. Drawing on the published literature, a suite of approaches that have been suggested or put into practice could be appropriate to address these particular gaps. While this is not an exhaustive list, using a combination of enhanced visual tools, place-based learning initiatives, interdisciplinary approaches, and a more reflective and iterative process between student and adult water education programs can help move the needle toward an improved and balanced water literacy.

Conceptual change around water and water systems is one of the greatest challenges to improve water literacy. Incomplete and incorrect conceptions abound, persist and may be exacerbated by the very tools we use to educate, such as the ubiquitous water cycle diagram. Thus, improved visual tools and messaging have been targeted as an important approach to improve water literacy. Studies demonstrate that depictions of the water cycle used in school curriculum, textbooks, online sources and even published academic and government documents are largely the same image of water moving through mountainous settings, devoid of groundwater movement and human interactions (Abbott et al., 2019; Shepardson et al., 2007). Instead, more inclusive and complete mental models can result from the depiction of more diverse settings, including urban and rural locations (May, 1996; Shepardson et al., 2007), varied biomes and different seasons (Abbott et al., 2019). Interactive computer simulations are another visual tool that can capture the dynamic and complex nature of water systems and are adaptable to a range of learners. Research has shown that such tools improved the systems-thinking skills of elementary students (Evagorou et al., 2009), corrected misconceptions about groundwater among secondary students (Unterbruner et al., 2016), increased groundwater knowledge among university students (Arthurs, 2019; Unterbruner et al., 2016), and increased water knowledge of primary and secondary teachers (Arthurs, 2019). Additionally, visual tools can tie local knowledge to actionable functional knowledge. For example, in Colorado, USA, Denver Water's award-winning "Use Only What You Need" drought campaign utilized visuals ranging from slogans on billboards to three-dimensional sculptures that demonstrated differences between current water use volumes and actual need volumes (DW, 2020). The information conveyed in these visuals that tailor actionable information to the Denver population corrects misconceptions that water is renewable, while pairing science and systems knowledge with local knowledge in visually stimulating and relatable ways. Ultimately, this can help learners to understand and hopefully retain information from childhood to adulthood.

The suggestion of emphasizing place-based learning requires that all lessons are situated in place and space. In terms of water literacy, this entails connecting typical science and systems curricula to the physical, social and political context of water resources. Indeed, attempts to increase water literacy that embrace place-based learning are often found to be more successful. For example, a 5th-grade place-based curriculum on watersheds led to improved identification of links between urban land-use, runoff, water quality and the concept of watershed drainage (Edreny, 2020). Additionally, place attachment to a rural lake region in Wisconsin led to adults not just understanding water quality better, but also expressing greater intentions to preserve water quality by voting for laws or joining a group (CWA, 2014). Both of these examples involve a stronger focus on local water knowledge, while the latter also weaves in functional knowledge and water literacy attitudes.

Place-based approaches also offer opportunities to address significant gaps in hydrosocial knowledge. Within Linton and Budd's (2014) hydrosocial cycle, the physical environment of one's water system helps to shape one's narrative of water. Thus, it follows that water literacy would be tied to one's geographic place. However, places can have different meanings to different people, which impacts how knowledge is internalized and understood. Assaraf et al. (2012), for example, highlighted how indigenous Bedouin 4th graders in Israel have "richer mental models of water cycle phenomena" (p. 451) than their small-town Jewish counterparts because they incorporate elements of their theology into the water cycle. Similarly, Swentzell (2012) showed how U.S. Indigenous Pueblo culture provides a deeper connection to the water cycle and watershed, which does not always fit within a traditional positivist scientific literacy perspective. Thus, attempts to teach social, cultural, and political water relationships must be contextualized within place. An example of such an attempt can be found in Australia, where a local water authority partners with the Widjabul/Bundajalung peoples to provide local Water Walks. Participants of all ages meet at a creek and dam location to experience oral history, bilingual interpretive signage and worksheets as “a walking, listening, breathing, discovery project that requires conscious and embodied participation” (Hawke, 2012, p. 240). The program offers an interactive, engaging lesson that ties our water knowledge not just to the local geographic context, but also to the cultural and social context of the region.

Gaps in hydrosocial and functional knowledge can also be minimized through greater valuation and development of interdisciplinary education. The future of water management and water justice needs citizens and leaders who firmly understand the numerous and complicated connections between water resources, human activities, and culture. As such, several new curricular models in post-secondary education have emerged that frame water education within interdisciplinary structures. These include efforts from Emory University, Atlanta, GA (Eisen et al., 2009), Fresno State University, CA (Sherchan et al., 2016) and University of Nebraska-Lincoln (Forbes et al., 2018; Sabel et al., 2017). In addition to student learning, these interdisciplinary efforts resulted in powerful faculty development through cross-pollination of ideas and perspectives on water. Graduate programs are also embracing this approach in training future water resource managers, citing that not only water knowledge, but "soft skills" are important (Blöschl et al., 2012). Further, the United Nations touts a "Multiple-Perspective Tool" as an important framework for sustainable development and freshwater issue education (UNESCO, 2012).

Finally, this review highlights a major disconnect between how we approach water literacy in student and adult populations. Specifically, we tend to survey, study and address their knowledge separately. While numerous studies have addressed student conceptions of the water cycle and scientific knowledge, less is known about their attitudes and values regarding water. The opposite is true regarding adult water knowledge. As such, the approaches used to educate these populations are disconnected. Such disconnects and inconsistencies between populations also make direct comparisons of survey results difficult. Thus, a more reflective and iterative approach linking student and adult water literacy initiatives is proposed, such that knowledge gaps in one population inform educational initiatives for the other population and vice versa. One such example of this exists in a research study by Thompson and others (2011), who surveyed 1000 adults in North Central Texas' Upper Trinity River Watershed, and then used the results to design a set of educational programs for each school year between kindergarten and 5th grade. Their results showed increased awareness and commitment by students to conserve water based on the new water programs. Such innovative studies and approaches should be more commonplace, as they address recognized knowledge gaps that prevent a more holistic water literacy.

Such reflective approaches should go in both directions. Indeed, there are several studies that highlight the important potential of intergenerational learning (Ballantyne et al., 2001; Duvall & Zint, 2001; Sutherland & Ham, 1992). What children learn in school they often share with their parents, creating an opportunity to share water knowledge. One Project WET program delivered in Arizona, USA, taught students how to audit household water usage, resulting in many of them showing their parents how to conserve water and install water-efficient faucet aerators (Ritter & Schwartz, 2008). Programs that engage youth and parents at the same time also show promise at increasing water literacy. Water festivals, which interface experiential education with classroom education, are a prime example. Studies have revealed statistically significant gains in student knowledge, conservation behaviors, and enthusiasm for water (Thomas-Hilburn & Schwartz, 2011) while also engaging parents and guardians with the same educational information and opportunities to speak with scientists and water experts (Fisk, 2016). It should be noted that many studies indicate the success of intergenerational learning is context-specific and can never replace adult education entirely (Sutherland & Ham, 1992). However, given the increasing complexity of modern water issues, and the revealed water knowledge gaps that span age groups, any and all tactics that can increase awareness and generate action should be employed.

2.6. Discussion & Conclusions

Through the review of existing definitions and descriptions of water literacy, we highlight what other scholars have also found, which is that current water literacy definitions, understandings, and applications vary substantially (AWC, 2016; Dean et al., 2016a). However, by coding and collating current definitions, we have also identified several commonalities. Our emergent knowledge set framework (see Figure 1) can be used as a guide for future work towards a more inclusive and relevant use of the water literacy concept. It bolsters the efforts of previous frameworks, like the AWC's water literacy ladder (2016), Project WET's water literacy principles (2020), and the UN's ESDG framework (Rieckmann et al., 2017), to analyze their strengths and weaknesses and identify specific elements of water literacy. The emergent framework highlights an uneven emphasis on cognitive domains compared to affective and behavioral learning domains, as well as a bias towards anthropocentric water needs. It also suggests new ways to view the interconnected nature of water knowledge with our identification of unique knowledge sets. The diversity of definition sources also makes clear that the development of common language and goals around what constitutes water literacy will require enhanced engagement, collaborations and communication among the diverse groups working in the field.

We applied the emergent framework to review existing surveys and studies of water knowledge, attitudes and behaviors among student and adult populations to highlight the current standings and broad knowledge gaps that exist around the world. There are limitations to this application, including the fact that most of the literature we analyzed studied relatively small populations in primarily westernized countries and typically addressed only a subset of all the knowledge sets identified in Figure 1. Additionally, our review has identified areas that are in need of additional research, such as in the values and attitudes and the action knowledge sets of students, or within the affective and behavioral domains of water literacy more broadly. However, the data that emerge from our analysis reveal several reoccurring knowledge gaps and inconsistencies in current water literacy initiatives, including the generation of misconceptions and misunderstandings among students that carry through to adulthood; the uneven emphasis of local knowledge; the widespread lack of hydrosocial and functional knowledge; the treatment of student and adult education as isolated and separate. If the goal is to work towards water sustainability by increasing water literacy among the public, these issues must be addressed in future efforts.

Indeed, the literature suggests a varied number of approaches for improving water literacy. In order to best address the knowledge gaps we identified, we have highlighted a select few approaches for future work. These include: creating and utilizing enhanced visual tools to correct student misconceptions while tying local and functional knowledge to current science and systems knowledge curricula; emphasizing place-based learning initiatives to convey local and hydrosocial knowledge; increasing the interdisciplinarity of educational curricula to shape future generations of water leaders that are well versed in hydrosocial and functional water knowledge; shaping future initiatives through more reflective and iterative processes between student and adult water programs.

However, as we consider water literacy and developing water literate populations, we would benefit to keep in mind several ideas suggested by Koballa, Kemp and Evans (1997) in their exploration of science literacy. First, the complexity and breadth of water literacy suggest that there will be different levels of literacies across multiple domains and that these will change over time in an individual based on personal and external motivations, experiences and values. Additionally, we must view the development of water literacy as a lifelong pursuit, supported at first by schooling to develop knowledge base, skills and motivation, but then supported and valued by society as a whole, (including government, industry, municipal water providers, resource managers, the media, etc.) (Koballa et al., 1997). Attempts to address misconceptions, knowledge gaps, and overall water literacy should occur at all ages, from “K to gray”.

Finally, as scholars, managers, and global citizens, we may also benefit from a reminder that the majority of views and surveys reviewed here about water literacy privilege a western science view of knowledge. Indeed, the vast majority of reviewed water literacy definitions emerge out of the Global North, with particular emphasis on Australia, Canada, and the USA. We were able to find more diverse literature when expanding the search beyond “water literacy” to surveys about water knowledge, attitudes, and behaviors, but there is still a strong bias towards western cultures. However, as numerous scholars note, deep cultural and eco-cosmological literacies about water are equally important as an understanding of a concepts like drought index (Hawke, 2012; Roncoli et al., 2019). Thus, future research on water literacy should seek greater exploration of non-western water knowledge across a much broader range of settings, with specific attention on developing countries.

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Chapter Three: Water literacy and the Day Zero climate shock: A political ecology analysis from Langa Township, Cape Town (South Africa)

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2	Thomas LaVanchy	Conceptualization, methodology, data collection, supervision, critical review and feedback, editing,	20%
3	Michael Kerwin	Supervision, critical review and feedback, editing,	10%
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iv. The candidate's stated contribution to the publication is accurate (as detailed above);

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vi. The sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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3.0 Abstract

Faced with countless water challenges, modern water management needs great reform. Of particular concern are climate shocks, which expose an urgent need for community water literacy within water security paradigms. Using a political ecology framework, we investigate the water literacy of Langa, a township in Cape Town (SA), in the wake of the Day Zero climate shock. Our results reveal mixed water literacies within Langa, with key strengths emerging from lived experiences, including Day Zero. We also identify weaknesses within community water literacy, which emerge from socio-political structures that limit information flows and discourage community engagement within water management.

3.1 Introduction

Cities around the world must reevaluate water security as population growth and climate change threaten once sustainable resources. Supply-focused water management paradigms centered around development of new surface and groundwater resources are increasingly unreliable and often depend on environmentally and socially damaging practices (Linton, 2008). Within this approach, growing urban demands push against the limit of finite water supplies, exacerbating competition and conflict between water users. In addition to urbanization and industrialization, climate change is shifting hydrologic patterns around the world, resulting in more intense wet and dry episodes and potential permanent shifts in precipitation regimes. The status quo of modern water management is proving insufficient to cope with these challenges.

A key component to building resilience into water management practice is developing citizen water literacy, one's collective water-related knowledge, attitudes, and behaviors (McCarroll & Hamann, 2020). Investments in water literacy also offer a chance to highlight water injustices and hold water managers accountable for shaping equitable outcomes. Communities that understand their water system can engage more readily in dialogues about water, both informally and formally, creating the opportunity to share their water needs and concerns (Dean et al., 2016).

Of particular concern in the water security paradigm is managing water in drought-prone regions. Although drought is a natural component of Earth's climate system, today's drought cycles can be far more impactful due to increasing temperatures and evapotranspiration, in addition to escalating population pressures and concomitant demand for water. Climate shock events (Clingingsmith & Williamson, 2008; Kondratyev, 1989) expose an urgent need for community water literacy so that citizens can understand and trust information from water managers and timely respond to calls for water conservation. Simultaneously, experiences of a climate shock offer opportunities to increase community water literacy facilitated by rapid transmission of information from water managers (Gilbertson et al., 2011).

This paper uses a political ecology framework to study a recent drought event in Cape Town, South Africa. Three consecutive years of historically low rainfall led to a climate shock colloquially called Day Zero, which brought the municipal water system to near failure. We sought to examine local community knowledge and reactions to the Day Zero drought to better understand how the experience of drought contributed to water literacy, as well as how water literacy can boost resilience to future climate shock events. Given the apartheid history and current uneven social landscape of Cape Town, it was expected that the various communities of Cape Town have different water literacies and experiences with a shared drought. This claim is supported by research demonstrating that historically marginalized townships experienced substantial and uneven impacts from the Day Zero drought due to inequitable communications, water shutoffs, and pressure reductions on water systems to indigent households (Enqvist & Ziervogel, 2019; LaVanchy et al., 2021; Savelli et al., 2023). Our research focused on one township, Langa, where anecdotal evidence from a preliminary focus group suggested varying water literacies and high levels of distrust of city water managers. This focus on Langa allowed us to analyze the water literacy of a community that was among the most impacted by the Day Zero drought and in need of the most adaptation for future droughts.

3.1.1 Water Literacy & Political Ecology

Water literacy is a relatively new field of research within water management, gaining in popularity in the past two decades. An extensive literature review conducted by McCarroll and Hamann (2020) found that the concept of water literacy is complex and comprised of different components, or "knowledges," including: science and systems knowledge, which encompasses the water cycle and water's unique scientific properties; local knowledge, which highlights local water sources, managing entities, and various water uses; hydrosocial knowledge, which ties together the give-and-take between diverse human activities and water resources; functional knowledge, or the awareness of water sustainability and the "how-to" of water resource protection; attitudes and values relating to topics like water conservation and water management; and actions, both individual and collective, that conserve, protect, or otherwise enhance sustainability of water resources. Collective knowledges, attitudes, and behaviors are built through educational achievement, both formal and informal, as well through associative learning presented by life experiences and personal interests (Dean et al., 2016; Harnish et al., 2017; McDuff et al., 2008). Notably, experiences of drought and water restrictions are suggested to contribute to the formation of water literacy (Booysen et al., 2019; Gilbertson et al., 2011).

A foundational water literacy among the public offers numerous benefits for water management. Water managers can foster trust in their actions by engaging the public with water knowledge and information (Attari et al., 2017; Cooper & Cockerill, 2015; Dean et al., 2016; Jorgensen et al., 2009). Such engagement may also increase community support and willingness to pay for various water management decisions or policies such as alternative water sourcing from desalination or recycled wastewater (Attari et al., 2017; Giurco et al., 2010; Stoutenborough & Vedlitz, 2014). For example, a study in Australia found correlation between increased water conservation and citizens with higher water-related knowledge (Dean et al., 2016). Finally, community water literacy can further equity and social justice within water management. Dean et al. (2016) argued that the more water literate a community is, the more they will engage in both water-related discussions and engagement opportunities in a productive manner. This alone can expose community needs and shape corrections of water management inequities (Berquist et al., 2020; Rusca & Di Baldassarre, 2019).

Here we analyze the concept of water literacy through the lens of political ecology, a framework grounded in the belief that natural resource management is fundamentally a political act, influenced by social and economic powers (Blaikie, 1999; Islar & Boda, 2014; Robbins, 2020). In relation to water management, political ecology calls for investigations of supply-focused, state-driven water solutions that have dominated human history, and how they create or further exacerbate water insecurity. Scholars have used this framework to reveal how modern water distribution systems are often a reflection of power differentials and turbulent social pasts (Loftus 2009; Swyngedouw, 1997), or how water scarcity emerges not just from limited quantities of water resources but also from inequitable access, changes in water demand, or sanctioned pollution of water bodies (Harris, 2020; Johnston, 2003; LaVanchy, 2017; Mehta, 2003).

Whereas water literacy has yet to be fully examined within the lens of political ecology, the concept itself is inherently political. For example, local water knowledge as laid out by McCarroll and Hamann (2020) includes an awareness of water sources, infrastructure, and boundaries of one's local watershed. Water resources, however, are often managed along political boundaries rather than hydrologic boundaries, and thus local water knowledge will often describe these political boundaries and power structures. Additionally, hydrosocial knowledge describes an understanding of the relationships between water and social systems (McCarroll & Hamann, 2020; Wesselink et al., 2017), which are influenced by dominant economic and political activities. Perhaps most importantly, the distribution of water-related information, which could be shared to increase public water literacy, is determined by those who have access to and control of water knowledge. Indeed, the accumulation of knowledge is associated with the accumulation of power (Hislop, 2003). Thus, to a large extent, a community's ability to become "water literate" depends on how and when those with information choose to share (or not share). This makes political ecology an ideal framework to understand the factors that encourage and prevent community water literacy.

3.2 Background

Cape Town is located in the Western Cape province in the southwest corner of South Africa (Figure 3.1). Situated at approximately 34 degrees south latitude, Cape Town enjoys a predictable Mediterranean climate that pairs wet winters with dry summers and recurring drought (Botai et al., 2017; Levey, 1996). The regional landscape is physically dynamic. The city center is nestled between the Atlantic Ocean and the towering 1000-m Table Mountain, yet most residents live in townships on the barren, low-lying Cape Flats just east of the city center. An average of 520 mm precipitation falls across the city, though it varies spatially as areas bordering Table Mountain can receive over 1,000 mm, while areas in the Cape Flats will receive a mere 350 mm.

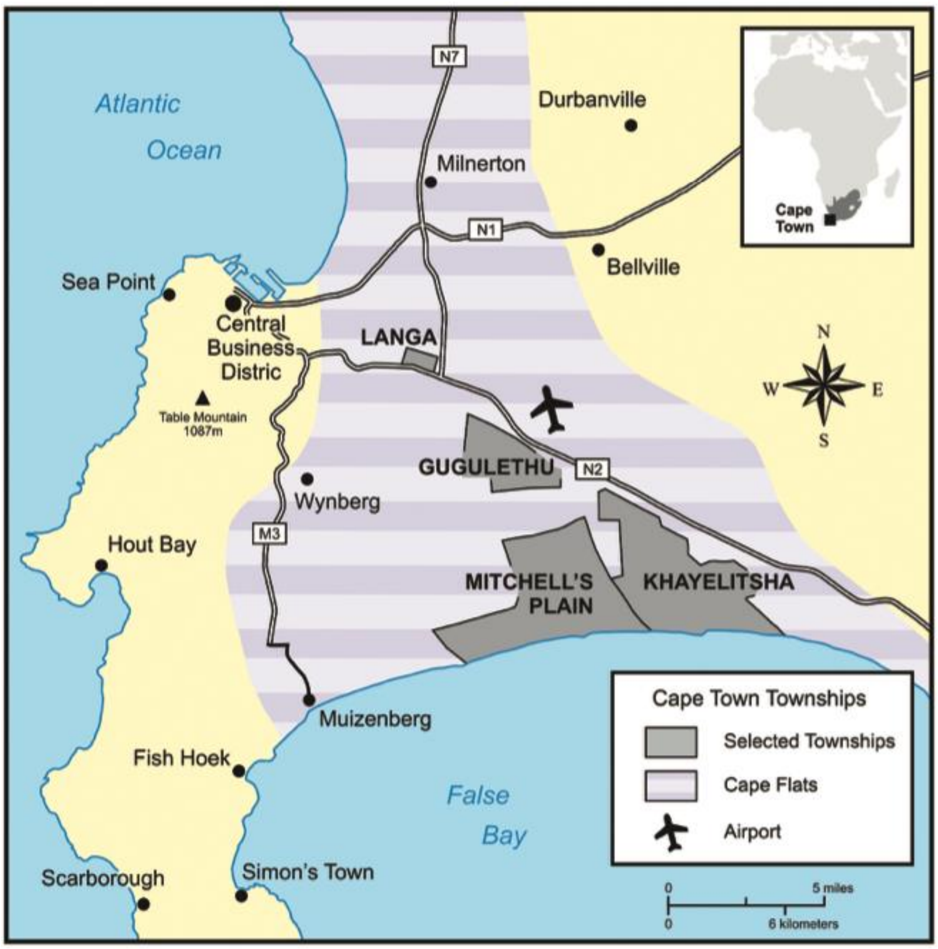

Figure 3.1: Location of Cape Town and Langa township within South Africa. Cartography from Michael Larson.

Within this geographic context, Cape Town utilizes the Western Cape Water Supply System (WCWSS) to collect winter precipitation in interconnected reservoirs for treatment and distribution to Cape Town's population of 4.7 million people. The WCWSS also provisions surrounding agricultural areas and a few smaller regional towns. Local water managers realized several decades back that the system had reached its maximum dam construction potential (Luker & Rodina, 2017). Thus in 2001, the City paired the WCWSS with an extensive Water Demand Management/Water Conservation (WDM/WC) Strategy to enforce regular water restrictions during recurring summertime droughts (CCT, 2016a). However, scholars such as Bakker (2010) argue that water systems are not inherently apolitical, and Cape Town is no exception. Understanding water literacy related to the current water system and the Day Zero drought requires exploring the region's long history with European occupation and subsequent apartheid policies.

3.2.1 History of Cape Town Water System

Access to abundant, clean water shapes human settlement. Prior to European colonization, indigenous groups known as the KhoiKhoi utilized freshwater springs and reliable surface water in and around modern-day Cape Town (Kidd, 2008). In 1652, the Dutch East India Trading Company (known as the VOC) established a replenishing station at the Cape of Good Hope. The VOC granted permission for local European settlement, effectively apportioning land and local water resources and driving away the KhoiKhoi from their traditional lands. Since it was a trading post, the VOC was primarily concerned with agriculture to support the replenishing station and passing ships. Thus, physical water infrastructure remained of minimal concern during their occupation. This changed when the British established a colony near Cape Town in 1806. Under their rule, water rights were allocated to white settlers, while non-white populations were pushed out of the city center, largely out of popular thought that these communities spread disease (Enqvist & Zeirvogel, 2019). The British invested heavily into urban water infrastructure, including a distribution system with a reservoir, a sanitation system, and a stormwater drainage system (Brown & Magoba, 2009). These upgrades improved water security in the city center, spurring industrial development and affording settlers the luxuries of their homelands.

South Africa gained independence in 1910 and land ownership was legally formalized through the Land Act of 1913. This act awarded the most desirable and fertile land near Table Mountain to European settlers and grouping displaced non-white people into “native villages” (later called townships) within the nutrient- and freshwater-poor lands of the Cape Flats (Enqvist & Ziervogel, 2019; Kidd, 2008). Racial segregation was legally codified shortly after World War II when the National Party gained political power in 1948 and implemented a system of apartheid, or “apartness”. Total apartheid required the physical fragmentation of water systems along three separate tiers to service white, coloured, and black populations (Smith & Hanson, 2003). White neighborhoods received infrastructural investments and highly subsidized water services, while non-white neighborhoods received minimal infrastructure funding from mismanaged and often illegitimate administrations (Smith, 2012; Smith & Hanson, 2003). Meanwhile, townships began experiencing mass influxes of non-white migrants seeking work in the city. The State funded the construction of hostels for migrant workers, but these quickly proved insufficient to accommodate the rapid growth. New arrivals began building dense informal settlements on the outskirts of the townships, straining the minimal existing water infrastructure. Deteriorating public services paired with increasing civil unrest resulted in protest-motivated water payment boycotts in the late 1980s and early 1990s, leading to mass accumulation of water debt within townships (Smith, 2004).

Apartheid officially ended with South Africa's first democratic election in 1994. Shortly thereafter, in 1996, a progressive constitution was introduced with aspirations of rectifying the wrongs of the past. This included a unique constitutional right to sufficient water with the explicit mandate that the State shape legislation to realize these rights (SAHRC, 2001). The 1997 Water Services Act defined "sufficient" water as a minimum of 25-L ppd or 6-kL per household per month, within 200-m of a household (Kidd, 2008), and the 2002 Free Basic Water (FBW) Policy specified that all municipalities must provide this quantity of water free of charge (Beck et al., 2016). Subsequent revisions included a commitment that local governments provide up to 50-L ppd whenever possible, while also limiting the applicability of FBW to indigent households because of associated cost and capacity difficulties (OECD, 2021). Water systems across South Africa have undergone marked improvements in capacity and distribution in recent decades to conform to these legislations. At a national level, the total population with access to basic water supply increased from 70% in 1994 to over 91% in 2015 (Nnadozie, 2011; Oskam et al., 2021).

Cape Town, specifically, is often applauded for improvements in water security. An official publication in 2017 estimated that 98.4% of the city's population have access to basic water through this system, which places it above the national average (WCG). However, Rodina and Harris (2016) suggest that these amalgamated official estimates significantly overestimate access to basic water in townships. Additionally, attempts to improve Cape Town's water security often exacerbate existing water injustices within townships. For example, incorporation of the townships within the Cape Metropolitan Area in 1997 and corporatization of Cape Town's water system in 2003 both spurred administrative difficulties of maintaining correct township water records and billing addresses (Smith & Hanson 2003; Smith 2004). Paired with the water payment boycotts from '80s and '90s, township residents received substantial accumulation of arrears within townships and subsequently high levels of water debts among township households. More recent attempts at equitable cost recovery include "pro-poor" increasing block tariff structures and free installation of Water Management Devices (WMDs) for qualifying indigent households, which supply FBW and limit water debt (Enqvist & Ziervogel, 2019; Mahlanza et al., 2016). But these tactics punish low-income households that have more than four individuals (a common occurrence in townships), and the shame of proving one's indigent status to receive FBW tends to discourage participation (Rodina & Harris, 2016; Enqvist & Ziervogel, 2019). Issues like these continue to racially fragment the city's water system well after the end of apartheid, demonstrating that water security requires more than just physical water hookups. In line with discussions of social structures and cultural stigmas, we expand the conversation to include water literacy as well.

3.2.2 Cape Town Water Literacy & Day Zero

Existing research on water literacy within Cape Town communities is limited, but a few key insights can be extracted. At the national level, research suggests that most South Africans do not fully understand their personal influence on water management and water conservation, even though they personally experience drought on a regular basis (Sershen et al., 2016; Ziervogel et al., 2010). Additional research reveals that South Africans misunderstand the complexities of water management and the roles of government officials, much less the information detailed on their own water bills (Sershen et al., 2016; Smith & Hanson, 2003). Specific to townships, municipal officials and residents hold contrasting perceptions and experiences of water security, often fueled by lack of knowledge, insufficient water communications, and views of the public as disjointed customers (Cameron & Katzschner, 2017; Meissner et al., 2018; Smith & Hanson, 2003). Collectively, these studies imply that community water literacy within Cape Town townships is likely low, with high levels of distrust emerging from a divided system that discourages public engagement. Indeed, Cameron and Katzscher (2017) concluded their review of Cape Town water policies with a recommendation towards more inclusive and holistic discourse.

However, popular theory suggests that public water literacy may have actually evolved in Cape Town thanks to the Day Zero climate shock. Climate shocks are unusual and unpredictable weather events, shaped by large scale changes in climate, which ultimately endanger social systems (Clingingsmith & Williamson, 2008; Wagner & Weitzmann, 2015). In the context of the Western Cape, climate shocks are driven by increasing air and sea surface temperatures (Cheng et al., 2019; Niang et al., 2014), which increase evapotranspiration rates and cause fewer but more intense rainy days (Burls et al., 2019). The Day Zero climate shock emerged in late 2017/early 2018 after three consecutive years of historically low rainfall that brought the city's water system to near failure (Sousa et al., 2018; Booysen et al., 2019). The city initiated a countdown to Day Zero, or the day when the municipality would no longer be able to supply the city with tap water.

To avoid Day Zero, Cape Town launched an ambitious water conservation program that utilized education, fearmongering, and public shaming as motivation for saving water. The city published an online Water Dashboard, which was regularly updated to share city-wide water usage rates, target usage rates, and reservoir levels (Snyman-Van der Walt et al., 2020; Wallace, 2021). Informational graphics and videos were shared across numerous platforms instructing residents on how to use water most efficiently. A residential water use map was created to applaud top water conservers, although it devolved into a blame-and-shame tool for top water wasters (Wallace, 2021). The City also pushed the installation of Water Management Devices (WMDs), which controversially targeted townships and low-income households as a tool to ensure delivery of the FBW policy (Enqvist & Ziervogel, 2019).

As a result of these programs and others, a massive increase occurred in the amount of shared water information from local water managers, politicians, media, scientists, and citizens. Twidle (2022) noted, “for a while it was hard to talk or think about anything except water” (p. 371). Almost immediately, the average citizen was receiving detailed information about dam levels, daily consumption rates, weather patterns and climate change, desalination, wastewater recycling, groundwater abstraction, and more (Robins, 2019; Shepherd, 2021). The crisis itself spurred rapid dissemination of water literacy information and positive actions despite concerted efforts to circulate false information and conspiracy theories (Robins, 2019). This information, however, was not provided evenly to all communities in Cape Town. Research indicates that townships received inequitable communications about the drought, which contributed to differentiated experiences of the Day Zero water crisis (Enqvist & Ziervogel, 2019; LaVanchy et al., 2021; Savelli et al., 2021).

Fortunately, Cape Town narrowly avoided Day Zero due to volunteer conservation measures, forced rationing, and a very timely start of the 2018 rainy season. However, the threat of future Day Zeros is far from gone. The Western Cape’s climate is becoming hotter and most likely drier, creating large-scale shifts in the region’s climatic systems (Burls et al., 2019; Jack et al., 2016). Climatologists predict that climate shocks like the Day Zero drought are now three times more likely to occur (Otto et al., 2018). The ability for timely and informed reaction to future events, in an equitable and inclusive manners, should be of utmost importance to Cape Town. With this in mind, we looked at the concept of water literacy in the wake of the Day Zero drought. Specifically, we analyzed community water knowledge and attitudes within Langa township, a historically marginalized community with variable levels of water security that was highly impacted by the Day Zero drought (Enqvist & Ziervogel, 2019; LaVanchy et al. 2021). The sociopolitical context of Langa allowed us to broadly explore the influence of sociopolitical factors on water literacy, while the Day Zero drought context allowed us to determine if and how experiences of a climate shock contribute to water literacy.

3.3 Study Area & Methodology

Langa is a predominantly black isiXhosa community, located 10 km east of downtown Cape Town at the intersection of two major motorways (N2 & N7) and surrounded by industrial activity and the Cape Town International Airport. It was built in 1927 as the original model Native Village to control the movement of non-whites and segregate living arrangements for black Africans displaced from the city center. Langa's population has increased rapidly since its construction due to its proximity to the city center (Muthige et al., 2020).

Physical infrastructure in Langa includes several types of housing, each of which affords different levels of access to water. The original development included state-funded construction of hostels for 2,000 men who could supply labor to the city (Coetzer, 2009). Hostel buildings (Figure 3.2a) comprise four bedrooms with two bathrooms, as well as a common kitchen/living space with a single shared indoor water tap. Designed to hold three male migrant workers in each bedroom, these housing units are now more densely packed, often with 12 families instead of 12 individuals. Also included in the original development were 500 single-family homes (Figure 3.2b) for married residents (Coetzer, 2009), which have piped water directly to their yard or inside their home.

Figure 3.2: The four types of housing structures in Langa, as recognized by Langa residents: (a) barrack/hostel; (b) single-family houses; (c) settlers; and (d) informal settlements. Photos by authors.

Additional single-family homes have been added since the original development, although Langa residents distinguish these structures as “settlers” (Figure 3.2c) because they tend to be larger, more private, and home to wealthier individuals or families. Similar to the original single-family homes, settler homes also have piped water directly to their yard or inside their home. Lastly, continuous rural-urban migration to Cape Town and subsequent rapid growth of the township has forced residents to build their own informal settlements, or self-built dwellings (Figure 3.2d). These are typically located on the outskirts of the township and are serviced by an outdoor communal water tap, requiring residents to walk up to 200m (or sometimes more) to access water. Informal settlements are also occasionally constructed in the backyards of single-family or settler homes who choose to rent out their unused land. In this specific scenario, the primary residents may choose to allow the renters access to their on-property water tap.

The most recent available census reports a total population of 52,401 within 17,400 households (CCT, 2013). Of this population, 32% live in informal dwellings, although this is likely an under-representation because of the difficulty in enumerating these dwellings. The census also provides an estimated breakdown of water access within Langa. In 2011, 49.6% of Langa households had taps within their homes, 17.4% had taps in their yards, 32.5% accessed taps outside their yard (mostly via communal taps), and <1% had no access to piped water at all. It is important to note that only those with taps in their homes or yards (i.e. single-family homes and settlers) receive their own water bill. These homes have been targeted by the City for the installation of Water Management Devices (WMDs), purportedly designed to ensure the delivery of FBW to indigent households. Research has shown, however, that WMD installations were commonly installed using manipulation and deceit and were actually used during the Day Zero drought to shut off water to households deemed as “wasting” water, without consideration of household size (Enqvist & Ziervogel, 2019; Mahlanza et al., 2016).

Langa was chosen as the research site for this study because of existing relationships between the authors and key community members, which afforded the research team trust and rapport within the community. Research development began with an exploratory focus group in June 2019 where a dozen Langa residents helped identify main water issues and concerns in the township. A broad 46-question survey was constructed to address water topics raised during the focus group, including water literacy, water security, and impacts from Day Zero. The survey draft was sent to key community members for review to ensure relevancy and clarity of questions. Finally, five local residents were recruited and trained as surveyors to administer the final version of the survey, which aided with translation needs from isiXhosa to English when necessary. Their familiarity with the township was also of benefit in navigating the community both physically and socially. A total of 501 surveys were collected during Fall 2019 using a stratified, randomized sampling method, which helped ensure representation from each of the four housing types. A breakdown of respondents in terms of housing types and demographics is provided in Table 3.1. Importantly, all participants were provided the option of not responding to any of the questions, thus some questions received less than 501 answers.

Table 3.1: Characteristics of Langa Survey Participants.

Category	**Responses (n)**	**Percentage (%)**
Residence type		
Hostel/Barrack	200	40%
Single-dwelling house	151	30%
Settlers house	75	15%
Informal shacks	75	15%
Head of household		
Female	225	45%
Male	240	48%
No answer	36	7%
Length of Langa residency		
0-5 yrs	40	8%
6-10 yrs	125	25%
More than 10 yrs	336	67%
Family size		
1-2	67	13%
3-5	263	52%
6-10	154	31%
>10	9	2%
No answer	8	2%
Source of water		
Household tap	288	57%
Community tap	168	34%
No answer	45	9%

The survey covered a wide array of water and drought-related topics, many of which are tangential to this paper and are addressed in other published work [see LaVanchy et al., 2021]. In this study, we narrowed the analysis of the data to water literacy based on a sub-set of 19 questions from the survey that specifically addressed water-related knowledge, attitudes, and values of participants. For a portion of these questions, we analyzed results based on a few demographic categories, namely length of Langa residency and source of water.

We also combined the results of five attitudinal survey questions into a descriptive index called water conservation sensitivity using the methods outlined by de Vaus (2014). First, a rough answer scale from 0-5 was applied to each of the five questions. Answers indicating higher conservation awareness were given a value of 5, and answers indicating low conservation awareness were given a value of 1. Responses of "no answer" were given a value of 0. These scales were tested for unidimensionality and reliability in SPSS software. All item-total correlations were significant at values above 0.30, indicating that these questions are all measuring the same underlying concept, and the grouping received a Cronbach's alpha coefficient of 0.815, indicating strong reliability of the scales based on item-to-item correlations. We then finalized the new index by adding the five responses for each survey participant together for a final scale ranging from 0-25. A value of 0 results from selecting "no answer" across all five questions; a value of 15 results from selecting "neither agree nor disagree" across all five questions; and a value of 25 results from selecting the answers that were tied to the highest level of water conservation sensitivity. Using this conceptual understanding of the possible values, we divided the scale into five categories of water conservation sensitivity (Table 3.2).

Table 3.2: Categories of water conservation sensitivity in Langa.

Category Name	**Water Conservation Sensitivity Scores**	**Category Frequency**
Very Insensitive*	0 – 7	0
Somewhat Insensitive	8 - 13	0
Neutral Sensitivity	14 – 16	58
Somewhat Sensitive	17 – 22	288
Very Sensitive	23 – 25	148

*Note: The “very insensitive” category of water conservation sensitivity exists across the largest range of values because of the impact of answering one or more questions with “no answer”.

In March 2022, after a COVID-19 pandemic delay, we assembled a focus group of six residents, including two key community members and four of the five original surveyors (the fifth was unavailable) to both validate the survey results and investigate additional questions. The focus group lasted two hours and specific prompts included:

- Do you see value in enhancing water awareness/literacy across Langa?
- Did participating in our survey make you more aware of your daily water use, of water-related news, etc.?
- The survey results indicated that respondents feel misunderstood by water managers. What do you think they don’t understand? What would help them understand?
- The survey results indicated dissatisfaction with current water management. What do you think is causing this dissatisfaction? What would you like to see changed or improved?

Researchers took notes during the focus group, paying attention to extensiveness and intensity of conversation topics, any specific responses deemed important by participants, and group dynamics and level of agreement. These notes were then collated and analyzed using both a constant comparative method to identify patterns and relationships among data, as well as a critical incident method that highlighted how Day Zero shaped participant actions or perceptions (Krueger & Casey, 2015).

3.4 Results & Discussion

In an effort to structure the results and discussion, we assigned relevant survey questions and emergent themes from the focus group to a knowledge set category based on McCarroll and Hamann's (2020) water literacy framework. It is important to note that not all knowledge sets were well represented within our data. For example, we did not cover functional knowledge or behaviors in a quantity worth analyzing. Additionally, while no survey questions focused solely on the science and systems water knowledge as described by McCarroll and Hamann (2020), a few of the local water knowledge questions could be considered tangentially science-related, as they inquired about climate and the water cycle. Thus, we grouped together these two knowledge categories for our discussion. This resulted in the following three sub-sections of water literacy in Langa: (1) local water and science knowledge, (2) hydrosocial knowledge and (3) water conservation attitudes and values. The following section discusses the results of each of these categories and their relationships to the socio-political context of Langa and the lived experiences of Day Zero.

3.4.1 Local & Science Knowledge

Local water knowledge encompasses an understanding of one's local water sources, managing entities, and various local water uses (McCarroll & Hamann, 2020). Six survey questions related specifically to local water knowledge, with the first three tangentially covering scientific topics such as climate and the water cycle (Figure 3.3).

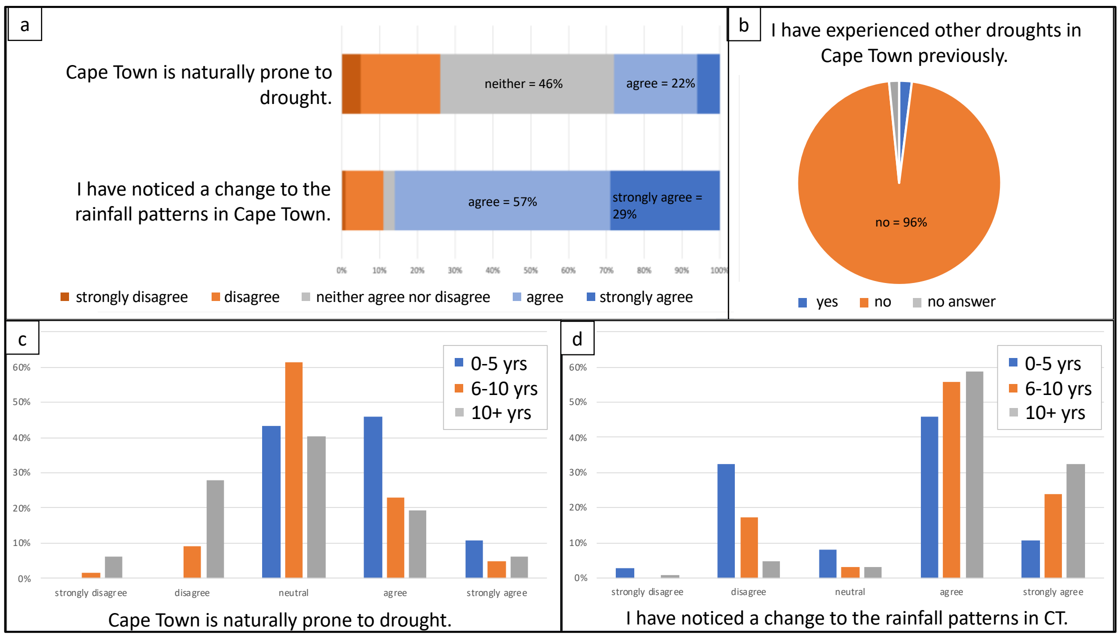

Figure 3.3: Survey results from (a) two Likert scale climate-related local knowledge questions, (b) Yes/no question about droughts previous to Day Zero, and (c) & (d) breakdown of (a) by length of Langa residency.

Participant responses to questions about local climate and climate change suggest important differences between held knowledge of rainfall patterns versus drought. Our results show that 85% of respondents (*n*=421) either agreed or strongly agreed that they have personally noticed a change to the rainfall patterns in Cape Town (Figure 3.3a). Scholarship shows that water literacy is often built through lived experiences (Booysen et al., Dean et al., 2016; Gilbertson et al., 2011; Harnish et al., 2017; McDuff et al., 2008), and rainfall is a phenomenon that can be physically experienced. Indeed, anecdotal evidence from our exploratory focus group in June 2019 revealed a common aversion to rainfall in the Cape Flats, attributed to flooding from naturally poor drainage and a high groundwater table. Dry spells are thus a notable reprieve from muddy conditions and standing water, particularly for those living in informal shacks. Additionally, we found that respondents who have noticed a change in rainfall were more likely to have longer residencies in the township (Figure 3.3d). In this sense, a greater amount of experience contributes to awareness of changing climates.

In contrast, participants demonstrated a lack of consensus regarding Cape Town's natural susceptibility to drought (Figure 3.3a). Nearly half replied neutrally when asked if Cape Town is naturally prone to drought (*n*=224 or 45%), while the rest were split in either direction. However, there are many types of droughts and not all of them are felt at a residential level. Meteorological and hydrological droughts, for example, occur with below-normal rainfall and reduced water resources respectively, while a socio-economic drought occurs when the water supplies are too limited to meet societal demands (Haile et al., 2020). Recurring droughts within Cape Town's climate trend towards the former types (Botai et al., 2017). Additionally, township residents generate among the lowest water demand within the urban environment due to the reality of sharing a collecting water from community taps (OECD, 2021). Thus, during an average summer, township residents would not experience socio-economic impacts to water access from typical recurring droughts. This theory is supported by a subsequent question that asked about drought experiences before Day Zero, in which only 2% of participants indicated experience with previous droughts in Cape Town, while 96% of participants did not (Figure 3.3b).

The conclusion then is that lived experiences of township residents contribute to environmental awareness, but awareness of the concept of drought is low because such knowledge cannot be easily gleaned solely through township experiences. Indeed, survey respondents who answered that Cape Town is *not* naturally prone to drought were exclusively residents with six plus years in Langa (Figure 3.3c). Transfer of knowledge about drought would need to be provided through more structured systems, like schooling or informational campaigns from the local water managers, and our results suggest this is not occurring. Indeed, research documents a historical lack of municipal communication with townships in Cape Town (Smith & Hanson, 2003). Even during the Day Zero crisis, the official conservation campaign largely overlooked townships because of their low water demand (Savelli et al., 2021).

Our survey reveals a similar lack of knowledge regarding local water sourcing, management, and policies, which again is knowledge that would likely come from more structured sources (Table 3.3). Most participants either could not name the water source that supplied their tap (n=110 or 22%) or said they could but declined to do so (n=312 or 62%). Those that did provide an answer overwhelmingly provided the wrong answer, claiming the source of their tap water was groundwater (n=75 or 15%). Only two participants correctly identified dams as the supply for their tap water. Such results are common within water literacy research, indicating that most people do not know the source of their water, even if they think they do (McCarroll & Hamann, 2020). A survey from twelve states in the western USA found that only 56% of respondents said they knew the source of their water (although they were not asked to specify the source) (Water Foundation, 2017). A second and even broader study across the whole USA in 2011 found that only 25% of respondents could correctly identify their water source, while another 25% provided an incorrect answer (Tobin, 2017). Although Langa's context is vastly different, residents demonstrate a similar tendency of lacking water source knowledge.

Table 3.3 Survey findings about local water sourcing, water management and water policies. Correct answers to questions are bolded.

	Yes *n* (%)	No *n* (%)	Unsure/No Answer *n* (%)
Do you know the water source for your tap? (e.g., dam, groundwater, desalinated water, etc.) If yes, please specify:	389 (78%)	110 (22%)	2 (<1%)
dam	*2*		
groundwater	*75*		
no source specified	*312*		
Do you know who manages water in Cape Town? If yes, who?	426 (85%)	74 (15%)	1 (<1%)
CoCT, Water & Sanitation Dept	*196*		
no entity specified	*231*		
Does the CoCT guarantee water to all citizens? If yes, how much per day?	134 (27%)	28 (5%)	339 (68%)
25 L/ppd, 50 L/ppd or 200 L/d (household)*	*38*		
wrong quantity specified	*73*		
no quantity specified	*23*		

*All answers equal to quantities from the original FBW policy or its subsequent revisions were considered correct. This included answers of 25-L ppd, 200-L per household per day, or 50-L ppd.

Answers regarding water sourcing also revealed a popular misconception about groundwater—that all water arriving from an underground pipe must be filled with groundwater. Groundwater is frequently misunderstood across other water literacy research, which demonstrates either unawareness of the concept (Gunckel et al., 2012; Pritchett et al., 2009) or misconceptions of groundwater as underground lakes or rivers, rather than subsurface water that fills fractures and pore spaces in rock and soil medium

(Arthurs, 2019; Gunckel et al., 2012; Unterburner et al., 2016). In this sense, Langa residents again demonstrate common water literacy trends regarding groundwater. This was further emphasized during our focus group when we shared this survey result with participants and were asked by focus group participants to describe the difference between groundwater and surface water to them. Interestingly, there are significant groundwater aquifers present in the Cape Town region, particularly beneath the Cape Flats, but these are currently largely untapped for water supply. Given the future role of groundwater in securing water for Cape Town (Foster et al., 2018; LaVanchy et al., 2019; Olivier & Xu, 2018), community unawareness of the aquifers beneath Langa seems problematic to the larger issue of water literacy.

Regarding local water management, survey respondents were largely unable to provide the name of the managing entity. Although 85% (*n*=426) of participants indicated they knew who was responsible for managing local water resources, only 39% (*n*=196) correctly identified the City's Water & Sanitation Department. Additionally, while no one named an incorrect managing entity, 15% (*n*=75) of participants said they did not know who managed the City's water or declined to answer entirely. These results suggest that most survey respondents are unable to name the local water managers, which is not uncommon among water literacy research. For example, only 40% of survey participants in San Diego, California (USA) could correctly name their local water agency (TNR, 2019), and only 7% of survey participants in Alberta, Canada could correctly name their Watershed Planning & Advisory Council (AWC, 2015). In Langa, this result could be a continuation of the weak public water communications noted back in 2003 (Smith &

Hanson), particularly for residents who do not have a household tap and thus do not get a water bill.

However, focus group data regarding water communications indicates a secondary problem. Three participants, all from single-family homes, shared openly about their experiences with water debt, which ranged from 15,000-50,000 ZAR. One participant in particular recounted an excessive water charge that resulted in a water shut-off and a summons to court. The conflict was not resolved for several months, delayed both by the difficulty in paying off the full debt and by the inconsistent, unhelpful, and contradictory communications she received from the water department. During that time, she was forced to collect water from a communal tap. She described her interactions with the water department as traumatizing:

> "You can't get help when you have debt. You walk in, and they immediately ask for your name and look up your account. As soon as they see the debt, they say, 'You have to pay this much by this date', but by then you are already gone. They scare you away so you can't actually get help" (Participant 1, female, single-family home).

The story of this focus group participant confirms weak communications with the Water & Sanitation Department and an inflexible approach towards debt management that has been noted in past research (Smith & Hanson, 2003; Mahlanza et al., 2016). It also reveals the municipality wields fear as a way to discourage public interactions. Such frustrating encounters were corroborated by the other two participants with water debt, suggesting that local water managers infuse interactions with intimidation as a tactic towards cost recovery. The resulting perception is that it is not just difficult but also pointless to contact the water department for help. Thus, Langa residents avoid these interactions unless absolutely necessary, thereby shutting down potential opportunities to gain water literacy. In this way, our findings attribute low local knowledge to weak communication strategies and an uncooperative attitude that dissuades Langa residents from seeking information on their own.

Our last finding of local water knowledge relates to South Africa's unique and progressive FBW policy. Participants were asked if the city guaranteed water to its residents. Those who replied yes were subsequently asked to identify the quantity of water guaranteed. The majority of participants (*n*=339 or 68%) were either unsure or declined to answer. Only 27% of participants (*n*=134) indicated they were aware of such a guarantee for basic water, and only 28% (*n*=38) of that group were able to correctly specify the quantity legally guaranteed. These results indicate widespread unawareness of the FBW policy, let alone its specific details. This constitutional right to water is incredibly rare at the global scale and was designed specifically for restitution within South Africa's townships. One of the ways by which a township resident would learn about FBW is through the installation of WMDs. The City of Cape Town requires that contractors inform residents about the devices and their purpose, which entails provision of FBW, before installation can occur (CCT, 2016b). WMDs were widely installed in Langa, both before and during the Day Zero drought, yet our results of low knowledge regarding FBW suggests that installation procedures involved poor or incomplete communication strategies. This conclusion is consistent with prior research regarding

WMDs (Mahlanza et al., 2019), and again indicates a structural barrier that is limiting community water literacy.

An inherent challenge in interpreting our local knowledge data was characterizing the large number of respondents who were unable or unwilling to specify an answer even after indicating they could do just that (Table 3.3). Such results could be a residual of the surveyors not pressing for a more specific answer. More likely, the lack of specificity is a product of the participants themselves. It could be that participants wanted to appear more knowledgeable than they were to avoid embarrassment or to make themselves look better. Research demonstrates that such occurrences are, in fact, common among survey research (Johnson et al., 2011). It is also likely there were cultural influences guiding how participants responded to certain questions. Even though the surveyors were themselves residents of Langa, all participants were notified that the survey was being conducted for researchers from the USA during the informed consent process. Cultural characteristics such as sociability, benevolence, and cooperation tend to inspire impression management and putting forth “a good face to the outside world” (Harzing, 2006; Johnson et al., 2011, p. 136).

3.4.2 Hydrosocial Knowledge

The next water literacy knowledge set we investigated is hydrosocial knowledge, which encompasses an understanding that water resources simultaneously influence and are influenced by human affairs and societal growth (Linton, 2008; McCarroll & Hamann 2020). Within our survey, we focused hydrosocial knowledge around the relationship between Cape Town’s diverse human water demands and the available quantity of local water resources (Figure 3.4). Roughly one third of respondents (*n*=180 or 37%) agreed there is enough water to meet current needs of all people and businesses in the Western Cape). However, when we posed a similar statement regarding available water to meet the *future* needs of all people and businesses for the next 30 years, most respondents disagreed (*n*=192 or 39%). We believe this demonstrates an understanding that the current status quo for water management will be insufficient in the future. Additionally, it shows awareness of current and increasing competition for limited water resources in the Cape Town region. Clarification during the focus group attributes this insufficiency to both changing climates and increasing fluxes of migrants moving into Langa. When combined, these data indicated a broad awareness of both increasing water demands and less predictable water supplies.

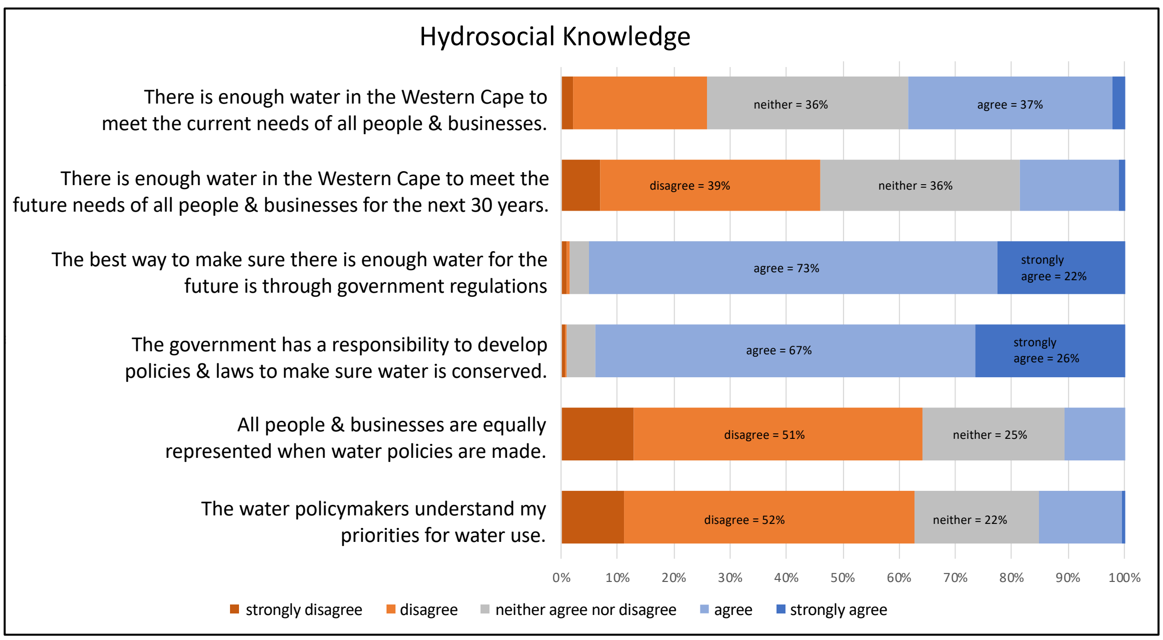

Figure 3.4: Survey results from hydrosocial knowledge questions. Modal responses for each question are indicated with percentage labels.

Hydrosocial knowledge also relates to the equitable distribution of water resources between competing needs of people, businesses, and the environment (Hawke, 2012; Linton & Budds, 2014). Thus, we asked survey participants about government regulations, responsibility, and equity (Figure 5). Past research suggests that South Africans often misunderstand the role of water managers or government regulations with water resources (Sershen et al., 2016; Smith & Hanson, 2003; Ziervogel et al., 2010). However, our findings offer a slightly more nuanced picture. For example, 95% (*n*=470) of survey participants agree or strongly agree that government regulations are the best way to meet future water demands. Another 93% (*n*=462) agreed that such regulations are the government's responsibility. Although most survey participants could not (or would not) name the exact city department responsible for water management, they did still seem to recognize the importance of water policies and laws. These findings suggest broad understanding of the role of government in water management, more so than past research. We attribute this apparent increase in community knowledge about water management to the timing of our survey after the Day Zero drought, suggesting that the lived experience of Day Zero contributed to hydrosocial knowledge.

Our final dimension of the hydrosocial category related to representation within water management. As noted earlier, Langa is a township primarily populated by isiXhosa people. The City of Cape Town, however, is the most ethnically and culturally diverse city in South Africa due to its history with trading, slavery, and migration. Cultural diversity brings a variety of different ways of understanding, using, and relating to water, although modern water management systems are not often set up to recognize this reality

(Hawke, 2012). The majority of our survey participants disagreed (*n*=252 or 51%) that all people and businesses are equally represented within water policies. At a more personal level, most survey participants also disagreed (*n*=253 or 52%) that water policymakers understand their own priorities for water use. These results mirror past findings from Sershen et al. (2016) that South Africans feel misunderstood and misrepresented by water managers. A follow-up discussion during the focus group confirmed this lack of representation:

> "The people who make decisions don't live in Langa, and they make decisions before they even come to visit. There are 'attempts'… to hold a space for the community to share thoughts and concerns, but they don't really answer questions… and if anyone expresses anger or difficult emotions, they are told they aren't making sense" (Participant 4, male, hostel).

This quote highlights a sense of being ignored or written off, which was echoed emphatically by all six focus group participants. There was a strong sense of futility among Langa residents regarding water management because "opportunities" for engagement feel insincere or disingenuous. Indeed, such themes about "community engagement" have been documented elsewhere in Cape Town (Mahlanza et al., 2016). Collectively, our findings confirm a hydrosocial knowledge among Langa residents that is not shared or respected by local water managers. In this way, we see a continuation of disjointed water management practices that exclude communities like Langa, subsequently limiting opportunities to increase water literacy.

3.4.3 Water Attitudes & Values

The final knowledge set of water literacy we investigated were water attitudes and values, as these often have a great impact on engagement and behaviors (McCarroll & Hamann, 2020). Because we focused on the Day Zero climate shock, we narrowed our specific attitudes and values questions to the topic of water conservation. Our findings highlight an overwhelming appreciation of water conservation among Langa residents (Figure 5). For example, 97% (*n*=486) of participants either agreed or strongly agreed with the statement "water conservation is important." Another 97% (*n*=480) of respondents agreed or strongly agreed that "more attention to water conservation is needed." Responses also revealed a clear connection between personal actions and drought management, with 90% (*n*=453) of respondents disagreeing or strongly disagreeing that water shortage issues do not affect them and 79% (*n*=394) of respondents disagreeing or strongly disagreeing that water conservation is not their responsibility. The conclusion is that water conservation is a topic of great and personal importance for Langa residents. Finally, we posed the statement "it is important to meter water so that we know how much water we are using", with which 64% (*n*=314) of participants either agreed or strongly agreed.

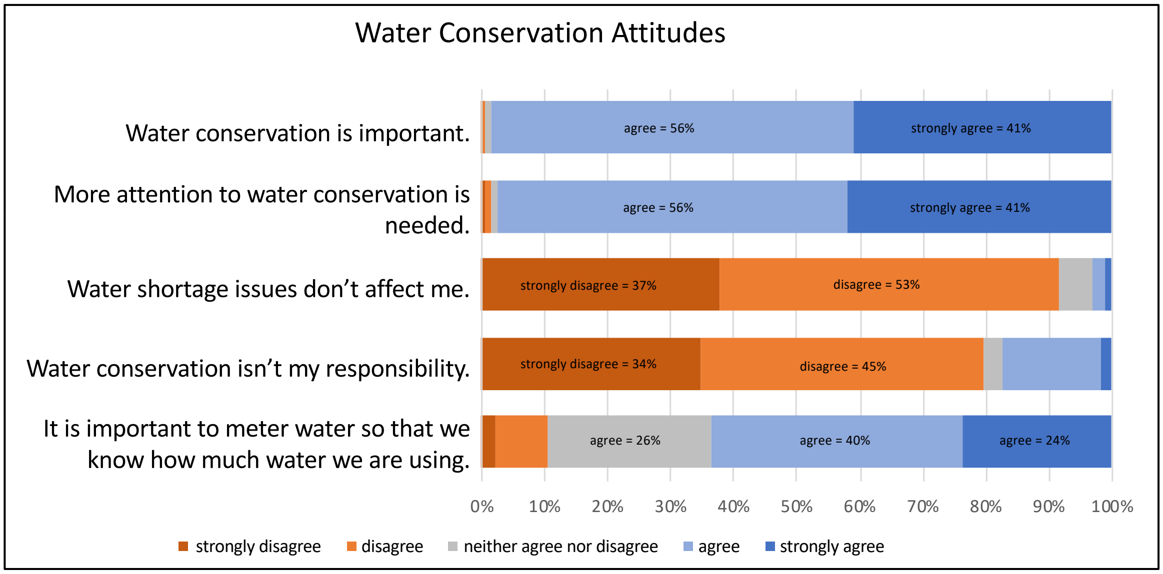

Figure 3.5: Survey results from water attitude and value questions. Modal responses for each question are indicated with percentage labels.

Responses from the five attitudinal Likert questions in Figure 5 were then combined to generate a Likert Scale for water conservation sensitivity, using the process described in the methodology section. A classification scale of water conservation sensitivity (very insensitive, somewhat insensitive, neutral sensitivity, somewhat sensitive, and very sensitive) levels was identified, and survey respondents were classified accordingly. Our results of this process found a positive skew towards higher water sensitivities among participants. That is, no survey participants were classified as insensitive, which indicates high levels of water conservation awareness within Langa. This finding is likely a reflection of the reality of water access in Langa. Those who walk to collect water from a community tap will naturally conserve how much they use due to the physical burden of collecting water from a community tap. Anecdotal evidence from the June 2019 exploratory focus group confirmed this when discussing Day Zero restrictions and how residents of the informal settlements have never used more than 50L ppd.

However, those who have household taps also receive communication from the City's Water and Sanitation Department and pay water bills, which also may also increase conservation sensitivity. Indeed, conservation is often a useful strategy for making water bills more affordable (Lu et al., 2019). Evidence for this argument can be found in Table 4, which offers a breakdown of the water conservation sensitivity variable between household and community taps. While 87% (*n*=142) of participants using community taps fall under either the somewhat sensitive or very sensitive category, the sum of the same categories for household tap users totaled 93% (*n*=266).

Table 3.4: Grouping water conservation sensitivities of survey respondents by type of water tap.

Type of Tap	**neutral sensitivity**	**somewhat sensitive**	**very sensitive**	**Total**
Community Tap	21 (13%)	119 (73%)	23 (14%)	163
Household Tap	21 (7%)	149 (52%)	117 (41%)	287
No Answer	16 (36%)	8 (45%)	8 (18%)	44
Total	58	288	148	494

We also suggest that the high levels of water conservation sensitivity are tied to the timing of the survey after the Day Zero drought. While we did not conduct a survey before the Day Zero drought to concretely confirm this, we did ask survey participants to gauge for themselves how much they thought about water conservation both before and after the Day Zero drought. The results show a clear shift in thinking (Figure 7).

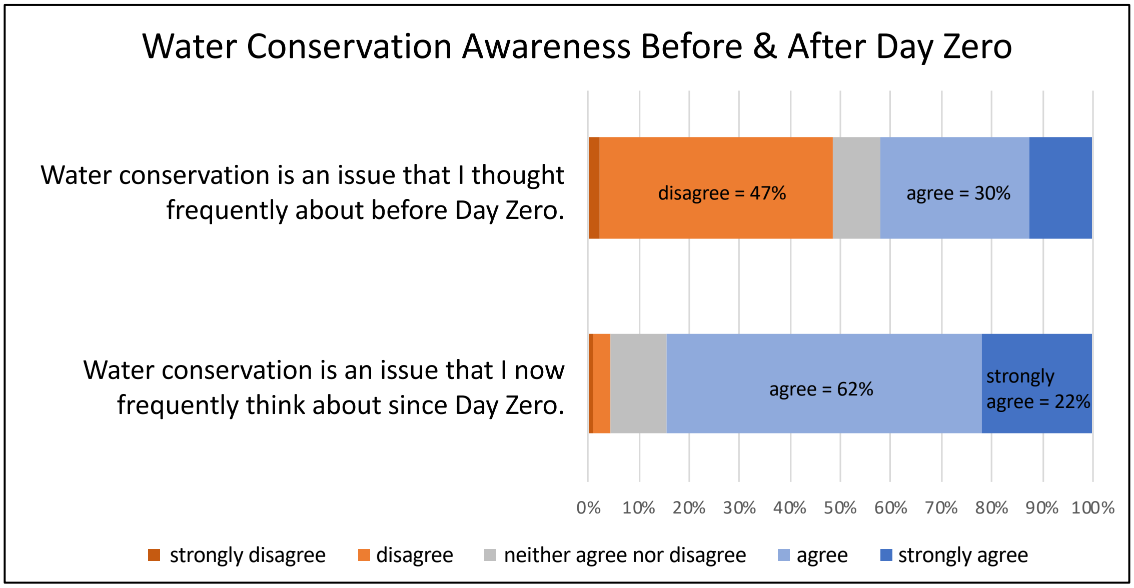

Figure 3.6: Survey results of water conservation awareness before and after the Day Zero climate shock. Modal responses for each question are indicated with percentage labels.

Whereas only 43% of respondents (*n*=208) agreed or strongly agreed that they thought about water conservation frequently before the drought, this number doubled to 84% (*n*=415) after the drought. Thus, while a decent percentage of respondents claim to have thought about water conservation before the Day Zero drought, they also clearly connected the lived experience of the drought with an increased awareness of water conservation. Discussions from the focus group also confirmed increases in water conservation awareness and sensitivity. The four surveyors in attendance at the focus group discussed how they were mostly met with curiosity and interest when they were distributing the surveys across the community:

> The surveyors said the initial reactions to the survey was curiosity, followed by a "oh yeah, let's do it!" when they found out the purpose and contents of the survey (Field notes of researcher #1).

The surveyors in the focus group also elaborated about differences in reactions between housing types, with those in single-family homes initially displaying suspicion but being swayed by their high levels of investment in the survey content:

> "They want to read it over before participating… But these are the people who felt Day Zero most, because they are the ones with individual taps and water bills" (FG Participant).

The strong interest in the survey content supports the survey findings about high water conservation sensitivity, particularly for those with individual taps. The connection drawn between water conservation sensitivity and Day Zero also corroborates other research that experiences of drought and water restrictions can contribute to community water literacy (Booysen et al., 2019; Gilbertson et al., 2011).

However, our final attitudinal finding reveals political barriers that could limit the influence of drought on community water literacy. Namely, we identified widespread dissatisfaction and distrust regarding Cape Town's water management. The majority of survey participants (*n*=245 or 49%) indicated they were dissatisfied with the current system of water management. Focus group participants elaborated substantially on this attitude with a lengthy discussion of falsified water usage data and perceived corruption within the water system.

> "They are making up the numbers, they are just guessing" (Participant 3, female, single-family home).

> The group connected political power with water problems, suggesting that water insecurity was artificially produced by shutting off taps or reducing flow rates. They

indicated that these were mechanisms to gain power over the people and get payment for the non-revenue water used by the informal settlements (Field notes of researcher #1).

Here we see strong feelings of distrust in local water managers. The quote emphasizes a lack of local water knowledge regarding water usage and account information, and highlights community suspicion of water meters and water managers. While Langa residents indicated that metering water use is important, they simultaneously do not trust the water metering system and therefore automatically believe the volumes reported on water bills as inaccurate. This is an inevitable result of the water department's long track record of inaccurate assessments of arrears and water debt (Smith & Hanson, 2003), as well as the participants' experiences trying and failing to get water information regarding their accounts. Additionally, the field note reveals perceptions that water resources and water information are wielded as tools to control and gain political power. Indeed, the other political ecology studies of Cape Town's water system demonstrate that such tools were used during apartheid for exactly that reason (Bourblanc & Blanchon, 2019; Loftus, 2009; Smith, 2001; Smith & Hanson, 2003). As a complement, case studies in Asia demonstrate that construction of ignorance by the State has been used to control the trajectory of development interventions (Zeng et al., 2017). Thus, there is good reason for Langa residents to be suspicious of Cape Town's water system, and local water managers are not doing a good job dispelling that suspicion.

Unfortunately, the widespread dissatisfaction and distrust in Cape Town's water system may limit Langa's ability to increase their water literacy. Even if local water managers improved their communication strategies, eliminated intimidation tactics and increased access to water information for all consumers, Langa residents may find little credence or reason to trust them. Our results give voice to their feelings of futility and neglect that are reminiscent of the era of apartheid, when decisions about the well-being of non-white South Africans were made for them by the white minority party. In this sense, real and perceived power distributions surrounding Cape Town's water management have a direct influence on Langa's current and future water literacy.

3.5 Conclusion

Our research provides a detailed case study of the complexities of water literacy within the sociopolitical context of Langa following the Day Zero water crisis. Our results highlight mixed levels of water-related knowledges, attitudes, and behaviors within Langa, many of which continue to fuel local water insecurity. Similar to other scholarship in the field of water literacy, we found that the water-related knowledges and attitudes of the Langa community specifically relate to *their* lived experiences. Survey respondents demonstrated high levels of awareness of shifting rainfall patterns because they experienced a decrease in rainfall as a decrease in flooding. Additionally, we found high levels of water conservation sensitivity, which participants related to the lived reality of daily collecting water from communal taps. We also found evidence that the experience of the Day Zero climate shock did contribute to certain aspects of water literacy within Langa. Residents themselves report a notable increase in water conservation awareness following the Day Zero drought. Finally, we found greater levels of hydrosocial knowledge in Langa than were suggested by pre-Day Zero studies.

Our research also highlighted several key gaps of water literacy within Langa. Participants demonstrated low comprehension of the concept of drought, as well as local knowledge regarding water sources, the managing entity, and FBW. The exposed gaps in water knowledge relate to topics that could not reasonably be gleaned from experiences alone. Rather, we expose through the lens of political ecology that gaps in Langa's community water literacy are fueled by social and political influences, which prevent a complete understanding of local water resource management. The City's historically weak communication strategies remain prevalent today and result in a poor flow of water information to water users in Langa. Additionally, corporatization of water and a rigid approach to cost recovery results in the use of fear and intimidation to settle massive debts, which subsequently dissuades Langa residents from seeking water information that could improve their water literacy. Finally, we argue that ineffective or incomplete communication during WMD installations hinders transfer of knowledge regarding FBW. Thus, while the experience of the Day Zero climate shock did contribute to certain aspects of water literacy in Langa, further increases in water literacy may be socially and politically constrained. In order to increase the flow of water information from the water department to communities like Langa, the structures of intimidation need to be broken down. Transparency surrounding local water management is needed to build community trust, and community members need to experience genuine opportunities for engagement. In this way, Langa residents can begin to advocate for themselves, rather than being trapped by the futility of the current system. The aftermath of the Day Zero climate shock makes it clear that the City of Cape Town needs to invest more in community education and water awareness, especially during periods of drought.

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Chapter Four: A Political Ecology of Tourism Resilience to Climate Shocks

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2	Thomas LaVanchy	Conceptualization, data collection, supervision, critical review and feedback, editing,	20%
3	Michael Kerwin	Methodology, data collection, critical review and feedback	5%

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i. The candidate's stated contribution to the publication is accurate (as detailed above);
ii. Permission is granted for the candidate to include the publication in the thesis; and
iii. The sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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4.0 Abstract

The unsustainable water demands of tourism threaten the sector's economic viability during instances of climate shock. An example can be found in Cape Town, South Africa, where the threat of Day Zero caused substantial losses in tourist numbers, revenues, and job securities. But the Cape Town tourism industry also contributed to unprecedented water conservation across the city. This paper analyzes the use of internal demand management strategies of six Cape Town hotels during the Day Zero drought to mitigate economic impacts, ease political tensions, and uphold their reputations. Our results suggest that during a severe water crisis, tourism can model and enforce demand management water conservation efforts while maintaining customer satisfaction or, in some cases, growing visitor loyalty through innovative sustainability leadership.

4.1 Introduction

Tourism is a key driver of global economic growth and job creation around the world (Ladkin et al. 2023). This is particularly true within Africa, where tourism receipts contribute significantly to local GDP and are expected to reach $260 billion across the continent by 2030 (Signé, 2022). South Africa in particular dominates the continental tourism industry, consistently ranking among the top of tourism indicators like numbers of visitors and highest levels of tourism revenue annually (Signé, 2022; UNWTO, 2023). Despite apparent positive outcomes of employment opportunities and economic benefit, tourism has also come under scrutiny in recent decades for its negative contribution to global environmental change. Research identifies the tourism industry as a major contributor of global carbon emissions and a driver of increasing resource consumption (Bekun et al., 2022; Lasisi et al., 2021; LaVanchy, 2017; Rico-Amoros et al., 2009). The association between tourism and unsustainable water consumption is particularly concerning since tourists consume significant amounts of freshwater water directly (i.e., drinking, washing, flushing toilets, etc.) and often in higher amounts than what they would otherwise consume at home due to an escapist mind-set (Becken, 2014; Lehmann, 2009). Tourists also consume water indirectly through demand for daily room cleaning and laundry, irrigated parks, gardens, and golf courses, and local food and electricity production, all of which draw from municipal water supplies (Becken, 2014; Dolnicar, 2022; Gössling et al., 2012; Warnken, et al., 2004). In destinations that offer recreational tourism like rafting, kayaking, and fishing, environmental water flows are also necessary to maintain the health of watersheds and the ecosystems they support (Gössling & Hall, 2006). Given this disproportional water footprint, the ability to secure the economic benefits of a stable tourism industry depends upon the reliability of sufficient water resources.

Despite the established relationship between water and tourism, the amount of water considered “sufficient” for tourism can be misunderstood and is often unknown. Scholars have attempted to quantify this amount by estimating tourism water footprints at various scales (e.g., locally, nationally, and regionally). Barberán et al. (2013) utilized a water footprint to evaluate water saving measures at the hotel scale in Zaragoza, Spain, whereas Zhang et al. (2017) constructed a comprehensive model of the water tourism footprint for the world heritage site of Mount Huangshan in China. Charara and others (2011) provided a comprehensive analysis of water use by the Barbados hotel industry, Cazcarro et al. (2013) looked broadly at Spain, and Hadjikakou et al. (2013) focused on the Eastern Mediterranean. The most comprehensive analyses of tourism water footprints were completed by Gössling et al. (2012) and Becken (2014), expanding to the global scale. Collectively, these studies found that tourism water consumption is large enough to strain local municipal water systems, often at the expense of non-tourists. It is also worth noting that indirect water consumption can be difficult to estimate; thus, most analyses tend to focus on direct water consumption and subsequently underestimate the true water footprints of tourism. This is particularly problematic within drought-prone destinations where tourism expected landscaping and pool amenities dramatically increase water demand (LaVanchy & Taylor, 2015).

Growing economic, social, and environmental concerns with overconsumption have forced the tourist industry to improve their water use practices. Supply management and alternative water sourcing are frequent topics of investigation (see Armstrong & Butler, 1996; Baños et al., 2019; Gössling et al., 2012; Lamei et al., 2007). Demand management strategies that target the water-related knowledge, attitudes, and behaviors of tourists, otherwise known as water literacy (McCarroll & Hamann, 2020) are less commonly studied, despite evidence suggesting such tourist water conservation campaigns are important (Baños et al., 2019; Vila et al., 2018). To achieve necessary water savings during severe droughts, it is essential to implement cutting-edge demand management schemes to complement better known supply management changes. This paper aims to further understand the tourism-water nexus and guide future water management options by uniquely applying political ecology to tourism demand management in the context of a climate shock in Cape Town, South Africa.

4.2 Political ecology of tourism water use

Political ecology is an established research framework for analyzing complex socio-nature relationships within the context of environmental conflicts (Blaikie, 1999; Robbins, 2012). It emerged from increasing recognition that management of natural resources is fundamentally a political act, influenced by economic and cultural powers (Cole, 2012; Islar & Boda, 2014; LaVanchy et al., 2017; Stonich, 1998). From this point of view, resolution of environmental issues must begin with a firm understanding of the inner workings of these power structures and how they influence the accessibility and consumption of natural resources.

Specific to water and tourism, a political ecology approach can illuminate how political, economic, and cultural factors influence water access and water equity within tourism hotspots. The framework was first introduced within tourism water management studies when Stonich (1998) demonstrated that tourism-related contamination of water resources was disproportionately affecting local communities in the Bay Islands of Honduras. Since then, political ecology has primarily been used to highlight how tourism development threatens the water security of non-tourists. For example, rapid tourism growth enabled by support from local governments reduced water availability for local and often impoverished communities in Zanzibar (Gössling, 2001), Bali (Cole, 2012), and Nicaragua (LaVanchy, 2017). Tourism-related commodification of water resources has also been tied to water costs increasing beyond the affordability of local communities in Indonesia (Cole, 2017). Such research clearly documents how the tourism industry drives or exacerbates water insecurities, especially in contexts of developing countries where complex power dynamics are at play.

Despite this rich literature, political ecology is commonly criticized for dissecting power structures without offering much in the way of a solution or pathway forward (Blaikie, 2008; Braun, 2015; Walker, 2006). In other words, political ecology is often "long on critique but short on concrete, actionable recommendations" (Ingalls & Stedman, 2016, p. 6). While understanding the root causes of an environmental conflict are essential to resolution, that alone will not generate policies or actions to effect change. Scholars are thus pushing for more reflective, affirmative, and creative applications of political ecology (Braun, 2015). Ingalls and Stedman (2016) suggested shifting the directionality of political ecology to look backwards and ask what resilience tells us about political ecology.

Further, political ecology has yet to be applied to the actions and behaviors of tourists themselves, although evidence suggests tourists have low levels of awareness of the water issues afflicting their destinations (Cole, 2012; Hadjikakou et al., 2013; Miller et al., 2010). And while there have been numerous campaigns from around the world targeting the demand management of tourists, the success of these campaigns is not entirely clear. Cole (2012), for example, suggested that making tourists aware of local water issues can generate a willingness to conserve, however, Gabarda-Mallorquí et al. (2018) demonstrated that awareness alone is not always enough to create environmental proactivity. Indeed, the issue of influencing tourist behavior is particularly complex given the hedonistic nature of tourism (Dolnicar et al., 2016). Notwithstanding these challenges, tourists remain actors at the crux of the water issue, creating demand and driving growth of the tourism industry.

Ideologically, our research expands political ecology scholarship in two ways. First, it uniquely focuses on tourist demand management. We seek to understand the political, economic, and social factors that influence the effectiveness of water conservation campaigns that specifically target tourist behaviors and awareness. Second, it takes to heart the issue of looking backwards to inform future action. The overriding goal is to increase the utilitarianism of political ecology by reflecting on a specific instance of resilience to a climate shock event. We focus on Cape Town (South Africa) where the tourism industry helped the city survive the Day Zero drought using a suite of water conservation techniques, including the notable "Use Like a Local" campaign and other water conservation measures specifically targeting tourist behaviors. By analyzing how the political, economic, and cultural factors impacted the effectiveness of tourist water literacy, we can better evaluate how investments in educating visitors can become a pathway towards managing climate shocks.

4.3 Cape Town tourism and Day Zero

As one of the country's largest economic sectors, tourism is a key driver of economic growth in South Africa. Indeed, estimates of the tourism sector in 2019 value total contributions to South Africa's GDP at R425 billion, or 8.6% of the total economy, as well as providing roughly 1.5 million jobs, or 9.2% of the total employment in the country (SAT, 2019). Tourism is also an important industry within the country's transformation agenda, viewed as a means of moving away from the era of apartheid and driving welfare improvements (Booyens & Rogerson, 2016; Maumbe & van Wyk, 2008). Yet, research demonstrates that tourism is generally concentrated in time and space (Gössling et al., 2012), and South Africa's tourism trends are no exception. Cape Town, as one of the eight large metropolitan areas in the country, is widely recognized as a major tourism hotspot.

Cape Town, located in the Western Cape Province at the southwestern-most point of Africa, enjoys a comfortable Mediterranean climate with moderate temperatures year-round, rainy winters, and dry summers. It is home to both Table Mountain, one of the seven natural wonders of the world (New 7 Wonder, 2021), as well as the Cape Floristic Region, one of the world's most biodiverse ecosystems (Goodness & Anderson, 2013).

These iconic attractions and an array of amenities help the city attract long-haul international and leisure tourists and contribute to its ranking as the single most significant destination for tourism in all of South Africa (Rogerson & Rogerson, 2021). As such, Cape Town's tourism industry holds great economic importance both locally and nationally.

There is little research available about the water use of tourism within either the context of Cape Town or South Africa more broadly. Only one study by Gössling et al. (2012) attempts an estimation of the direct water consumption of South African tourists based on number of tourist arrivals, average length of stays, and average water use per tourist per day. Their findings suggest that the direct water use of tourism amounts to a mere 4.04% of total municipal supplies countrywide. However, they acknowledge that the actual water footprint of tourism is likely to be much larger should one also account for indirect water uses in tourism. Additionally, the estimations formed by Gössling et al. (2012) are based on aggregations of national data, which tend to obscure regional variations. Knowing that Cape Town is a tourism hotspot, it can safely be concluded that the water demand of tourism on Cape Town's local municipal supply is considerably larger than 4.04%.

While the Mediterranean climate attracts many tourists who are looking for warm and dry summer conditions, it also means the City frequently deals with recurring drought, or temporary dry spells that are a normal part of the climatic cycle (Maliva & Missimer, 2012). Occasionally, Cape Town's recurring droughts are worsened by regional shifts in climatic patterns that exacerbate the dry spell's magnitude or duration well beyond the scope of predictability. These unusual droughts are known as climate shocks because of the risk they pose to social systems (Clingingsmith & Williamson, 2008; Wagner & Weitzmann, 2015). Recently, though, the Western Cape has been witnessing an increase in climate shocks, largely in the form of increasing dry spells, which climatologists largely attribute to warming air and sea surface temperatures and the subsequent shift of normal precipitation patterns (Burls et al., 2019; Otto et al., 2018; Sousa et al., 2018).

To protect water supplies during predictable recurring droughts, the City developed an extensive Water Conservation/Water Demand Management (WC/WDM) strategy to enforce light water restrictions (Luker & Rodina, 2017; LaVanchy et al., 2019). Unfortunately, this strategy does not include anything specifically targeting the tourism industry, which is especially problematic because the timing of these recurring droughts typically coincides with the Western Cape's peak tourist season. As a result, there has been little in the way of official or structured attempts to engage tourists or include them in conservation plans. Additionally, this strategy's relative newness (implemented in 2001, revised in 2007) means that it was relatively untested against a climate shock event. That is, until three consecutive years of historically low rainfall began in 2015. The result was the worst drought in over a century and a countdown to "Day Zero" when the city taps would be turned off due to low reservoir levels (Booysen et al., 2019; Sousa et al., 2018). Cape Town received international attention as the water crisis headlined in media all over the world. News stories were paired with evocative images of desiccated reservoir beds and people queueing to collect buckets of water from local springs. And uniquely, the tourism agency began engaging tourists with drought education and water conservation campaigns (see Fig. 4.1).

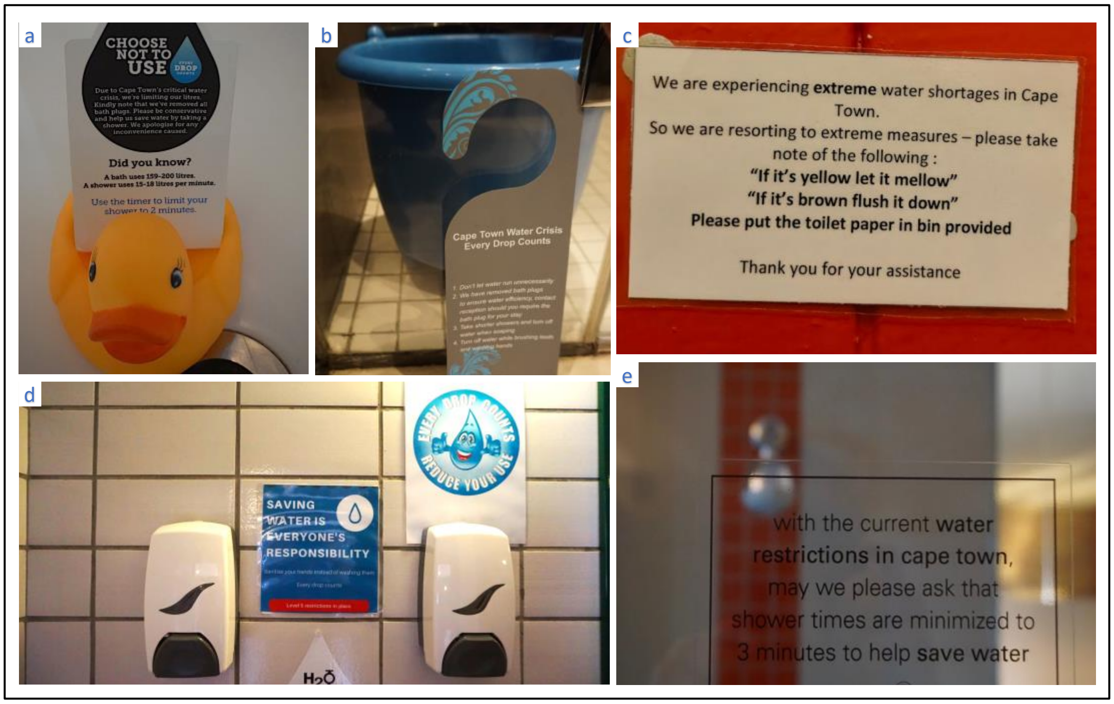

Figure 4.1: Signage to create awareness and water literacy for tourists, including: a) rubber duck to replace bath plug; b) a bucket to collect shower water; c) instructions for "if it's yellow, let it mellow"; d) hand sanitizer in bathroom; and e) shower timers.

The Federated Hospitality Association of South Africa (FEDHASA) created a Water Wise Pledge to challenge tourism associations and businesses to take action to save water, including “in your face tactics” to generate water conservation (Bizcommunity, 2017). Within hotel rooms, communications emphasized individual actions like shortened showers, forgoing baths, and collection of shower water for non-potable use elsewhere. Hotels provided shower timers (Fig. 4.1e) and buckets (Fig. 4.1b) and removed bath plugs to encourage uptake of these actions. Some hotels even replaced bath plugs with rubber ducks to uniquely introduce an element of amusement to conservation (Fig. 4.1a). Low-flow aerators or misters were installed on faucets, and some public facilities and hotels took it a step further by asking tourists to use hand sanitizer stations instead of washing their hands with water (Fig. 4.1d). Guests were taught mnemonic phrases like "If it's yellow, let it mellow - if it's brown, flush it down" (Fig. 4.1c).

Collectively, communications and marketing collateral like those depicted in Figure 1 targeted tourist water literacy, or the combination of water-related knowledge, attitudes, & behaviors (McCarroll & Hamann, 2020). Water literacy is a complex topic that is often utilized to increase appreciation of water systems or generate water-conscious behaviors. Along these lines, tourists received education briefly describing Cape Town's water system and current drought status, encouraging water-conscious attitudes and values, and providing information about specific actions that they could enact to help conserve. Signage in guest rooms and public areas attempted to increase ownership of water conservation with sayings like "saving water is everyone's responsibility" and "every drop counts". Local travel agencies like Cape Town Travel and Go2Africa wrote blogs for tourists entitled "Save like a local: Water-saving tips" (2018) and "How to still visit Cape Town in the drought" (2018), respectively.

Yet, the notoriety of Day Zero wreaked havoc on Cape Town's reputation as a top tourism destination (Nhamo & Agyepong, 2019). Analysis of tourism data collected during the drought years confirms that not only did fewer tourists visit during the Day Zero crisis, especially from international locations, but also that those who visited stayed for fewer nights and spent less money (Dube, Nhamo & Chikodzi, 2020). Moreover, whereas the City was ultimately able to avoid the arrival of Day Zero thanks to unprecedented levels of water rationing and conservation, as well as a timely 2018 rain season, the threat of another Day Zero-type crisis is long from gone. The impacts of climate change in the Western Cape region increase the likelihood that Cape Town will experience droughts with more frequency and greater magnitude than have been recorded thus far (Otto et al., 2018; Pascale, Kapnick, Delworth & Cooke, 2020). Additionally, although Cape Town is now well known for its battle with Day Zero, it is only one of many cities around the world that have been or will be brought to the brink of running out of water (Simpkins, 2018). Thus, learning from Cape Town's experience from the perspective of tourism is of tantamount importance, particularly if tourism sectors around the world are going to build resilience to increasingly arid climates and future climate shock events.

With that in mind, we seek to understand how members of the tourism industry dealt with the Day Zero crisis, focusing on tourist drought communications and conservation. First, the drivers of tourist water conservation programs are teased out to understand the interconnectivities between tourism water use and surrounding social, political, and economic systems. Next, we analyze the effectiveness of these conservation campaigns from the perspective of six Cape Town hotels. Such an understanding offers a reflective review of drought management within the tourism industry with the goals of increasing tourism sustainability and building tourist water literacy.

4.4 Methodology

Data for this study were collected in 2019 through semi-structured interviews, guided by a set of interview questions but allowing the freedom and flexibility to follow related tangents and new leads (Bernard, 2017). Initial participants were identified through established contacts within Cape Town's tourism industry. Snowball sampling was then utilized by asking participants to recommend others who work within the tourism industry. Hotel managers and staff were initially targeted for interviews. Managers typically have broad oversight of tourist experiences and sustainability programs, whereas staff directly influence on site water consumption (i.e. cleaning, gardening, cooking, etc.) and maintain direct contact with hotel guests regarding water conservation initiatives (Gössling, Hall & Scott, 2015). Beyond hotel employees, the snowball technique introduced us to several additional key tourism stakeholders including owners, consultants, and activists. Our data thus come from:

- 15 employees from four 4-star hotels, one 5-star hotel, and one hostel;
- one employee of FEDHASA;
- the owner of an environmental consultancy hired by numerous hotels during Day Zero to analyze water inefficiencies and implement conservation techniques; and
- one individual who is both the owner of an AirBnB and lead of the Drought Response Learning Initiative (DRLI), which preserved the observations and lessons of the Day Zero crisis by documenting 39 in-depth interviews with local experts from various backgrounds, including the tourism sector.

An aggregated list of interviewees and their tourism-related roles is provided in Table 4.1.

Table 4.1: Description of Interview Participants.

Interview No.	Sex	Title/Role	Yrs in Role	Organization Type
1	M	General Manager	13	four-star Hotel
2	M	Director	4	Environmental Consultancy
3	M	Environmental Manager	18	Hotel Group
4	M	Food & Beverage Manager	9	four-star Hotel
5	F	Guest Relations Specialist	12	four-star Hotel
6	F	Guest Relations Intern	>1	four-star Hotel
7	M	Technical Manager	4	four-star Hotel
8	M	Deputy Manager	2	four-star Hotel
9	F	Executive Housekeeper	-	four-star Hotel
10	M	Maintenance Manager	-	four-star Hotel
11	F	Personal Assistant of General Manager	-	four-star Hotel
12	M	General Manager	1	five-star Hotel
13	F	Guest Relations Specialist	5	four-star Hotel
14	F	General Manager	2	four-star Hotel
15	M	Maintenance Manager	3	four-star Hotel
16	F	General Manager	4	Hostel
17	M	Former Chairperson	2	FEDHASA
18	M	Initiative Co-lead	1	DRLI & AirBnB

Interviews were conducted in the English language, South Africa's lingua franca and one of the eleven national languages of South Africa (SAT, 2023). Interview content focused around gaining an understanding of tourist water conservation campaigns from the Day Zero crisis. The guiding questions included: how did your hotel/organization react to the Day Zero crisis? What communication or information was provided to tourists during the Day Zero crisis? Why did you target tourist behaviors/awareness? What were common reactions or feedback received during this time? In your opinion, did water conservation among tourists make a difference? Interviews lasted from 30-65 minutes, and all but two were audio-recorded with the permission of the participants to allow for verbatim transcriptions. Interviewers also took detailed notes and wrote post-interview summaries while the discussion was still fresh in their minds. The collection of transcriptions and these interviewer notes was then coded by the primary researcher both deductively, using the guiding interview questions, and inductively, identifying instances of connections, repetition, and emphasis within data. A codebook was developed and the inter-coder agreement (ICA) was measured using the method outlined by Hennink, Hutter & Bailey (2020), whereby two researchers coded the same selection of text independently of each other but using the same codebook. Three of the 18 interviews were randomly selected for the ICA and the codebook was adjusted until an 82% level of agreement was reached.

Lastly, the researchers themselves carried out field observations during their own stays, focusing on visible conservation marketing collateral displayed in tourist hotspots, local restaurants, and hotel rooms. These observations helped inform the structure of the interviews and connect qualitative data with visual evidence of tourist communications.

4.5 Results

The coding process revealed two predominant themes among interview data: drivers for tourist water conservation campaigns, and tourist reactions. These themes and their relative frequencies are detailed in Table 4.2 and discussed in detail below.

Table 4.2: Emergent drivers of water conservation campaigns and tourist reactions.

Theme/Topic	No. of times mentioned	No. of interviewees who mentioned topic (% of total interviews)
Drivers for conservation/water literacy initiatives		
external pressures (i.e., political and community)	14	9 (50%)
internal pressures (i.e., environmental and social responsibility)	24	12 (67%)
economic pressures of Day Zero	26	12 (67%)
Tourist reactions		
selfish cancellation	6	5 (28%)
selfless cancellation	7	6 (33%)
anger/frustration	10	8 (44%)
understanding/cooperation	13	11 (61%)
enthusiasm/inventiveness	7	5 (28%)

4.5.1 Drivers for Tourist Conservation Campaigns

Tourist water conservation programs are an important contributor to overall water savings, particularly during climate shock droughts (Baños et al., 2019; Gabarda-Mallorquí et al., 2018). Describing the drivers of successful conservation initiatives from the Day Zero crisis is central to our research and likely to guide future conservations efforts in the tourism industry. Participants were asked to explain why they targeted tourist water conservation, which revealed three primary drivers: external pressures from sources outside the tourism industry; internal pressures from within the tourism industry; and economic pressures from negative public communications of the Day Zero drought (see Table 4.2).

External pressures included imposed expectations from political leaders and local community members to use less water. The entire city was expected to come together and mobilize to avoid Day Zero. Political leaders who had the voice and platform to push for action did so loudly and often. Within the tourism industry, this included direct phone calls and in-person visits, sometimes unexpected, to hotels and tourism organizations.

> "The Mayor approached [our hotel] early 2018, and said, 'you're still way out of line because you were supposed to be making 50% less [water use] and you aren't anywhere close to that'" (Interviewee 3, male, environmental manager).

This quote provides an example of external pressure from then-Mayor Patricia DeLille. In fact, DeLille was a frequent topic of both our interviews and local media for her accusatory, apocalyptic approaches during the Day Zero crisis (Robins, 2019). And as the quote reveals, such political peer pressure was not framed as helpful suggestions but rather as blame and demands for action. Similarly, interviewees described experiences of blame-throwing from local community members who took it upon themselves to enforce water conservation at all levels.

> "We had a few local people walk into the property… and they didn't see any [marketing] collateral, any notices or anything like that. And they made quite a bit of noise. So they put it on Facebook and in social media, because they felt as a hotel, we have a responsibility to also do our part" (Interviewee 14, female, general manager).

> "There are many annual events that take place traditionally in March. And also, from around January through April, every year. And they [the locals] are saying, well, if we're so short on water, why are you bringing these additional tourists? Why do we have marketing to get international tourists to come to our city, when they're telling us we got no water?" (Interviewee 17, male, FEDHASA chairperson).

Despite rigorous efforts among hotel owners to fix leaks, access groundwater through boreholes, and harvest rainwater, accusations of water wasting from the community mirrored those from political leaders. With so many fingers pointing towards the tourism industry, implementing every drought management strategy possible was of utmost importance. Marketing, water literacy campaigns, and clear communication to tourists became an important way to maintain reputations and alleviate the impact of outside pressures during the Day Zero crisis.

Interviewees also described internal pressures that emerged from environmentally and socially responsible business plans. Indeed, the City of Cape Town has pushed for responsible tourism since the 2002 World Summit on Sustainable Development in South Africa (Fang, 2020). The concept of responsible tourism was frequently mentioned by interviewees, and many stressed that sustainability and green initiatives are not new within Cape Town's tourism industry.

> "This hotel is renowned, not only in Cape Town but throughout the country, for being a leader in environmental sustainability. Long before the water crisis hit Cape Town, this hotel, or this group rather, was implementing environmental sustainability strategies. So, it wasn't just a knee jerk reaction or reactive approach" (Interviewee 8, male, deputy manager).

Many echoed the sentiments within this quote when describing how tourist water conservation campaigns were just another way to do their part in shaping sustainable tourism. Equally important was social responsibility and ensuring tourism wasn't using water at the expense of local communities.

> “You are here just for a while; you pop in and pop out. You must think of the people that live in that environment, right… So, if you've got them [tourists] at reception, you've got a captive audience, because you're not getting your key card until I'm done talking. It’s selfish, but at that time we were selfish” (Interviewee 13, female, guest relations specialist).

> “If you are Mr. Jones staying in the Cape Flats in a struggling environment, you’ve got no water because there isn’t any. But here’s this luxury hotel with all the people from overseas with lots of money, and they’re getting plenty of water, and they’re not using 50 liters per day” (Interviewee 3, male, environmental manager).

Expressed here is a perceived accountability for ensuring equitable water access. The first quote frames tourism within the context of the local community, highlighting how tourist’s awareness of drought was raised to ensure water availability for all Cape Town residents. The second quote expresses a similar framing but with a focus on the socioeconomic context of townships. Tourist water conservation campaigns were a means of taking ownership over local water security and contributing to social justice.

The final but most mentioned emerged driver for tourist water conservation campaigns stemmed from the economic pressures of Day Zero. The phrase “Day Zero” was largely deemed a scare tactic, conveying the seriousness of the situation while inspiring action using fearmongering. Media coverage of the drought, both nationally and internationally, clung to that fear, spreading doom-and-gloom messages to the far corners of the world. Interviewees attributed their numerous booking cancellations, ranging from individuals to families to entire conferences, to public communications that they described as “over-exaggerated”, “over-sensationalized”, and “destructively negative”. Indeed, research calculated city-wide tourist arrival declines as great as 12.6% during the peak period of Day Zero (Dube et al., 2020). Other sources suggest that bookings at the hotel scale were down anywhere from 10-50% (Jainchill, 2018). Interviewees correlated the reduced tourist numbers to a variety of economic impacts to the tourism sector.

> “It [tourist water conservation] was something that if we wanted to keep on to business at the time, the way that was being said then with Day Zero, it had to be done” (Interviewee 16, female, general manager).
>
> “For every ten visitors into Cape Town, we support one job. So, by you, or a conference of one hundred people, saying, ‘sorry, I feel very sorry for you and I can’t come and use your water’, we go, ‘ok, well you just cost 10 jobs’” (Interviewee 1, male, general manager).

The first quote here describes how the Day Zero drought threatened business, implying a reduction in industry profits. This corresponds with official reports of revenue losses between R723 million and R1.7 billion per year during the entirety of the drought (Dube et al., 2020). The second quote connects the decrease of tourists and subsequent loss of revenue to decreased job security within the tourism industry. Without a reliable revenue, hotels were unable to pay their normal staffing salaries, which also corresponds with official reports tracking job losses to between 1,707 and 4,024 per year (Dube et al., 2020). Interviewees also described more extreme economic impacts, including the possibility of bankruptcy and shutting down completely. Because of the enormity of these economic impacts, hotels implemented any and all drought management strategies that would allow them to earn revenue and stay open, including tourist water conservation campaigns. And while they did reduce their water consumption, conservation campaigns also importantly offered a mechanism through which to persuade tourists to keep coming to Cape Town.

> "I think if we can get the message out to the rest of the world or whatever, that we're not in crisis-mode here, and we're not at Day Zero… then it will certainly go a long way" (Interviewee 4, male, food & beverage manager).

Communicating to tourists that they were not at Day Zero proved essential to combating negative media and encouraging continued tourist flows. Tourist conservation campaigns that provided education about the drought, current dam levels, and city usage rates helped explain the situation, while guidance on how tourists could reduce their own water demands during their visit helped to alleviate tourist concerns about burdening an already-stressed system. Tourists were given a way to take ownership of their impact while still enjoying their holidays.

4.5.2 Tourist Reaction to Conservation Campaigns

In response to drought communications, interviewees reported mixed responses from tourists. The most notable and detrimental to businesses, as mentioned before, was the outright cancellations of hotel bookings and planned trips to Cape Town. Interviewees elaborated on these cancellations to explain the rationales tourists provided for these cancellations.

> "People had this almost guilty feeling that they don't want to travel to Cape Town and add to the pressure, they'd rather go to Johannesburg, Durban or whichever

elsewhere, than come into Cape Town. Because you feel guilty that you're going to add to the stress of our water resources. There was definitely that, that trend. And also, people who don't want to spend money staying here when they didn't have the luxury of the amenities that they used to" (Interviewee 14, female, general manager).

This quote clearly distinguishes between two separate rationales, which we distinguish as selfless and selfish. The selfless rationale emerges from a consideration for burdening the already-stressed water system and reducing the availability of water for the locals. Such an explanation given by tourists demonstrated empathy and thoughtfulness regarding water insecurity. In contrast, the selfish rationale emerges from a concern that the drought would impact the quality of one's own vacation. Hotel staff relayed how tourists asked if they would be required to queue themselves to collect water during their trips. While emerging from very different logics, the results of either rationale was the same. Tourists reconsidered whether their trips were still worthwhile, given the drought.

For the tourists that decided to still visit Cape Town, interviewees describe mixed reactions to tourist water conservation measures, ranging from anger to understanding, and even to enthusiasm and inventiveness. The least common reaction was frustration or anger at water restrictions.

> "Attitudinally, [they] were treating it like, 'it's your problem, not mine'. You know, 'I'm paying X amount of money to stay in your hotel. I'm on holiday. So don't make your problems my problems'" (Interviewee 8, male, deputy manager).

Some tourists argued with hotel staff about taking baths or using the pool during peak evaporation hours. This frustration with tourist conservation campaigns mirrors the emotions behind the tourists who canceled for selfish reasons. Some people did not want to sacrifice the luxury of their vacations because of a drought that was not 'their problem'. However, interviewees also unanimously agreed that anger was by far the minority reaction among visiting guests. In fact, most displayed far more understanding and cooperation with water restrictions and conservation campaigns.

> "The feedback was amazing. Very positive… The international clientele really took to it, were proud of what we were doing, listened to us and understood" (Interviewee 12, male, general manager).

Drought and conservation information from hotel staff and various marketing collateral was appreciated and understood by the vast majority of tourists. Interviewees received feedback from guests that they were following the instructions for conservations for shorter showers and letting toilets "mellow". This "how-to" information is also known as functional knowledge and is a critical component to shaping water-related knowledge and attitudes into actions (McCarroll & Hamann, 2020). And according to interviewed hotel managers, there was a marked decrease in water usage corresponding with the timing of tourist water conservation campaigns, indicating that this functional knowledge resulted in the desired effect.

Perhaps most interesting though are reports of guests who took their actions a few steps further. Interviewees described conversations with tourists who not only followed the suggested conservation guidelines within hotels, but also voluntarily enacted extra behaviors on their own to save more water.

> “The bulk [of our tourism] is leisure. So they were more understanding. In fact, you would find that some of them would even travel with their own water” (Interviewee 14, female, general manager).

> “Some guests would say that they left their wash basin full, so every time in the day they would use that” (Interviewee 5, female, guest relations specialist).

These quotes illustrate how a handful of guests were inspired to invent their own ways to reduce their water footprint, and excitedly shared it with hotel staff. By purchasing and bringing their own bottled water or filling their bathroom sinks with water for their own personal reuse, tourists reduced their demand on the municipal system even further. Nobody asked them to take these extra steps, but interviewees described the pride and enthusiasm of the guests as they relayed to hotel staff how they were going above and beyond with conservation measures. Similarly, many guests told interviewees how they were taking the new practices home with them.

> “I had a number of my long-staying guests through February from the UK saying, ‘I’ve trained my husband, if it’s yellow let it mellow’ … I actually had one of our couples who stayed, she’s from Scotland, and she said to me, “where we come from in Scotland, we’ll never have a water issue” but, they took this practice back with them to Scotland” (interviewee 1, male, general manager).

> “A lot of guests have taken them [shower timers] home for their children. Meaning buying them” (interviewee 5, female, guest relations specialist).

Tourists excitedly told staff how they planned to continue the water-conscious behaviors in their own homes, even if they came from more water-secure regions.

Shower timers in particular became so popular that several hotels began selling them to guests as souvenirs at reception. Participating in the drought management in Cape Town created an eye-opening event for tourists, allowing them to not only understand but take pride in their ability to help avoid Day Zero.

4.6 Discussion

The data collected from eighteen tourism interviews demonstrate that responding to such droughts and building resilience is a complex matter. The Day Zero crisis originated from a climate shock of historically low rainfall over several years. Broad action was only taken when the situation reached dire proportions, and then the responsibility for water conservation fell on the shoulders of all in Cape Town – residents, businesses, and tourists alike. Our analysis of the tourism industry through a political ecology lens demonstrates that climate resilience must be approached from numerous angles. Specifically, conservation measures are directly influenced by political, economic, and social systems.

Strong internal environmental initiatives fueled responsible tourism and water conservation actions among some hotels in Cape Town, even before the Day Zero crisis. That said, the drought acted as a reminder that sustainability is a moving target, and more can be done to reduce the environmental impacts of tourism. It is also clear that there are powerful factors influencing water conservation campaigns outside of environmental responsibility. Interviewees described negative interactions with politicians and the broader Cape Town community, which placed hotel reputations at risk. Hotels perceived as wasting water were verbally attacked and shamed in news stories and public forums.

Such defamatory attention decreased the attractiveness of the establishments in question for both local travelers and international tourists. Innovative tourist water conservation campaigns allowed hotels to visually demonstrate their commitment to their community and maintain esteem in their operations. Additionally, these campaigns allowed hotels to reassure tourists that their visits would not overwhelm the local water system. In this way, tourist water conservation campaigns offered a pathway to alleviate the guilt of guests and maintain positive business relationships even as some non-cooperative guests protested. For hotels in Cape Town, doing the right thing and being environmentally responsible was a priority, but avoiding mass cancellations, huge profit losses, and widespread layoffs was equally important.

The appearance of prioritizing environmental sustainability was also important during the Day Zero climate shock. Hotels needed external parties to perceive them as water conscious to save their reputations. Posting marketing collateral about drought initiatives and conservation campaigns in lobbies, restaurants, bathrooms, and guest rooms helped to reduce the defamatory shaming while easing concerns of politicians and locals who wanted to ensure everyone was doing their part. Communications to tourists about how they can "Save Like a Local" offered peace of mind to concerned tourists that their visits wouldn't contribute substantially to water insecurities. Past research demonstrates that tourist water conservation campaigns provide small but important water savings (Baños et al., 2019; Gabarda-Mallorquí et al., 2018). Our research demonstrates that tourist water conservation campaigns also provide psychological benefits that help mitigate the economic impacts of drought.

Finally, our research demonstrates that tourists overwhelmingly responded positively to water conservation campaigns. Interviewees described interactions with a few selfish tourists who reacted with anger and frustration when burdened with someone else's water crisis, but simultaneously clarified that these interactions were few and far between. Instead, the vast majority of tourists displayed understanding and willingness to change their own behaviors. The suggestion that notable decreases in water consumption were tied to the implementation of tourist conservation campaigns implies that they were successful, although we do not verify those correlations within this study. But the adoption of water conserving behaviors by tourists does emphasize the importance of functional knowledge within water conservation campaigns. Additionally, the number and intensity of positive conversations interviewees had with guests during the Day Zero drought highlights a strong valuation of sustainable tourism and a desire to reduce the environmental impacts of holidays. This supports other research that suggests tourists are looking for guilt-free vacations (Burrai, Buda & Stanford, 2019; Fang, 2020). In this way, tourist water conservation campaigns offer an opportunity to increase the water literacy of tourists, alleviate their concerns about visiting during droughts, and provide them with the knowledge and tools to take control of their own impact.

It is also worth noting the suggestion within our results that the benefits of tourist water literacy may extend beyond the geographic boundaries of the destinations. Several interviewees were informed that tourists were planning to take their newly learned behaviors home with them. One guest in particular told hotel staff that she would 'let it mellow' back home in Scotland, which would "never have a water issue". Yet, parts of

Scotland did in fact experience not long after Day Zero. Although typically a water-secure country, the Scottish Environment Protection Agency (SEPA) reported extreme variability in 2022 precipitation patterns that resulted in water scarcity within eastern regions of the country (SEPA, 2023). Thus, it is possible that by increasing the water literacy of these guests, and others in similar situations, tourist water conservation campaigns could increase appreciation for and efficient use of water elsewhere around the world.

4.7 Conclusion

Climate shocks like Cape Town's Day Zero drought give rise to significant and far-reaching socioeconomic consequences. For Cape Town tourism, the risk of running out of water generated powerful political tensions and extensive economic impacts that threatened the industry's economic viability. Responding to these threats and avoiding the arrival of Day Zero ultimately took a combination of drought management strategies, including an unprecedented level of water conservation across the entire city. This included innovative conservation within the tourism industry, targeting tourists themselves as part of the solution. Our research applies a political ecology lens to this example of resilience to extract key lessons regarding tourism water management at six Cape Town hotels.

Through interviews with eighteen hotel and tourist industry leaders, we find that tourist water conservation campaigns are as important for mitigating economic impacts as they are for reducing water consumption and stretching diminished water resources further. Hotels marketed their conservation efforts to avoid political defamation and reputational harm. Campaigns targeting tourist water use alleviated tourist concerns about visiting during drought, helping to the mitigate the economic impacts of declining tourist numbers, reduced revenues, and decreased job securities.

We also find an overwhelmingly positive response from tourists to water conservation campaigns. Hotels actively increased the water literacy of guests, generating water sensitive attitudes and appreciation for the value of water. The provision of functional knowledge, detailing helpful instructions and guidelines on reducing individual water consumption, gave guests agency to change their behaviors. Apart from a minority group of selfish tourists who responded with anger and frustration, these water conservation campaigns were not just positively received but inspiration for creative efforts above and beyond what was asked. Such unparalleled efforts to provide drought education may have garnered tourism loyalty, and also generated a ripple effect of conservation behaviors across the globe.

Climatologists expect the Western Cape to become increasingly hot and dry with rising global temperatures, escalating the risk of climate shocks like the Day Zero drought (Otto et al., 2018). Moreover, cities across the world are experiencing similar trends of aridification due to climate change, threating the water systems of numerous tourism hotspots. The ability to structure and rollout effective conservation campaigns is of the utmost importance. Our results highlight how the tourism industry can model and enforce demand management strategies during severe droughts that not only mitigate economic impacts and produce water savings, but maintain customer satisfaction, grow visitor loyalty, and possibly spread conservation awareness across the globe.

4.8 References

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Chapter Five: Promoting sustainable water management through community water literacy: A case study from Aurora, Colorado (USA)

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Order of Authorship	*Name of Author*	*Contribution to Paper*	*Overall Percentage*
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2	Hillary Hamann	Conceptualization, data collection, supervision, writing of drafts, critical review and feedback, editing,	15%
3	Michael Kerwin	Supervision, critical review and feedback, editing	5%

By signing the Statement of Authorship, each author certifies that:

iv. The candidate's stated contribution to the publication is accurate (as detailed above);

v. Permission is granted for the candidate to include the publication in the thesis; and

vi. The sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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5.0 Abstract

Water managers in the southwestern United States are contending with long-term drought conditions that are threatening their ability to ensure water security for urban populations. Combined with trends of aridification and growing urban water demands, they must increasingly engage with demand management techniques that rely on community water knowledge, attitudes, and behaviors. This is known as water literacy, and at a community level it can build trust in water managers, generate quick responses to drought, and expose water inequities. Recognizing the importance of community water literacy, we seek to understand its application within the sociopolitical context of Aurora, Colorado. Following a severe drought in 2002 that caused near-failure to the local water system, Aurora Water has become a state leader and innovator in demand management and water literacy programs. Thus, we utilize a mixed methods approach to understand water literacy strengths and weaknesses within the community. Then, applying a political ecology lens, we reveal sociopolitical structures that both help and hinder community water literacy, including experiences of drought, engagement with Aurora Water, subjective norming, and institutions like homeowner associations. The results provide Aurora Water with a baseline understanding of community water literacy and a tool with which they can evaluate changes in that baseline. Additionally, the study reveals the need to address power structures limiting water literacy, in order to successfully manage demand and work towards water sustainability.

5.1 Introduction

For more than two decades, long-term drought conditions in the southwestern United States have been challenging water managers and their ability to ensure water security for urban populations. Reduced river flows and drying soil conditions combined with increasing water demands are surging vulnerability to water shortages and system failures (Heidari et al., 2021). This region is no stranger to drought. Indeed, paleoclimate evidence dating back hundreds of years reveals the occurrence of persistent and extreme droughts, many of which exceed dry periods of measured records from the 20^{th} century (Woodhouse & Lukas, 2006). However, increasing global temperatures and the effects of climate change are producing patterns of aridification across the southwestern states, increasing the risk of multidecadal megadroughts (Ault et al., 2014; Cook et al., 2015) like the one in which we currently find ourselves (Williams et al., 2020).

Within this increasingly water-challenged region is the semi-arid, landlocked state of Colorado. Water managers in Colorado have always contended with the complexities of drought because of the state's spatially and temporally variable precipitation patterns. Recurring droughts of abnormally dry or moderate levels regularly develop during hot summer months, particularly within the eastern plains where the majority of the state's population lives. To provide reliable and sufficient water supplies to growing urban populations, Colorado water managers must increasingly engage in demand management techniques, like increasing the efficiency of water-using technologies or pushing water conservation campaigns.

The success of demand management is inextricably tied to community water literacy, or collective water related knowledge, attitudes, and behaviors (McCarroll & Hamann, 2020). Water literacy at a community level enables the public to react quickly to the onset of droughts and engage in dialogues about water management at multiple scales (Dean et al., 2016). Simultaneously, water literate communities are better able to communicate their water needs and hold water managers accountable for sharing information and affecting equitable decisions relating to water management.

The Colorado Front Range city of Aurora offers a leading example of water literacy engagement and outreach. Evolving largely after the near-disastrous drought of 2002, Aurora Water (AW) has built a robust collection of water outreach and engagement programs that sets it apart from other Colorado cities. However, the effectiveness of their investments in community water literacy has yet to be systematically analyzed. In this paper, we use a political ecology lens to investigate current water-related knowledge, attitudes, and behaviors held throughout the Aurora community. We then analyze whether trends in water literacy are correlated to experiences of drought or engagement with AW's programs. The results of our research will not only help evaluate the effectiveness and equity of AW's existing programs, but also reveal gaps in community water literacy and provide a structure for monitoring water literacy in the future.

5.1.1 Water Literacy

Water literacy is an evolving concept of increasing importance within the field of water management. While summarized as the culmination of one's water-related knowledge, attitudes and behaviors, recent research from McCarroll and Hamann (2020) suggests that water literacy is multi-faceted and comprised of several different components or “knowledge sets”. Within the cognitive domain, water literacy includes: science and systems knowledge, or knowledge about the scientific properties of the water molecule and its flow through the water cycle; local knowledge, or knowledge of one’s local water sources and who manages them, as well as key infrastructure and local water demands; hydrosocial knowledge, or knowledge of the interconnections between water resources and social systems that allow them to “make and remake each other over space and time” (Linton & Budds, 2014, p. 170); and functional knowledge, which connects awareness of water sustainability to the actual “how-to” of water conservation and water resource protection. Water literacy also includes the affective domain of knowledge with water-related attitudes and values that highlight the subjectivity and accessibility of water sustainability. And finally, water literacy includes the behavioral domain of knowledge with water-related actions from both individuals and broader collectives that directly affect water sustainability.

Community water literacy in an important component of sustainable water management. While augmentation schemes like desalination and recycled wastewater have been derailed by community fears in the past (Caball & Malekpour, 2019; Kosovac et al., 2017), scholars suggest that community water literacy may boost public support and willingness to pay for these projects (Giurco et al., 2010; Stoutenborough & Vedlitz, 2014). Research also implies a correlation between water literacy and the uptake of water conservation behaviors (Dean et al., 2016). Thus, community water literacy has the power to make or break both supply and demand management projects. Additionally, enhanced water literacy offers opportunities to increase water injustices by encouraging more water-related discussions among community members and with water managers (Dean et al., 2016), thereby increasing the opportunities to reveal community needs and concerns and bring attention to alternative water knowledges and management strategies (Hawke, 2012).

5.1.2 Water Literacy & Political Ecology

Socio-cultural, political, and environmental factors strongly influence the development of water literacy. Educational programs in schools or summer camps contribute substantially to the water literacy of youth (i.e. Attari, Poinsatte-Jones & Hinton, 2017; Forbes et al., 2018; Sammel 2014; Dann & Schroeder, 2015), while lived experiences and personal interests prove important for both youth and adults. For example, fishers and anglers in Florida demonstrated greater water knowledge than those who didn't interact with the waterways (McDuff et al., 2008). Experiences of water insecurity also generate water literacy. Increased water knowledge is found in cities with elevated lead concentrations in tap water (Harnish et al., 2017), as well as in regions that experience drought and water restrictions (Booysen et al., 2019; Gilbertson et al., 2011; He, 2018). Thus, we must understand the surrounding socio-cultural and political contexts of a community in order to fully understand that community's water literacy.

Within this in mind, we approach water literacy through political ecology, a research framework centered on the theory that the management of natural resources is intrinsically bound by political, social, and economic powers (Blaikie, 1999; Islar & Boda, 2014; Robbins, 2020). For example, the state-driven hydrologic paradigm of the

20th century demonstrated human's control of water through the mass damming of waterways, while simultaneously fueling environmental degradation and inequitable water access (Bakker, 2012; Linton, 2008; Linton & Budds, 2014; Phare, 2009). Thus, political ecology offers a critical dissection of the socio-cultural and political power structures within Aurora that both build and inhibit community water literacy.

5.2 Aurora Background

Aurora is the third largest city in Colorado, located immediately to the east of Denver, the state capital and largest municipal water user in the state (Figure 5.1). Both cities are growing rapidly, but Denver is increasingly "landlocked" by surrounding suburbs whereas Aurora still has large amounts of undeveloped land and is expanding outwards with countless suburb developments. In 2022, Aurora had a population of over 398,000 with a 2.9% growth rate (CoA, 2023c). Aurora is also home to one of the state's most diverse ethnic and racial populations, with 44% of the total population identifying as non-white, and 22% foreign-born (CoA, 2023c).

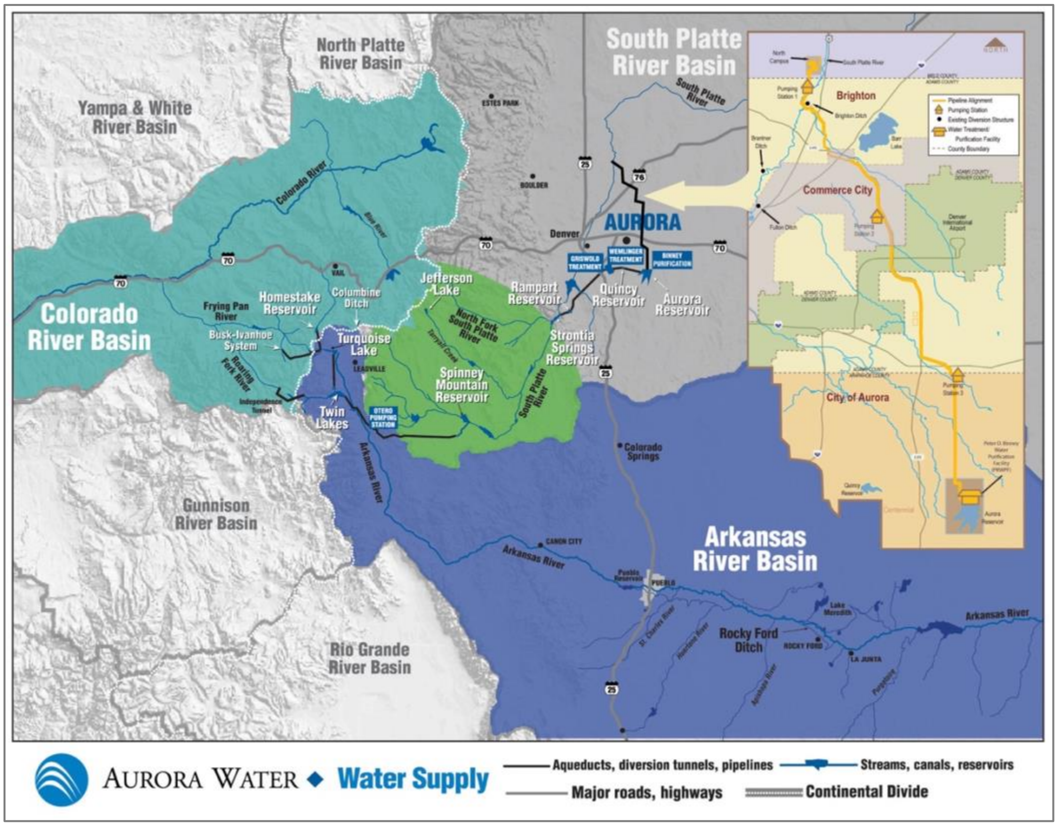

Figure 5.1: Location of Aurora in relation to the Colorado Front Range and Aurora Water's three source watersheds (CoA, 2023b).

Incorporated in 1891, the City of Aurora originally sourced water through the Denver Water Union Company (now Denver Water). Responding to increasing competition and growing demand for water, Aurora Water (AW) was created in 1949 and was able to stop relying on Denver Water's supply entirely by 1967 after the construction of the Homestake Reservoir. It now relies primarily on surface waters fed by snowmelt. AW manages a system of 12 reservoirs throughout the mountains and eastern Front Range, transporting water across the Continental Divide and as far as 230km (180 mi) from the Colorado, South Platte, and Arkansas River basins (CoA, 2023e). However, the delay in creating its own water system resulted in the City acquiring more junior water rights than many surrounding cities and because of this, it runs the risk of failure during periods of prolonged drought (Kho, 2013). The most notable example of such near-failure occurred at turn of the 21st century.

Abnormally dry conditions began in late 1999 and reached disaster proportions by 2002 (CWCB, 2013). According to climatologists, the 2002 calendar year was the worst single year drought in Colorado since 1685 (Pielke et al., 2005). While cities across the Colorado Front Range were all hit hard, AW proved drastically unprepared to handle a drought of this magnitude. A lack of climate resilient water sources and demand management strategies exacerbated the environmentally produced drought and fueled water scarcity, dropping AW reservoir capacity to 25% (CWCB, 2013). That said, AW responded quickly and aggressively to avoid system failure. The Aurora Water Management Plan (2017) was created in 2002 to structure responses to reduced water supply conditions, including: the implementation of an increasing block rate to economically disincentivize greater water usage; mandatory restrictions for outdoor water-use that limited watering to three days a week outside of the hours of 10am to 6pm; city-sponsored rebate programs for low-flush toilets and high efficiency upgrades to sprinkler systems; and water conservation education and outreach programs for youth and adults (Kenney et al., 2008). Collectively, the water savings of these programs was enough to help them avoid a complete system failure and make it through the drought.

However, the experience of near-failure in 2002 provided an enormous wake-up call to start planning and preparing for drought. This manifested into action in several ways, including the augmentation of water supplies with innovative sources. The Prairie Waters Project (PWP), for example, is an advanced water reclamation scheme that is widely applauded for its ability to supplement Aurora's water portfolio without the purchase and diversion of more runoff from Colorado's mountains. PWP pulls treated wastewater from the South Platte River using sandbank filtration, pumps it 34-miles upstream to an advanced purification plant in Aurora, and then blends the finished product with conventionally treated water from Aurora Reservoir (AW, 2021). The first potable wastewater reclamation facility of its kind in the state PWP continues to supplement the city's municipal supply with up to 10 million gallons of water per day (Best, 2010). It was also recently approved for a $13 million expansion, funded partially by the 2023 Federal Bipartisan Infrastructure Law, which will double the capacity of this treatment facility (Booth, 2023). Given the limited (and overallocated) nature of Colorado's water resources, Aurora Water has also sought inventive supply solutions like the 2018 purchase of water rights from the London Mine. This purchase not only supplements the city's water portfolio with a previously untapped source, but also provides environmental benefits by reducing the amount of mine pollution that is dumped into Colorado streams (AW, 2018).

The 2002 drought also prompted AW to build out their conservation programs into one of the most progressive and comprehensive demand management strategies in the state. For example, the rebate programs have expanded to include funding for the installation of smart irrigation controllers, which use weather data to automatically adjust watering schedules, as well as the conversion of water-thirsty lawns to xeriscape or water-wise landscapes (CoA, 2023d). The City of Aurora limits the allowable amount of irrigable land to 33% of new commercial developments and 30-50% of new residential developments, depending on lot size (CoA, 2016). Starting in 2017, AW began the "Know Your Flow" (KYF) program, which provides an emailed monthly breakdown of the water usage of participating single-family homes and compares it to the recommended usage based on number of residents, landscaping details, and weather trends (CoA, 2023b). Additionally, the mandatory outdoor water restrictions from 2002 are now permanent from May 1st to October 31st, and subject to increasing restrictions depending on the level of drought. For example, AW tightened these restrictions for the 2023 growing season to a maximum of two watering days per week in response to low reservoir levels caused by the current megadrought (CoA, 2023a).

More recent measures include a unanimously approved ordinance banning cool weather turf on new golf courses and "non-functional" residential areas (i.e. front yards, curbside landscapes, medians, etc.) (AW, 2022). The first of its kind in Colorado, this cool weather turf ban has provided inspiration to other municipalities along the Front Range, like Castle Rock and Thornton (Aguilar, 2022). Additionally, a subsequent City memorandum pledges to reduce nonfunctional turf across the city by 30% (Hindi, 2022).

Collectively, Aurora Water's drought management strategies makes it a state leader of innovation and water sustainability. The robust conservation programs create a strong emphasis on community education and engagement, which likely contributes to a foundational community water literacy. That said, Aurora's water literacy has yet to be systematically analyzed. Thus, Aurora is an ideal context to understand water literacy in the context of drought experiences and community engagement. Through this paper, we investigate baseline levels of Aurora's community water literacy and its correlation to experiences of drought, engagement with AW, and the sociopolitical context of Aurora. Such results not only will further our theoretical understanding of how to build and shape community water literacy, but also assists Aurora Water to tailor their programs to any existing needs or knowledge gaps within their community. Our specific research questions include:

- What water literacy exists within Aurora in terms of water-related knowledge, attitudes and behaviors?
- Does engagement with AW and/or experiences of drought influence Aurora's water literacy?
- What sociopolitical factors in Aurora influence water literacy?

5.3 Methodology

Aurora, Colorado was selected as the research site because it is both an example of a rapidly expanding city in the arid southwestern US, and also is a leader in water conservation and community outreach. Additionally, we as researchers have pre-existing relationships with AW, which we shaped into a partnership. This afforded our study trust and rapport with the Aurora community. The research process is illustrated in Figure 5.2 and described in detail below. Ethical clearance was obtained for all three phases from the University of Denver Institutional Review Board (IRB) prior to research commencement.

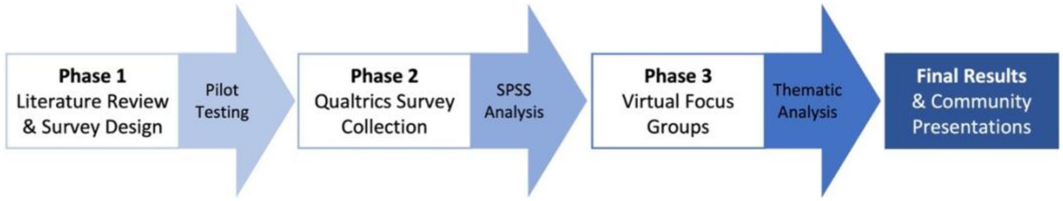

Figure 5.2: Sequential process flowchart for data collection and analysis, based on Driscoll (2007) & Creswell (2015).

5.3.1 Method Design & Data Collection

The survey was initially modelled after other water literacy surveys and scholarship, and then fitted to the Aurora community using feedback from AW Conservation staff. A draft survey was piloted in Spring 2021 by eight AW customers, who provided feedback on the survey content and design. It was then adjusted to its final 46-question version, nine of which covered basic demographics. The core survey content included questions about water-related knowledge, attitudes, behaviors, and engagement with AW programs. There were also several communication preference questions added by AW that are relevant for their strategies but fall outside the scope of this study.

The survey was distributed online through Qualtrics to AW customers from September 1st through October 31st, 2021. Participation was incentivized with entry into a raffle for credit towards a water bill (or a gift card, for residents of multi-family units), and was limited to one AW customer over the age of 18 per household. Recruitment occurred through flyers mailed to the 77,000 single-family homes AW services, as well as through advertisements on AW's website, social media platforms, monthly water bill newsletters, and emails, and at in-person at city festivals and events. A total of 706 responses were collected, which were filtered to ensure participation from AW customers only. That left a final response tally of 612 surveys, which were analyzed to identify broad patterns in water-related knowledge, attitudes, and behaviors.

Finally, we conducted a series of focus groups to investigate interesting survey results and any emerged questions. All 612 survey participants were polled for interest in continued participation in the research project, which yielded expressed interest from 234 participants. A stratified random sample of 15 women and 15 men from the subset of 234 survey participants were invited to one of three different virtual focus groups in February 2022. Focus groups were conducted outside of normal working hours through Zoom and lasted two hours each. A no-show rate of 20% was observed, leading to participation from 24 AW customers. Focus groups discussions were audio recorded, transcribed, and paired with researcher notes that paid specific attention to breadth and depth of covered topics, intensity and consensus of opinions and beliefs, and group dynamics. Together, these data were analyzed using a constant comparative method to identify patterns and relationships (Krueger & Casey, 2015) and codes were developed using both the water literacy framework from McCarroll & Hamann (2020) as well as reoccurring themes.

Table 5.1 provides a demographic breakdown for both the surveys and the focus groups. Based on expressed interest levels and size limitations within the focus groups, it was not possible to represent all of the community demographics presented in the survey. It is also worth noting that the survey was offered in both English and Spanish, but we collected only 3 Spanish versions from the 612 total surveys.

Table 5.1: Demographics of research participants.

Demographic Category	**Survey Participants (total=612)**		**Focus Groups Participants (total=612)**	
	n	%	*n*	%
Gender				
Male	243	39.7%	11	45.8%
Female	354	57.8%	13	54.2%
Nonbinary	1	0.2%	-	-
No answer	12	2.0%	-	-
Residence type				
Homeowner	586	95.8%	24	100.0%
Renter	25	4.2%	-	-
Water bill payer				
Self/Household member	597	97.5%	24	100.0%
HOA	15	2.5%	-	-
Aurora Residency (yrs)				
0-2	61	9.9%	-	-
3-7	154	25.2%	7	29.2%
8-13	92	15.0%	4	16.7%
14-19	53	8.7%	2	8.3%
20-39	168	27.5%	9	37.5%
40+	84	13.7%	2	8.3%
Race & Ethnicity[1]				
White/Caucasian	493	80.6%	20	83.3%
Black/African American	27	4.4%	1	4.2%
American Indian/Alaskan Native (AIAN)	16	2.6%	-	-
Asian/Pacific Islander (API)	33	5.4%	1	4.2%
Hispanic/Latinx	62	10.1%	4	16.7%
Multiracial (not specified)	5	0.8%	1	4.2%
No answer	59	9.6%	3	12.5%
Highest Level of Education				
Some high school	3	0.5%	-	-
High School Diploma or equivalent	37	6.0%	1	4.2%
Associate degree or some college	150	24.5%	3	12.5%
Bachelor's degree	227	37.1%	4	16.7%
Master's Degree	140	22.9%	14	58.3%
Doctorate Degree	25	4.1%	2	8.3%
Professional Degree	18	2.9%	-	-
No answer	12	2.0%	-	-
[1]Question allowed for multiple answers, sum of response rates is greater than 100% because they represent any level of identification with racial/ethnic group				

5.3.1.1 Statistical Analysis

Following the completion of the data collection, we conducted an in-depth statistical analysis of the survey using SPSS with the goal of identifying relationships between water knowledge, water attitudes, water behaviors, and engagement with AW programs. This involved grouping related survey questions to create scaled indices of several water literacy *element*s, following methods *outlined by de Vaus* (2014).

- *Water Knowledge Index:* a subset of 10 knowledge questions with objectively correct answers were used to generate a water knowledge scale (i.e. facts about Colorado climate, Aurora's water sources, treatment needs, etc.). Water knowledge scores were calculated for each participant based on the sum of correct answers (range 0-10). Two questions were rated on a 5-point Likert scale (strongly disagree to strongly agree) and only answers of "somewhat agree" or "strongly agree" were considered correct and awarded a point. Remaining questions were a mixture of True/False or multiple-choice questions, and each correct answer received a point. Two of the multiple-choice questions had multiple correct answers - for these, participants were given a partial point for each correct answer selected, but only received the full point if they selected only the correct answers. For all questions, neutral answers (i.e. "neither agree nor disagree" or "not sure") or no answers (skipped questions) were coded as incorrect.
- *Water Sensitivity Index:* five questions rated on a 5-point Likert scale assessed functional knowledge about water sensitivity or water sensitive attitudes (i.e. water conservation is important, more water conservation is needed, my actions can impact water conservation/water quality, water shortages don't affect me). Four of the questions were positive items (1 = "strongly disagree"

to 5 = “strongly agree”), but the fifth was a negative item and required reverse-coding (5 = “strongly disagree" to 1 = “strongly agree”). Water sensitivity scores were calculated for each participant using a mean of these items (range 0-5; Cronbach’s α =0.755).

- *Conservation Behaviors Index:* seven survey items assessed uptake of individual water conservation behaviors indoors (i.e. fixed leaks, installed water-wise appliances, shorter showers, etc.) and seven items assessed uptake of individual water conservation actions outdoors (fixed leaks and/or increased efficiency of sprinkler systems, used car washes, installed xeriscape, etc.). Response options were yes or no, and each action was correlated with a 1-point value. Conservation behavior scores were calculated by summing the total points of each participant for both indoor and outdoor actions (range 0-14). Importantly, this scale is a simplified indication of conservation behavior uptake and cannot be correlated to actual quantity of water savings from our survey results.
- *AW Engagement Index*: ten survey items assessed engagement with AW programs (i.e. rebates, conservation classes, outdoor and indoor water assessments, Know Your Flow, etc.). Response of ‘Unaware of’ and ‘Aware of, but have not participated’ were both given no point value and responses of ‘Have participated in’ were given a 1-point value. Points were then aggregated for each participant to summarize their engagement level with AW (range 0-10).

5.4 Results

Data from both the survey and the focus groups were first analyzed using the water literacy framework from McCarroll and Hamann (2020) to present an overview of key findings about Aurora's community water literacy across each of the knowledge sets. We then present the findings from the statistical analysis, including correlations between the newly created water literacy index scales and ANOVA tests of these scores across demographic groups.

5.4.1 Overview of Aurora's Water Literacy

5.4.1.1 Science & Systems Knowledge

One of the key ideas within the science and systems knowledge set is the understanding of a watershed (a.k.a. drainage basin, catchment). Student education often focuses on watersheds because of their influence on water flows and contamination risks (Shepardson et al., 2007; Gunckel et al., 2012). However, knowledge about watersheds is not often carried through to adulthood. Several surveys from across the world reveal that respondents are unfamiliar with term "watershed", let alone what it conveys (NGS, 2001; Zagarola et al., 2014; Duda et al., 2015). Aurora's citizens show no exception to this pattern. Only about one third of survey respondents (*n*=216) correctly identified that they live within a watershed after being given the definition (see Figure 5.3). Another one third (*n*=186) incorrectly indicated they do not live in a watershed, and the remaining third (*n*=195) were not sure.

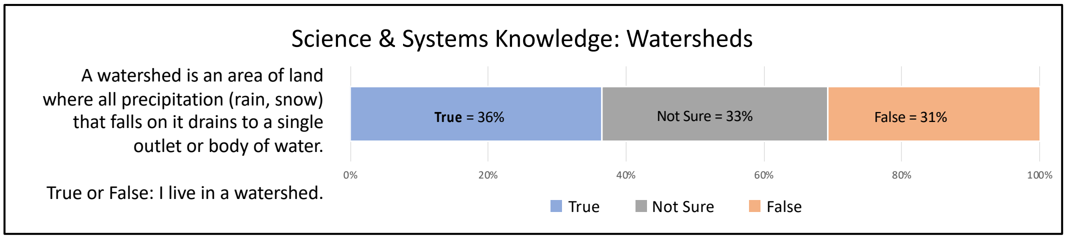

Figure 5.3: Survey results of true/false question about watersheds. Correct choice is bolded.

Still, survey respondents may be aware of some watershed functions. A subsequent survey question, which combined water-related attitudes with science and systems knowledge, asked for participants to rank the benefits of a healthy watershed by personal importance (Figure 5.3). Water quality and environmental health were most frequently ranked as most important to respondents, indicating at least a basic awareness of how water flowing through land can dissolve and suspend different materials, while providing sustenance to local flora and fauna. These findings mirror others such as from a study in Chile and Argentina where community members lacked basic knowledge about ecological concepts but recognized the value and services of their watersheds (Zagarola et al., 2014).

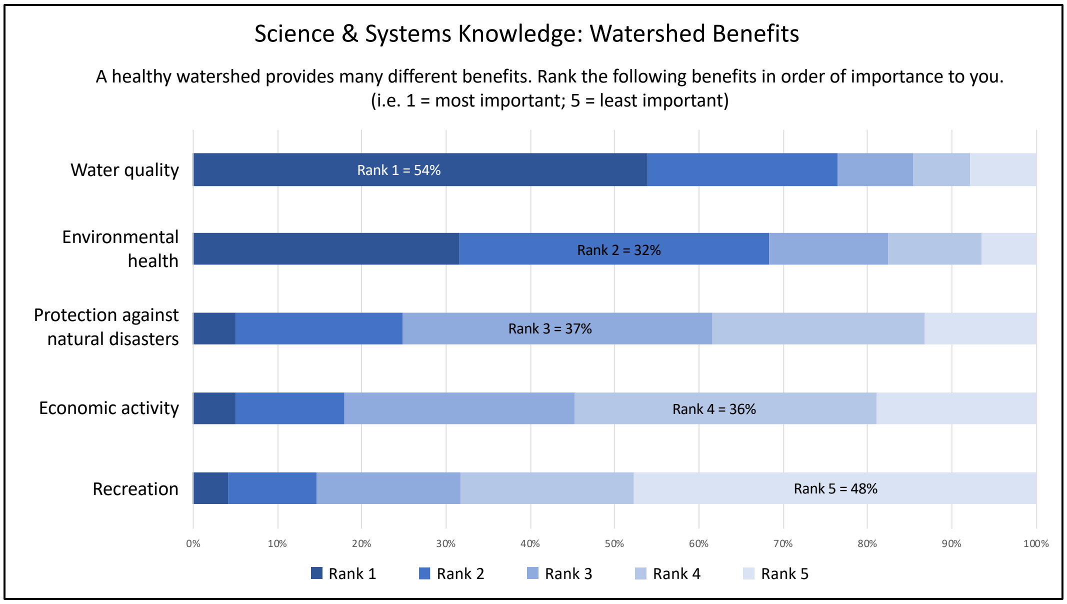

Figure 5.4: Survey question asking for ranks of ecosystem benefits from healthy watersheds. Modal rank responses for each benefit are indicated with labels.

Combined, these results suggest that while community knowledge regarding specific water-related scientific concepts like watersheds may be limited, there is still a general understanding of the functions behind the concept. More broadly, they imply that the Aurora community might understand the essence of information important for water-conscious behaviors and perceptions without needing a deeper scientific understanding. However, the results also highlight a problematic division between how community members perceive society versus the environment. Respondents seem to understand the importance of a healthy watershed but lack the ability to see themselves *within* the watershed. Further evidence of this was found during focus groups when discussing water quality:

> "I think all of us have this idea that there's a basin that holds our water, it goes through treatment, and then it comes to our house. And there's nothing that I do that's going to impact that basin or that treatment" (Participant 6A, male).

"We absolutely have control over how we impact water quality by not dumping garbage, you know… we do impact the quality of the water *at its source*" (Participant 12B, female, emphasis added).

Only nine of 24 focus group participants indicated awareness of how they could impact water quality. Of those nine, most emphasized the importance of their actions at the water sources specifically, which were described in the distant and othering manner present in these comments. Additionally, prompts about water quality were followed with lengthy discussions within all three focus groups about the impact of lawn chemicals and animal waste on stormwater, and of flushed pharmaceuticals and wipes advertised as "flushable" on wastewater.

"I never knew that the dog poop made a difference, and I never knew that it affected [water quality]" (Participant 18C, female).

Here, we see both a lack of science and systems knowledge regarding water quality as well as a perceived separation between society and the water system.

5.4.1.2 Local Knowledge

Local knowledge refers to knowledge about local water sources, infrastructure, and managing entities. Such knowledge is often the focus of water literacy engagement because the content is considered more simplified and relatable than other types of water knowledges (McCarroll & Hamann, 2020). Within our survey, we gauged local knowledge using 10 questions that targeted local water sources, uses, and treatment. Most of these results went into the aggregated water knowledge index, but a detailed look at subset of true/false questions (Figure 5.5) reveals key gaps in knowledge about AW's water system.

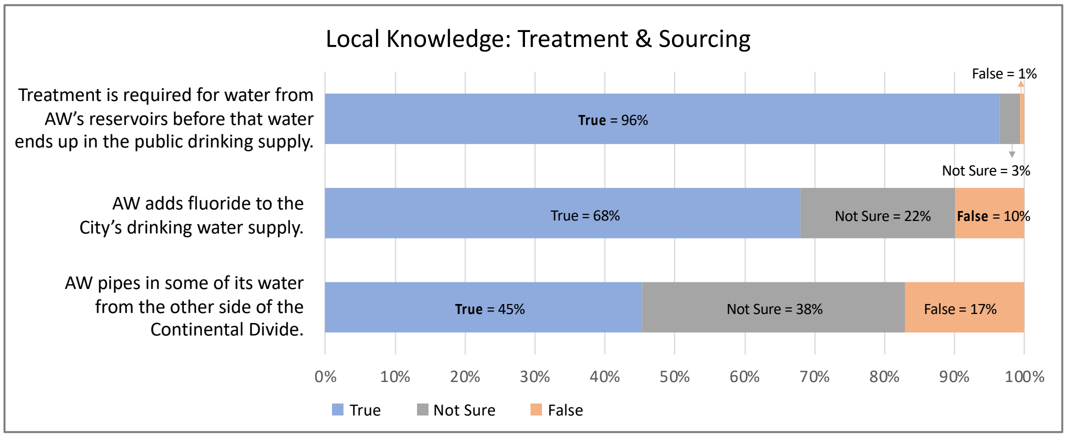

Figure 5.5: Survey results of local knowledge true/false questions. Correct choices are bolded.

Survey respondents demonstrate an overwhelming awareness (*n*=567 or 96%) that treatment is required for all of AW's potable water. However, the specifics of water treatment are less understood. For example, water fluoridation is a common practice in westernized countries because of its proven link to reduced tooth decay (CDC, 2020). Fortunately for AW, fluoridation is not required because their source watersheds are naturally rich in mineral fluoride, which dissolves into the water through erosion and in healthy concentrations. Yet, most survey respondents (*n*=398 or 68%) incorrectly believe that the municipality is fluoridating the City's water supply. This misconception is problematic because water treatment techniques like fluoridation are often highly contentious.

"People think that fluoridated water is healthy, and I think it's not healthy" (Participant 5A, male).

This focus group comment introduces a common misunderstanding of fluoridation, which often emerges from scientifically unfounded or misleading sources and has been known to generate waves of public outrage (Armfield & Askers, 2010; Podgorny & McLaren, 2015). Indeed, focus group data suggest such community frustration may exist in Aurora, fueled by false beliefs that AW is fluoridating water supplies.

Regarding local knowledge about AW sourcing, only 45% of participants (*n*=267) were able to correctly state that AW pipes in water from across the Continental Divide. Such knowledge is important because such large-scale interbasin transfers have significant financial consequences for the price of water and also are known to fuel social discord (Ben Fraj et al., 2019). But more than half of survey respondents are unaware of the distance their water travels, and thus likely are similarly unaware of its socioeconomic impact.

Results from a follow-up question corroborate the lack of knowledge regarding AW's sources. Participants were asked to identify Aurora Water's source watersheds question (Figure 5.6). Interestingly, more participants stated that Aurora pipes in water from the Continental Divide (*n*=267 or 45%) than selected the Colorado River watershed as one of AW's sources (*n*=197 or 32.2%), which may indicate unfamiliarity with the boundaries of the Colorado River Watershed. But nearly half of participants (*n*=266 or 43.5%) were simply unable to answer this question, and only 5.6% (34) of participants were able to answer most correctly by selecting *only* the three correct source watersheds.

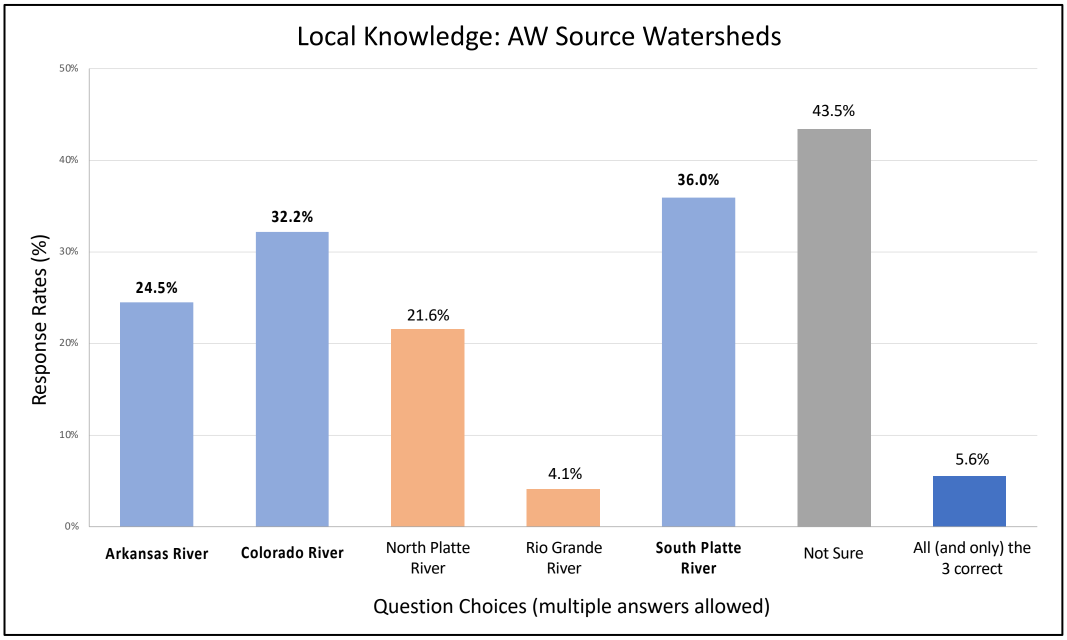

Figure 5.6: Survey results of question about AW's source watersheds. Question allowed multiple answers, meaning participants could select anywhere from 0-5 watersheds. The correct 3 choices are bolded.

Thus, very few survey respondents can identify where their water is coming from. This knowledge gap is expanded by focus group data that discussed other types of water sourcing:

> "My understanding is that potable drinking water comes from storm drains and that the water that goes down the sewer does not end up back for us to drink. Is that a bad conception?" (Participant 5A, male)

It is not uncommon for the public to be unaware of the paths and treatment of stormwater and wastewater (Dean et al., 2016; Duda et al., 2015; GBSM, Inc, 2011). Though, AW's Sand Creek Reclamation Facility and PWP are fairly unique, only 5 of all 24 focus group participants knew about the Prairie Waters Project. Collectively, these results confirm a widespread gap in local knowledge regarding AW's system.

5.4.1.3 Hydrosocial Knowledge

Hydrosocial knowledge underscores the give and take between physical water resources and surrounding social systems (McCarroll & Hamann, 2020). It emphasizes how humans shape water flows and water quality as much as water resources shape human health and development. Within the survey, we targeted the hydrosocial relationship between growing urban demands and quantity of water resources (Figure 5.7).

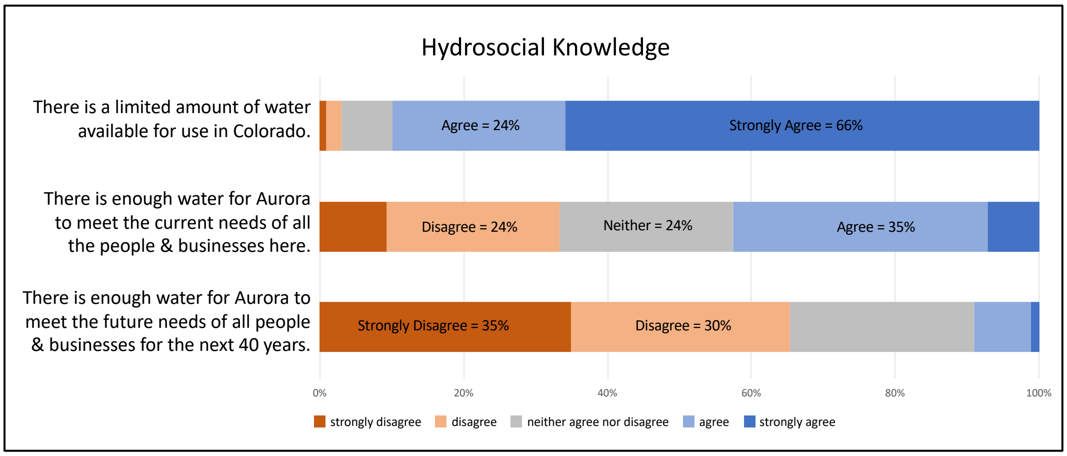

Figure 5.7: Survey results of hydrosocial knowledge questions, with labels added to the two modal answers for each question.

Results show that 90% of participants (*n*=546) agree or strongly agree that there is a limited amount of water available for use in Colorado, indicating high awareness of the finite nature of our water resources. Nearly half of participants (*n*=258 or 43%) agree or strongly agree that there is enough water to meet all current needs, but this response plummets to 9% (*n*=54) when asked about water required to meet all future needs. Aurora residents harbor substantial concerns regarding future water scarcity, mirroring findings from surveys across the state and western US region (Pritchett et al., 2009). And while our survey data is insufficient by itself to explain this concern, focus group data offers some insight:

> "The planning department is approving landscaping that we know is not successful in our arid climate" (Participant 7A, male).
>
> "In my community, in my neighborhood, and my coworkers that even live outside of Aurora – we are concerned about… the global climate. We know that we're suffering a drought, you know, for several years" (Participant 20C, female).

The first quote highlights two different rationales that contribute to future water concerns. All 24 focus group participants expressed concern about inefficient landscaping in Aurora and societal valuation of thirsty lawns. But we also see these concerns connecting to seemingly conflicting economic priorities within the city. Participants perceive a hypocrisy between the city encouraging new developments and approving large installations of new turf lawns while simultaneously trying to conserve water resources. The second quote introduces another common concern regarding climate and the influence of the current southwestern US megadrought. Collectively, we see heightened awareness of how social, political, and environmental systems influence Aurora's water supply, which indicates a relatively high level of hydrosocial knowledge.

Additional focus group data about water equity in Aurora supports the existence of high hydrosocial knowledge among the Aurora community:

> "Based on my experience… HOAs, especially in the eastern parts of Aurora, probably get better information than, say, the western parts of Aurora. You know, the western parts of Aurora are the older parts of Aurora" (Participant 1A, female).

> "I live on the south end of Aurora, and I work on the north end of Aurora, and I taste the water and it's substantially different from my house to where I work. And coincidentally, where I work, it's a lower income community" (Participant 13B, male).

Here we see the focus group participants tying sociopolitical differences to issues of water information access and water quality. Several participants perceived homeowner associations (HOAs) as receiving unequal attention and access to information. Additionally, the second quote suggests a difference in water quality based on geographic location and socioeconomic status. While AW ensures equal levels of water quality across their looped distribution system, it is also true that the older neighborhoods tend to have outdated or deteriorating infrastructure (like lead service lines) and are also home to lower income and more diverse households. These facts, which could be contributing to differences in water taste between neighborhoods, indicates an awareness among participants of different physical water needs between various parts of the city.

5.4.1.4 Functional Knowledge

The fourth knowledge set identified by McCarroll and Hamann (2020) is functional knowledge, which they describe as a knowledge set that bridges cognitive water knowledge into water-related atttitudes and behaviors. In other words, functional knowledge introduces the "how-to" of water sustainability. We targeted this category of knowledge using four questions that asked broadly about access to information and perceptions of personal impacts (Figure 5.8). In doing so, we reveal that participants believe they have access to the information they might need to engage with water sustainability. The majority of participants agree or strongly agree that they can access information about AW's system (*n*=454 or 77%) and their own household use (*n*=517 or 89%). This suggests that residents have the functional knowledge of finding information necessary to engage with water sustainability.

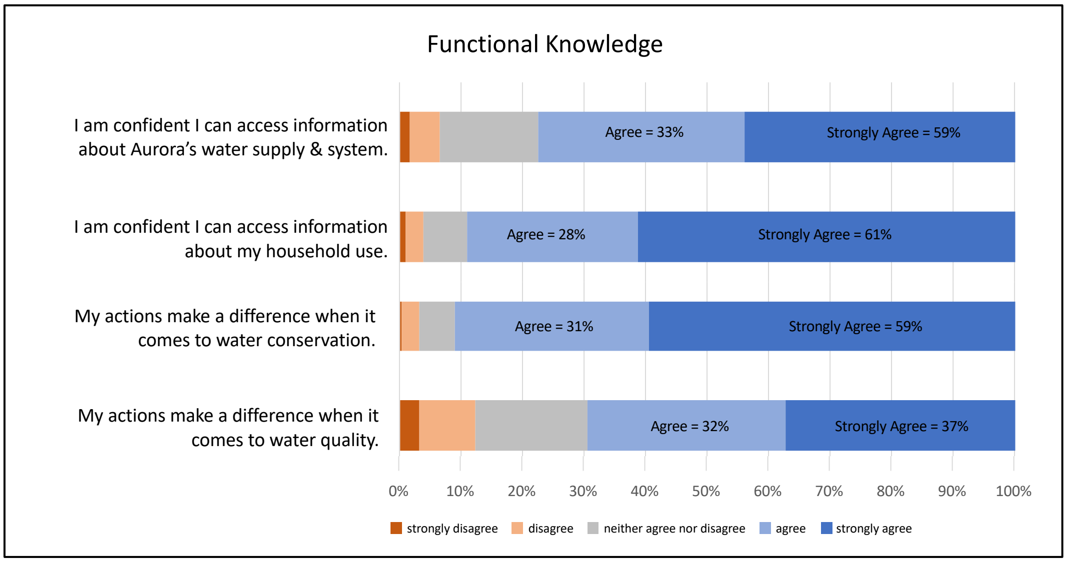

Figure 5.8: Survey results of functional knowledge questions, with labels added to the two modal answers for each question.

Survey respondents also overwhelming agree or strongly agree that their personal actions impact both water conservation (*n*= 552 or 91%) and water quality (*n*=421 or 69%). This suggests they have the functional knowledge or "know-how" of engaging with water sustainable actions. That said, there is an important discrepancy within responses to these two questions. That is, participants perceive more influence from their actions on water conservation than water quality. This discrepancy was explored further in the focus group and was first met with two different responses:

> "It would seem to me that water quality takes place in the water treatment plant and in the infrastructure. Not so much in [my actions]" (Participant 14B, male).

> "I don't know if residential users are the things most impacting water quality - if that's the case that would be news to me - and I guess I just wonder if that's why most people don't feel like they can have an outside impact on water quality, because they don't view themselves as the person perpetrating the pollution" (Participant 15B, male).

These quotes highlight several potential explanations for why there is a discrepancy about personal impacts to water quality versus water conservation. First, there is a belief that individuals are not responsible for pollution or impacted water quality. In other words, there is a lack of science and systems knowledge regarding water quality, as well as a lack of hydrosocial knowledge regarding how humans impact watershed health. Additionally, we see a lack of ownership over water quality. That is, participants lack the functional and hydrosocial knowledge of how they can improve water quality themselves. Finally, there is an implied sentiment in the second quote that the actions of residential users do not really matter because they are not generating the greatest impact. This interesting sentiment devalues the benefits of water-conscious behaviors because their perceived impact is so small. This sentiment was also tied to certain water conservation actions, although to a lesser extent. Specifically, participants noted that saving shower water for use elsewhere is a drop in the bucket compared to the potential of agricultural water savings. While this is true, it is interesting that these sentiments shift ownership and responsibility of the water issues by surrounding individual actions with a sense of futility.

5.4.1.5 Water Attitudes & Values

Research has demonstrated that knowledge alone is insufficient to generate water literacy and promote water stewardship (Cole, 2007; Kollmuss & Agyeman, 2002). Water-related attitudes and valuation of water as important and limited are also necessary components. Thus, we investigated predominant attitudes and values within the Aurora community through a set of Likert survey questions. Results demonstrate a high level of water-sensitive positions among participants (Figure 5.9). For example, survey respondents overwhelmingly strongly agreed that water conservation is both important (*n*=537 or 88%) and in need of more attention (*n*=453 or 75%). Additionally, 80% (*n*=487) of survey respondents overwhelmingly recognize the personal impacts of water shortages.

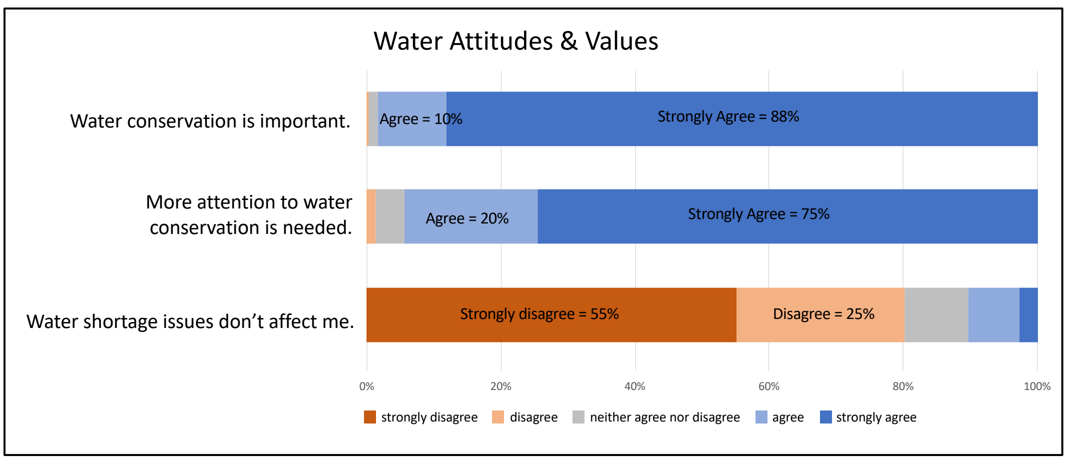

Figure 5.9: Survey results of attitudes and values questions. Labels are added to the two modal answers for each question.

These survey results indicate a high level of appreciation for water conservation and mirror the results of water literacy surveys from other drought prone regions, like Australia (Gilbertson, Hurlimann & Dolnicar, 2011), suggesting a relationship between experience of drought and water-conservative attitudes.

5.4.1.6 Individual & Collective Behaviors

The final water literacy knowledge sets actually refer to water-related behaviors, which McCarroll & Hamann (2020) isolate as separate categories within the water literacy framework because of their importance in generating sustainable water management. Additionally, literature suggests that water knowledge and water-sensitive attitudes may contribute to the formation of water conscious behaviors, although the nature of this relationship is messy and often unpredictable (Dean et al., 2016; He 2018; Jorgensen et al., 2009). Within the survey, we focused on the water conservation behaviors of Aurora residents at an individual or household level (Table 5.4).

Table 5.2: Uptake levels of conservation behaviors from survey results.

Individual Behaviors	**Uptake % (*n*)**
Indoor Behaviors	
Only ran dishwasher and/or washing machine with full loads	63.6% (389)
Turned off tap while brushing teeth and/or washing dishes	62.6% (383)
Fixed leaks inside the home	55.1% (337)
Took shorter showers	54.6% (334)
Installed low-flow devices (i.e. showerhead, faucet aerator)	48.9% (299)
Installed water-efficient appliances (i.e. toilet, dishwasher)	48.7% (298)
Collected shower or sink water for use elsewhere	11.8% (72)
Outdoor Behaviors	
Used automated car washes instead of hand-washing car	63.1% (386)
Fixed leaks in sprinkler system	60.0% (367)
Increased the efficiency of my sprinkler system	54.6% (334)
Installed a smart controller for my sprinkler system	44.8% (274)
Removed my grass/turf and installed a water-wise landscape	29.1% (178)
Reported others for wasting water during restrictions	13.2% (81)
Installed rain barrel(s)	7.4% (45)
Collective Behaviors	
I discuss water restrictions with my neighbors	28.1% (172)
I have reported others for wasting water during restrictions	13.2% (81)

Survey responses from Aurora follow data patterns worldwide that indicate small behaviors with minimal upfront costs are the most commonly enacted (McCarroll & Hamann, 2020). For example, it is relatively easy and cheap to only run dishwashers when full (*n*=389 or 63.6%) and to turn off the tap while brushing one's teeth (*n*=383 or 62.6%). In contrast, collecting one's shower water for use elsewhere (*n*=72 or 11.8%) is a physically intensive task and removing turf for a water-wise landscape (*n*=178 or 29.1%) can be quite costly.

McCarroll and Hamann (2020) also differentiate individual behaviors from collective behaviors, which involve water-conscious actions at a group level. In the survey, we targeted this through the idea of group discussions about water restrictions (*n*=172 or 28.1%) and the act of reporting those who were wasting water (*n*=81 or 13.2%). The results of these were both quite low, mirroring global preferences for individual actions over collective actions. However, they also suggest that fewer people are discussing water issues with each other in Aurora than in other regions, like Alberta (Canada) (AWC, 2015). Focus group participants confirmed these results, saying that they likely wouldn't discuss water with their neighbors even if they witnessed an egregious instance of water wasting. When prompted to explain this, participants revealed a strong concern that water-related discussions, whether one was initiating or receiving them, would be perceived as condescending or accusatory. Pointing out inefficient sprinkler systems or discussing watering schedules was viewed as antagonistic and could create tension with neighbors who could be around for a while. One focus group participant in particular expanded upon this concern:

> "My question is, does this have to be an adversarial conversation? Do we have to say, 'hey you're doing this wrong?' I have a neighbor across the street… and I sit there and I watch them [their sprinklers] making a fine mist, blowing it away, and I don't

> know how to talk to them… I don't have the skills, or I've not figured out the skills, but I know I don't want to have an adversarial conversation" (Participant 23C, male).

This participant summarizes the consensus among the focus groups that although residents care about water conservation, they would rather avoid water-related conversations than risk upsetting the social dynamics within their neighborhood. Even when someone is clearly wasting water, the drive to avoid confrontation ultimately wins. Additionally, this quote introduces a second problem, which is lack of functional knowledge about *how* to engage others. He doesn't have the skills to shift conversations from adversarial to friendly or helpful, and so he avoids them.

Beyond a lack of functional knowledge, there appears to be social and political barriers for engaging in individual and collective actions:

> "I'm just going to water it [my lawn] 'cause I don't want to hear it. I don't want to get a letter from the HOA. I don't want to hear my neighbor. So I'm just going to keep it, you know, green enough 'cause I don't want the drama" (Participant 10B, female).

> "Isn't Aurora [AW] a municipal water authority? So the city is really responsible, and how many people want to get involved with the city? When you look at the politics… many people are just not going to be involved" (Participant 19C, female).

HOAs strictly enforce the management of pristine landscaping with financial threats. One participant shared that her HOA fined her $25/day because her front lawn wasn't green enough, and on top of that fine, she had to spend $1,500 on new sod and a tree to become "compliant". As she shared this story, her body language and tone conveyed deep emotions and frustration regarding the incident. Other participants sympathized, describing with exasperation the angry letters they received from HOAs regarding the installation of their xeriscape. Technically, Colorado HOAs are not legally allowed to prohibit xeriscape under the State House Bill 21-1229 (Colorado Common Interest Ownership Act, 2021). But that doesn't stop them from employing their social power to pressure residents into following social norms or financially disincentivize water conservation. On top of the "drama" of HOAs, participants rationalized the lack of collective action with a disinterest in becoming politically involved. Specifically, the current polarized political climate makes collective action unappealing, no matter the potential benefits. Thus, our data reveals that the uptake of water-conscious actions is hindered by low functional knowledge, as well as attitudes that value community cohesion more than water conservation.

5.4.2 Statistical Analysis of Water Literacy Indices

5.4.2.1 Descriptive statistics of newly created variables

Our statistical analysis reveals important relationships between overall water knowledge, water sensitivity, water behaviors, and AW engagement. These variables were all crafted using specific combinations of survey results, as described in the methodology. The inputs for water knowledge are provided in Table 5.5, along with the corresponded accuracy rates across survey data. Resulting levels of accuracy suggest a pattern inversely related to the level of question specificity or detail. That is, questions that inquire about broad water facts seem to have higher levels of accuracy among survey participants. Examples include facts like drought is a natural occurrence in Aurora (n=520 or 85%), or that water resources in Colorado are limited (n=546 or 89.2%). But when questions target the finer details of Aurora's water system, like source watersheds or fluoridation, accuracy rates decrease.

Table 5.3: Subset of knowledge questions that comprised water knowledge index scores, with answers and respective response rates.

Knowledge Questions	**Accuracy % (*n*)**
Drought is a natural occurrence in Aurora.[1]	85% (520)
There is a limited amount of water available for use in Colorado.[1]	89.2% (546)
Which of the following uses the most water in the state of Colorado:[2] ***Farms & Ranches****; Households; Industrial/Commercial; Other (please specify)*	29.7% (182)
A watershed is defined as an area of land where all the precipitation (rain, snow) that falls on it drains to a single body of water. **True** or False: I live in a watershed.[3]	35.3% (216)
Aurora receives water from which of the following watersheds:[4] **Arkansas River**; **Colorado River**; North Platte River; Rio Grande River; **South Platte River**	
At least 1 correct Watershed	28.1% (172)
At least 2 correct watersheds	18.5% (113)
At least 3 correct watersheds	9.5% (58)
Only the correct 3 watersheds	5.6% (34)
True or False: Aurora Water pipes in some of its water from the other side of the continental divide.[3]	43.6% (267)
My drinking water comes from the following source(s):[4] ***Reservoirs****; Desalinated water;* ***Lakes & Rivers****; Groundwater;* ***Recycled Water; Snowmelt****; Private Well*	
At least 1 correct source	3.4% (21)
At least 2 correct sources	21.1% (129)
At least 3 correct sources	30.7% (188)
At least 4 correct sources	23.4% (143)
Only the correct 4 sources	8.0% (49)
True or False: Treatment is required for water from Aurora Water's reservoirs before that water ends up in the public drinking supply.[3]	92.6% (567)
True or **False**: Aurora Water adds fluoride to the City's drinking water supply.[3]	13.7% (84)
Aurora residents use an average of ____ gallons per person per day for all household uses.[2] *30-40;* ***80-90****; 150-170; 300-320*	30.7% (188)

[1]Likert scale question and correct responses were "somewhat agree" or "strongly agree."
[2]Multiple-choice question, choices listed in italics and correct answers are bolded.
[3]True-False question, correct answer is bolded.
[4]Multiple-choice question with multiple correct answers, choices listed in italics with correct ones bolded

A histogram depicting the collective water knowledge scores is provided in Figure 5.10a. Collectively, survey respondents received water knowledge index scores ranging from 1 to 9.60 (out of 10 total) but displayed a high degree of variability around a mean of 4.93. While no participant scored a knowledge level of 0, there were also no participants who scored a perfect level of 10 either.

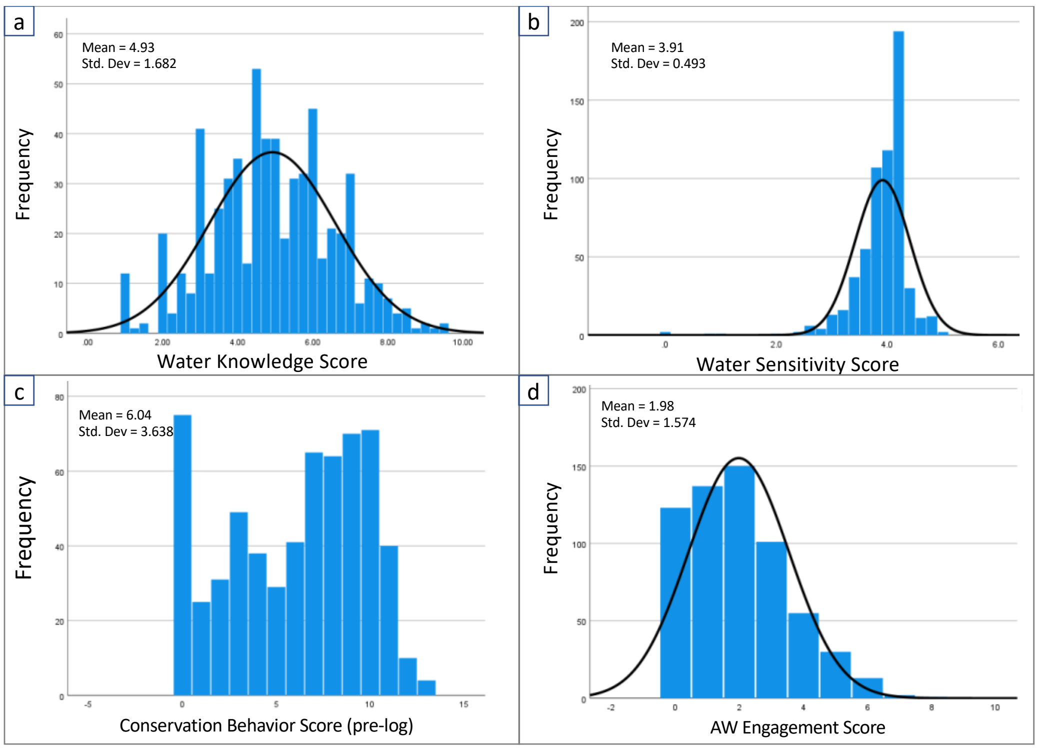

Figure 5.10: Histograms for new water literacy indices across survey responses. Water knowledge, water sensitivity, and AW engagement histograms are overlaid with a normal curve for comparison.

Figure 5.10b depicts the histogram of collective water sensitivity scores, which denotes aggregated responses for water attitudes (i.e. water conservation is important) and functional knowledge (i.e my actions make a difference for water conservation). Survey respondents scores ranged from 0 to 5 (out of 5 total), centered around a mean of 3.91 (Figure 10b). The location of this mean above the median range value indicates that survey respondents trended towards higher levels of water sensitivity. This result matches the results discussed within the functional knowledge and attitudes and values sections previously.

Figure 10c depicts the histogram of individual conservation behavior scores for each survey respondent, which range from 0 to 14 (out of 14 total). Whereas a score of zero (*n*=75 or 12%) was the most common response, 88% (*n*=537) of respondents adopted at least one conservation behavior. These results suggest that most respondents have assumed at least some level of water conservation. Additionally, more than 50% (*n*=324) of respondents have adopted seven or more conservation behaviors. For comparison, Dean et al. (2016) conducted a theoretically similar but methodologically different water literacy study which grouped survey participants in Australia into water engagement clusters. Only the top three clusters (72.5% of the sampled population) indicated uptake of water conservation behaviors, and only the top two clusters (41.1% of the sampled population) indicated high uptake of water conservation behaviors. This suggests that most Aurora residents are actually espousing many of the conservation actions recommended by AW.

Finally, AW engagement scores range from 0 to 8 (out of 10 total) with a right skewed distribution (Figure 5.10d), indicating that most participants engage with only a few of the AW programs specified in the survey. Indeed, the mean is only 1.98, which sits on the lower end of the possible range. Realistically, any form of engagement with AW is better than no engagement, and many of the programs specified in the survey have the potential to impact multiple facets of water literacy. The monthly KYF emails, for example, provide information and suggestions for indoor and outdoor water use. Thus, we interpret the 57.5% (*n*=352) of respondents that engage with two or more of the specified AW programs as a positive result. Additionally, there are likely several ways to engage with AW that would not be represented within this index. For example, visiting AW booths during city festivals and events would likely contribute to water-related knowledges, attitudes, or behaviors, as would strolling through the expansive AW water-wise demonstration garden. Neither of these were encompassed within our survey.

For the programs that were contained in our survey, a more detailed breakdown of participation rates is provided in Table 5.6. The results highlights than most of the programs have less than 15% participation rates among survey participants. The notable exceptions are reading the yearly water quality reports (*n*=326 or 53.5%) and the KYF program (*n*=256 or 41.8%). Both of these are easily accessible online or through one's email, making participation easier than those requiring in-person commitments. Additionally, participation rates for the KYF program are likely an overestimation, given that we recruited survey participants through the KYF listserv. It is also worth noting the higher participation level of 28.8% (*n*=176) in the rebate programs, which can likely be attributed to the financial incentivization of such programs.

Table 5.4: Participation levels with AW education and outreach programs.

AW Engagement	**Participation Level % (*n*)**
Read AW's Yearly Quality Report	53.5% (326)
Know Your Flow Program	41.8% (256)
Rebates for water conserving fixtures (i.e. toilets, sprinklers)	28.8% (176)
Outdoor Water Assessment for lawn/yard	18.8% (115)
Follow AW on social media (i.e. Twitter, Facebook, Instagram, Nextdoor)	14.5% (89)
Indoor Water Assessment for home	13.1% (80)
Conservation classes	12.6% (77)
Facility Tours	8.2% (50
Youth Education	5.7% (35)
Other (please specify): (i.e. Water-wise Landscape Planning)	1.0% (6)

5.4.2.2 Correlations between variables

A 2-tailed bivariate Pearson Correlations analysis was used to identify linear relationships among the newly created water literacy indices. The results of this test, provided in Table 5.7, demonstrate positive and statistically significant relationships between almost all possible pairings of the water literacy indices. We also included length of residency in Aurora as a variable, as well as the number of times they would have experienced drought declarations from Aurora Water based on their length of residency (labelled Aurora Drought Experience) as variables.

Table 5.5: Associations between water literacy indices.

		Aurora Drought Experience	Water Sensitivity	Conservation Behaviors (log scale)	AW Engage-ment	Water Knowledge	Aurora Residency (yrs)
Aurora Drought Experience	r	--					
	p-value						
Water Sensitivity	r	0.040	--				
	p-value	0.319					
Conserva-tion Behaviors (log scale)	r	.249**	.274**	--			
	p-value	<0.001	<0.001				
AW Engagement	r	.244**	.146**	.370**	--		
	p-value	<0.001	<0.001	<0.001			
Water Knowledge	r	.155**	.146**	.265**	.319**	--	
	p-value	<0.001	<0.001	<0.001	<0.001		
Aurora Residency (yrs)	r	.821**	0.007	.234**	.231**	.165**	--
	p-value	<0.001	0.861	<0.001	<0.001	<0.001	

** Correlation is significant at the 0.01 level (2-tailed).

The only variable pairings that do not indicate significance are between water sensitivity scores, Aurora residency in years, and Aurora drought experiences. Thus, we cannot infer a significant relationship between water sensitivity and the length of time a participant has lived in Aurora, nor between water sensitivity and the number of AW drought declarations they have witnessed. Additionally, the high level of correlation between Aurora drought experiences and Aurora residency is meaningless because the latter is used to calculate the former.

In contrast, we find the strongest relationship between AW engagement and combined behavior scores, indicating that survey participants with greater uptake of water conservation behaviors also demonstrate greater engagement with AW programs. Indeed, this follows from the design of most AW programs. For example, the suite of rebate programs necessitates that participants actually engage in a conservation behavior (i.e. replace old toilet, install a smart controller, etc.) before they can be financially reimbursed. Additionally, the indoor and outdoor water assessments often identify inefficient or leaky toilets or sprinkler systems, and participants are then directed towards the rebate programs to encourage repairs and updates.

Our results also suggest many other meaningful associations between important water literacy elements. For example, water knowledge is positively correlated with both water sensitivity and uptake of water conservation behaviors. This suggests that participants with higher water knowledge also tend to have higher water sensitivity and increased uptake of conservation behaviors. Additionally, Aurora drought experience is positively correlated with water knowledge, water behaviors, and AW engagement. This suggests that participants who have experienced Aurora's drought declarations may also have higher water knowledge, larger uptake of conservation behaviors, and greater engagement with AW programs. While none of these correlations indicates direct causation, the strong associations indicated within these results highlight the importance of AW's interactions and experiential learning within Aurora's community water literacy.

5.4.2.3 Water literacy indices across demographic groups

Our last statistical tests included running one-way analysis of variance (ANOVA) using our water literacy indices and the survey demographic groups. These results are provided in Table 5.8.

Table 5.6: One-way ANOVA of water literacy variables.

	Water Knowledge		Water Sensitivity		Water Behaviors		AW Engagement	
	F	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**
Home Ownership	5.73	0.017*	1.21	0.283[w]	0.23	0.633	38.24	<0.001**[w]
Aurora Residency	4.97	<0.001**	0.72	0.607[w]	5.78	<0.001**[w]	17.41	<0.001**[w]
AW Drought Experience	8.32	<0.001**	1.04	0.356[w]	6.97	0.001**	19.52	<0.001**
Education	2.69	0.007**	0.50	0.849[w]	1.33	0.224	0.84	0.571
Race	3.94	<0.001**	0.28	0.949	0.46	0.841	1.79	0.098
Ethnicity	5.66	0.004**	0.95	0.388	1.61	0.202	1.13	0.323
Income	1.49	0.192	0.95	0.446	1.15	0.335	1.24	0.002**[w]
Gender	17.38	<0.001**	4.732	0.015*	1.70	0.184	7.34	<0.001**

** significant at 0.01 level
* significant at 0.05 level
[w] calculated with Welch test to accommodate violated assumption of homogeneity of variance

The results of the ANOVA tests reveal that there are statistically significant differences in mean water knowledge scores across nearly all demographic characteristics. Mean water knowledge is higher among participants that own their homes, have lived in Aurora for longer periods, and have experienced more AW drought declarations. Average water knowledge scores for resident groups who have lived in Aurora long enough to experience the 2002 drought are notably higher, suggesting that water knowledge is correlated not just to number of drought experiences but also severity of those droughts. We also find higher mean water knowledge scores among participants who are male and self-identify as white, American Indian or Alaskan Native, or not of Hispanic or Latinx origins. This could indicate that white, non-Hispanic males score slightly higher in terms of water knowledge. But these results are more likely a function of the lack of diversity represented among our survey respondents.

Mean water sensitivity scores did not show nearly as much variation as water knowledge scores. Only divisions within gender demographics generated a statistically significant variance, with women and those who preferred not to answer demonstrating slightly higher mean water sensitivity scores than men.

Mean water conservation behavior scores showed significant variation across Aurora residency groups and experiences of AW drought declarations. Those who have been in the city longer, and have experienced all of Aurora’s drought declarations, demonstrate slightly more uptake in water conservation behaviors. This emphasizes again the importance of lived experiences within water literacy.

Finally, we see a few notable differences in mean AW engagement scores across several demographic groups. Homeowners who have lived in Aurora longer and experienced more drought declarations exhibit slightly higher mean AW engagement scores. Indeed, homeowners with experiences of drought would likely have more to gain from reducing their water bills, fixing leaks, and being financially rewarded for installation of water saving devices. These results indicate that AW engagement is stronger among these demographic groups. This theory is supported by the fact that renters comprised a mere 4% (n=25) of our survey respondents. Additionally, we find that mean AW engagement scores are significantly different across gender groups, with men averaging higher AW engagement scores than women, as well as across income groups, with a positive relationship between increasing income and increasing AW engagement.

5.5 Discussion

Our results reveal strengths and weaknesses within the community water literacy of Aurora. For example, we find that Aurora residents understand basic water concepts, like the benefits of a healthy watershed and the fact that all of AW's supply needs treatment to become potable. However, our findings also suggest that community literacy decreases as the information in question becomes more technical or detailed. Familiarity with scientific terminology is low, and the specifics of AW's supply and treatment system largely go unrecognized. There is some debate among scholarship about whether the public needs to understand scientific terminology in order to engage with water management (Giurco et al., 2010; Huxhold, 2016; Sammel, 2014; Zint, 2011). However, there is widespread agreement that the public should understand where their water comes from both to protect source watersheds and to make informed and responsible decisions (AWC, 2016; Eldridge-Fox et al., 2010; Hensley, 2014; Laporte et al., 2013; McCarroll & Hamann, 2020; Sherchan et al., 2016). In this sense, Aurora residents might be lacking critical knowledge about their own system to help ensure sustainable water use.

That said, our results also suggest that Aurora residents have strong hydrosocial and functional knowledge. There is an understanding that our water resources are both limited in nature and highly demanded. There is also an awareness that water injustices may be shaped by socioeconomic status, where low-income neighborhoods have both old, deteriorating infrastructure and HOAs that receive less water information when compared to newer, high-income neighborhoods. Additionally, we find high functional knowledge regarding individual actions and information sourcing, as well as strong water-conscious attitudes and values. This leads to a moderate adoption of water conservation behaviors at the individual level. Similar to findings from other US populations, individual actions that require minimal time and energy are among the most popular (NGS, 2001; True North Research, 2019). However, our research suggests that uptake of collective actions is hindered by low functional knowledge of how to engage others, as well as a desire to preserve community amity. We also find a lack of functional and hydrosocial knowledge driving a divide between individual actions and water quality.

By creating and comparing water literacy indices, we contribute to our theoretical understanding of water literacy. For example, we find significant positive correlation between AW engagement levels, water knowledge, water sensitivity, and water behaviors. This suggests that residents with higher engagement with AW also tend to have higher water knowledge and sensitivity scores, as well as greater adoption of water conservation behaviors. Additionally, we find significant positive correlations between experience of drought, water knowledge, and water behaviors, which supports theories that lived experiences of drought contribute to greater water literacy. However, we argue no direct causation within these messy and interwoven relationships. For example, it is unclear from our results alone if increased conservation behaviors occur because of engagement with AW, or if increased AW engagement occurs as a result of seeking ways to conserve. In fact, we suggest that the strong correlation between these variables may indicate a circular feedback system, which would offer numerous pathways towards increasing community water literacy.

However, investigating Aurora's community water literacy through the lens of political ecology reveals numerous sociopolitical systems that influence water-related knowledges, attitudes, and behaviors. For example, the desire to preserve community amity actually stops Aurora residents from engaging their neighbors with conversations about water, even when excessive water wasting is observed. Additionally, individual water behaviors are stalled by what residents perceive as conflicting priorities within the City. Residents considering efficiency updates on their own sprinkler systems watch city sprinklers turn on during peak evaporation hours and spray impermeable surfaces. When considering xeriscape installations, they see enormous developments with acres of green grass that were approved by the City. On the one hand, these complaints demonstrate knowledge regarding evapotranspiration and local watering restrictions. On the other hand, residents perceive hypocrisy within the local government, which generates resentment and inaction. Jorgenson et al. (2009) found that people are more willing to reduce their own water consumption when they believe their water managers and local government are also doing their part. Our research reveals the inverse is also true – that Aurora residents are disinclined to conserve water themselves because the city does not appear to be doing their part. Additionally, the situation is confounded by feelings that residential savings from collecting shower water in a bucket is inconsequential to the losses from irrigation systems on city parks. Thus, frustration and resentment surrounding city actions are paired with a sense of futility. In these ways, social relations and the actions of the city act to inhibit water literacy and water conservation.

We also find formal sociopolitical structures influence water literacy in Aurora. The influence of HOAs, for example, often dissuades the valuation and adoption of sustainable actions. Angry letters about xeriscape and fines for grass that isn't green enough pressure residents to abide by HOA expectations, even if they aren't legally enforceable. Again, the desire to avoid conflict and "drama" discourages residents from adopting water-conscious behaviors. It's important to note that HOAs are created and funded by community members, and so the barriers to water literacy shaped by HOAs are also reflecting societal valuation of lush lawns as visually appealing and desirable. In this sense, our finding regarding the influence of HOAs hinder water literacy mirrors research that suggests outdoor water conservation is dominated by subjective norming (Chaudhary et al., 2018; Larson & Brumand, 2014). However, our findings suggest that some HOAs in Aurora are utilizing their power to enforce subjective norms and disincentive water conservation.

5.6 Conclusion

For nearly two decades, AW has been a state leader and innovator in water literacy and demand management. Our research provides a systematic analysis of community water literacy, and its relationship with AW engagement and experiences of drought. Our results highlight current strengths and weaknesses within community water literacy, and how these relate to AW programs, subjective norms, and community interactions. Importantly, our survey provides AW with a tool that can be used to continually poll the community about their water-related knowledges, attitudes, and behaviors. Water literacy is a moving target that ebbs and flows with demographic shifts, community growth, and changing precipitation patterns.

Development in Aurora isn't going to let up any time soon. That fact paired with the status of the current megadrought means AW will need to increasingly rely on water literacy and demand management. Thus, perceptions of water use inequity and the futility of water conservation need to be addressed quickly. AW and the City of Aurora need to visually demonstrate more holistic integration between planning and water management and confront neighborhood structures that disincentive water conservation. Perhaps most importantly, our research demonstrates a need to shift the dominant social norms and valuation surrounding water conversations. We suggest AW facilitate the transition from adversarial, political, and divisive lectures, to considerate, collaborative, and beneficial discourse.

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Chapter Six: Conclusion & Theoretical Contributions

Water literacy is an increasingly important field of research within water management, particularly for drought-prone regions that face aridification and worsening drought patterns due to the impacts of climate change. Given the concepts relative newness, I sought to add to the theoretical understanding of water literacy, including how it is understood, applied, and impacted by sociopolitical contexts and experiences of drought. Framing my research on theories of political ecology and the theory of planned behavior, and combining multiple qualitative and quantitative methods of research, I sought to address the following research questions:

1. How has the concept of water literacy been understood and applied in the literature and in practice?
2. What are the water literacies of communities in Cape Town and Aurora, measured by water-related knowledges, attitudes, and behaviors?
    a. Are there correlations or relationships between these elements of water literacy?
3. How do water literacies of communities in Cape Town and Aurora relate to their geographic, sociopolitical, and economic contexts? How do they relate to lived experiences of drought?
    a. How was water literacy used to engage tourists in Cape Town during the Day Zero drought?

I will now discuss the summarize the key findings of these research questions, as well as the theoretical contributions and the policy implications. Finally, I will conclude with thoughts of future research directions.

6.1 Key Findings

My first research question sought to synthesize how the concept of water literacy has been understood and applied in existing literature and in practice. Simply put, the answer to this question is that water literacy has been understood and applied with incredible diversity. Water literacy definitions, like those presented in Chapter 2, range from a single all-encompassing sentence to exceedingly detailed and specific structures. The interdisciplinary nature of water, weaving through all facets of our world, results in a vast number of opinions on what water-related topics one should know. Thus, the synthesis of these definitions organizes our understanding of water literacy into eight concrete categories, or knowledge sets: general knowledge, science and systems knowledge, local knowledge, hydrosocial knowledge, functional knowledge, attitudes and values, individual actions, and collective actions. The framework depicting these knowledge sets is specific enough to structure how we approach water literacy, but flexible enough to allow for differences between case studies. To answer the second half of research question 1, I apply this water literacy framework to existing surveys and studies from across the world and identify common strengths and weaknesses. This establishes a rough baseline of water literacy strengths, from which future water literacy research can be compared.

The second research question was primarily addressed by surveys that were distributed to both Cape Town and Aurora. While the surveys were similar in some ways, they were also tailored to the specific community in question. Importantly, the Langa survey was created, distributed, and collected before the water literacy framework was fully developed. This means that not all of the knowledge sets were built into the Langa survey, as they were in the Aurora survey. The specific findings of water knowledges, attitudes, and behaviors in Langa and Aurora were provided in Chapters 3 and 5, respectively. While these two case studies offer vastly different sociopolitical and economic contexts, there are some key findings that emerge from the combination of these case studies. For example, both communities held knowledge about general water concepts, but lacked familiarity with more specific terminologies that would be utilized by managers (i.e. drought, groundwater, watershed). Both communities also lacked specific knowledge about local water sources. Finally, both communities demonstrated high hydrosocial knowledge and water-conscious attitudes, which are attributed to lived experiences. Langa and Aurora residents demonstrate strong appreciation for water conservation, which is tied to experience of drought for both and the lived reality of water insecurity for Langa.

The answer to Research Question 2b was extracted mostly from the Aurora case study largely because of the timing of the survey after the development of the water literacy framework. The results identified strong positive correlations between Aurora's water knowledge, water sensitivity, and conservation behaviors. Moreover, these were also positively correlated to engagement with the local water managers, indicating that pathways for community engagement are tied to water literacy. The exact nature of these correlations was not fully explored, so I cannot with full confidence say which causes which. However, a deeper reflection of the water literacy framework causes me to believe that determining exact causal relationships is a moot point. They are all important elements within water literacy, and the borders between them are faded and continually changing. The suggestion, then, is that all of these elements need to be centered in water management processes to truly build water literacy.

The final components of my research centered around the relationships between water literacy within Langa and Aurora and their respective sociopolitical, economic, and geographic contexts. The answer for Research Question 3 emerged largely from the focus groups, which were more numerous and extensive in Aurora than they were in Langa because of the COVID-19 pandemic. For Aurora and Cape Town, drought is a regular occurrence. Both communities have recently experienced climate shocks in the form of severe socioeconomic droughts that threatened municipal failure. Within each case study, I find evidence of increased water literacy that is attributable to the lived experience of these climate shocks. However, contrasting sociopolitical contexts result in substantial differences in the benefits of these water literacy increases.

For Aurora, the 2002 drought dropped reservoir capacity to 25% and fueled widespread innovation. Since then, water managers have embraced demand management. Water information is accessible and opportunities for engagement abound. I argue that this has built a firm foundation of water literacy within the community. As a result, community concerns about Aurora's water future emerge out of fear of an uncertain climate, as well as unrealistic societal values and expectations regarding water use. There is still a desire to hold the city accountable for their own water use, but the community expresses an internal need for reflective reevaluation of societal preferences, like those for lush green lawns in a semi-arid climate.

In stark contrast is Cape Town and its surrounding sociopolitical context. A long history of racial fragmentation has manifested in highly unequal water access and an enormous accumulation of water debt among those who can least afford to pay it. As a result, the local water department focuses so much on cost-recovery that they shut out local communities like Langa township and disregard their needs or input. This not only acts as a barrier for the transfer of water knowledge, but it also fuels distrust to the point of invalidating water information during climate shocks. Day Zero, for example, was viewed as a hoax in Langa even as the reservoir capacity plummeted below 20%. Thus, we can see that while the community who can access water knowledge and engage has begun to turn a reflective eye inward, the community who is shut out no longer trusts what could be sources of water knowledge.

Cape Town also presents a unique economic context, where tourism is an essential contributor to local jobs and GDP but also drives unsustainable water use during climate shocks. My investigation of tourism demand management in Chapter 4 reveals that such programs were not only an important contributor to tourism water savings during Day Zero, but also benefitted Cape Town broadly in several key sociopolitical and economic ways. Additionally, I argue there is a desire for such demand management from tourists, who want to continue exploring but in a socially and environmentally responsible way.

The conclusion, then, is that tourism demand management is an important contributor both to drought management and economic sustainability and can potentially create a ripple effect across the world regarding water conservation.

6.2 Overriding Themes

The side-by-side comparison of water literacy within Aurora and Cape Town present several overriding themes. First, both case studies confirm theories from other scholars that water literacy is shaped by lived experiences, and experiences of drought in particular (Booysen et al., Dean et al., 2016; Gilbertson et al., 2011; Harnish et al., 2017; McDuff et al., 2008). Second, they both confirm that nearby surrounding sociopolitical influences that directly influence water literacy development and community engagement within water processes. However, for all their similarities, the unique factors of these case studies also emphasize the importance of contextualization. Community water literacy differs based on municipal management of climate shocks, and dominant social institutions. Water literacy in Cape Town is limited by the organization and dominant attitudes of Cape Town's municipal structure. Specifically, a focus on cost recovery restricts information flow until debts are paid, and the use of intimidation and fear dissuades community members from seeking information. Meanwhile, the municipal structure and attitudes of Aurora Water actively embraces community education and engagement, thereby encouraging the development of community water literacy. For Aurora, limitations emerge instead from subjective norms, community dynamics, and social institutions like HOAs.

Finally, these differences in sociopolitical influences emphasizes the third overriding theme, which is the need for contextualization and qualitative study. I argue that the concept of community water literacy is intrinsically linked to the community's setting and must be understood as such. For example, the awareness of shifting precipitation patterns among Langa residents emerges not from a recognition of aridification and reduced water resources but from a reduction in flooding experiences. This explanation would not have been evident from the survey alone, developing only through the detailed discussions and follow-ups that occurred within the focus group. In terms of water literacy, then, a holistic understanding of the intricacies between water-related knowledges and attitudes must be understood within its socially constructed reality, which necessitates the inclusion of detailed qualitative research on daily lived experiences. This theme also rounds back to the results of my first Research Question, which found a broad array of existing definitions and applications of water literacy. That is, the sheer diversity of the use of water literacy emerges from contextual differences that subjectively shape the concept in different ways across different case studies.

6.3 Theoretical contributions

My research contributes to the fields of water security, political ecology, and hydrosocial scholarship in the following ways.

Water security has been a central topic of research for roughly two decades now, following recognition that supply-focused management paradigms of the past are increasingly insufficient, unequitable, and problematic (Linton, 2014). As an alternative paradigm, water security seeks a more holistic and inclusive approach to managing water as both a beneficial resource and a destructive power (Grey & Sadoff, 2007; Loftus, 2015). Importantly, water security allows for multi-scale contextualization to maximize operationalization (Cook and Bakker, 2012; Cook, 2016; Chomba et al., 2017). Therefore, within my dissertation, I approach water literacy with a similar approach – first generating a large-scale, integrative theory of water literacy and how its contributions to achieving water security, and then contextually narrowing into the communities of Aurora and Cape Town for greater operationalization. Water security also seeks to bring all members of society into water management to become makers of change (Loftus, 2015). Here, within the inclusivity goal of water security, is where my research contributes the most. Sustainable water management requires the broad participation and engagement across society, but it is difficult to engage in meaningful ways without a foundational water literacy. Indeed, community water literacy helps generate constructive dialogues and transfer of knowledge between water managers and community members. Thus, my research helps to build community water literacy, give voice to water injustices, and increase transparency and trust within water management processes.

My research also contributes to the political ecologies of water in two main ways. This field, which has been around for several decades now, is already quite extensive has been used to understand the intersections between environmental issues and surrounding social, political, and economic systems. For example, it has demonstrated that water scarcity is created by unequal social powers, inequitable access to water resources, and the privatization of water systems as much as it is created by physical drought. All of these themes were directly relevant to my research within Cape Town and Aurora to varying degrees. But importantly, the application of political ecology to the concept of water literacy is a new and unique contribution. In this way, my research expands political ecologies of water beyond the concept of water management and water security, but into the realm of *how* and *why* we know what we know. For example, in Chapter 3, political ecology helps to reveal how gaps in Langa's community water literacy are shaped by water corporatization and communication structures that discourage or even outright prevent the flow of actionable water information. With this unique combination, I thus add complexity to the political ecology conversation.

A second contribution to the field of political ecology can be found in Chapter 3, where I explore tourism demand management through the lens of political ecology. This specific chapter answers a common criticism of political ecology for revealing problematic power structures without offering much of a solution or path forward (Blaikie, 2008; Braun, 2015; Ingalls & Stedman, 2016; Walker, 2006). Within Chapter 3, I apply an approach recommended by Ingalls and Stedman (2016) to apply political ecology to an instance of resilience. Such an approach allows a backwards look, a reflection, on power structures or actions that worked to resolve environmental crises, therefore informing future actions. Specifically, I look to examples of resilience within Cape Town's tourism industry to reveal that tourism demand management is not only an effective way to help survive drought, but it also benefits the surrounding sociopolitical and economic systems and shapes an excited and loyal tourist base.

Finally, my research utilizes and expands upon hydrosocial theory. Water managers increasingly recognize that supply-focused paradigms designed to capture, control, and commodify water are often the cause of countless environmental and social injustices. From this recognition emerges hydrosocial theory, which investigates the ways in which water and society are intrinsically intertwined (Linton & Budds). This theory was a critical component within existing water literacy research, and became a key knowledge set within the emerged water literacy framework in Chapter 2. In this way, the use of hydrosocial theory was critical to understanding and applying the concept of water literacy. However, the lessons learned from my applications of water literacy within Cape Town and Aurora also help to inform our understanding of hydrosocial theory. That is, the findings from the case studies reveal how water knowledge, attitudes and behaviors can influence how social systems engage with water resources. In as much as hydrosocial theory is a circular give-and-take relationship between water resources and society, so too is water literacy.

6.4 Policy implications

The results from my research provide a contextualized baseline of water literacy for both Langa and Aurora, from which future water literacy efforts and water management programs can be developed and evaluated. Unfortunately, this has limited ability to affect great or immediate change in Langa, given the difficulties of engaging the Water and Sanitation department. Even local researchers struggle to engage Cape Town's water managers. However, at the very least my research can give residents of Langa ownership of their water literacy. It also adds to the growing body of literature demanding more equitable and engaged water management structures within Cape Town.

In Aurora, my former working relationship with AW offers a unique opportunity to suggest policy or program changes to those who have the power to make the change. They have already expressed a desire to do just that and use an enhanced understanding of community water literacy to shape their current and future programs. Additionally, my research confirms that they are not reaching out to their entire community, and therefore need to expand their programs accordingly.

More generally, my research contributes to the field of water management and water policy by encouraging more direct and open channels between water managers and communities. A strong bi-directional transfer of water information, attitudes, and behaviors is needed to increase sustainability within water management. It is critical to keep a continuous pulse on community water literacy, to both increase acceptance of supply management techniques like recycled wastewater, as well as encourage demand management techniques.

6.5 Directions for future research

The results of the research within this dissertation greatly adds to the academic field of water literacy. However, it also leads to several trailheads that could be shaped into future research paths. In terms of data from the mixed methods used within this dissertation, I ambitiously collected more data in both of my research sites than I could possibly have synthesized within the bounds of this dissertation. Thus, I focused on answering the main research questions, and have saved the additional data for future research. In Langa, this includes a breakdown of water literacy elements by type of dwelling. In Aurora, this includes an geographic examination that spatially examines water literacy elements across Aurora neighborhoods, as well as an analysis of AW communication strategies and their effect on community water literacy.

In terms of new research, my findings establish several new questions that are worth exploring. For example, the constitutional right to water in Langa is both incredibly unique and widely misunderstood. The lack of knowledge about FBW within my survey was striking and unfortunate. Would an increased understanding of the FBW policy enhance the agency of Langa residents? Do non-township residents of Cape Town know and understand FBW? These are questions I hope to build out in future research.

Aurora uniquely was engaged with continued research in mind. The goal is to refine the survey again, using the results of my dissertation, and redistribute it on a semi-regular basis to Aurora residents. This could be especially critical now, as the southwestern US has officially declared megadrought status. How would survey results change now, with the raised awareness of megadroughts? Additionally, would it be possible to pair survey results with actual water usage data? This would require acquiring the water meter information for each survey respondent, which is harder but entirely possible.

Lastly, the highly contextual nature of water literacy necessitates a broader array of case studies. Of particular importance are case studies within developing countries, as well as studies involving non-traditional forms of water knowledge.

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Appendices

Appendix A: IRB for Chapter 3 (Langa)

UNIVERSITY of DENVER
OFFICE OF RESEARCH & SPONSORED PROGRAMS
Research Integrity & Education

DATE:	June 3, 2019
TO:	Gary Thomas LaVanchy, PhD
FROM:	University of Denver (DU) IRB
PROJECT TITLE:	[1387876-1] Geographies of Day Zero
SUBMISSION TYPE:	**EXPEDITED NEW PROJECT**
APPROVAL DATE:	June 3, 2019
NEXT REPORT DATE:	June 2, 2021
RISK LEVEL:	Minimal Risk
REVIEW TYPE:	Expedited
ACTION:	**Approved**
REVIEW CATEGORY:	Expedited Category # 7 **Category 7:** *Research on group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.*

Thank you for your submission of the **New Project** materials for this project. The University of Denver Institutional Review Board (IRB) has granted Full Approval for your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission. The IRB determined that the criteria for IRB approval of research, per 45 CFR 46.111, has been met.

This submission has received an Expedited Review based on applicable federal regulations. This project has been determined to be a Minimal Risk project. Please note that the following documents were included in the review and approval of this study:

- Consent Form - IRB_information&consent_JUN2019.pdf (UPDATED: 05/16/2019)
- Consent Waiver - Appendix_A_Waiver of written consent.pdf (UPDATED: 05/3/2019)
- DU - IRB Application Form - DU - IRB Application Form (UPDATED: 05/16/2019)
- Other - Appendix_G_International Form.pdf (UPDATED: 05/3/2019)
- Protocol - Verbal recruitment script_JUN2019.pdf (UPDATED: 05/16/2019)
- Protocol - Protocol Narrative_expedited.pdf (UPDATED: 05/16/2019)
- Questionnaire/Survey - IRB_Questionnaire.pdf (UPDATED: 05/3/2019)

Informed Consent Process

Please remember that informed consent is a process beginning with a description of the project and the assurance of participants understanding. Informed consent must continue throughout the project via a dialogue between the researcher and the research participant. Federal regulations require that each participant receives a copy of the consent document.

Implementation of Changes to Previously Approved Research

Prior to the implementation of any changes in the approved research, the investigator must submit any modifications to the IRB through completing an amendment form and await approval before implementing the changes, unless the change is being made to ensure the safety and welfare of the subjects enrolled in the research. If such occurs, a Reportable New Information Form should be submitted, via the IRBNet system, within five days of the occurrence indicating what safety measures were taken and provide an updated protocol and/or consent if applicable.

Unanticipated Problems Involving Risks to Subjects or Others (UPIRTSOs)

Any incident, experience or outcome which has been associated with an unexpected event(s), related or possibly related to participation in the research, and suggests that the research places subjects or others at a greater risk of harm than was previously known or suspected must be reported to the IRB. UPIRTSOs may or may not require suspension of the research. Each incident is evaluated on a case by case basis to make this determination. The IRB may require remedial action or education as deemed necessary for the investigator or any other key personnel. The investigator is responsible for reporting UPIRTSOs to the IRB within 5 working days. Use the Reportable New Information (RNI) form within the IRBNet system to report any UPIRTSOs. All NON-COMPLIANCE issues or COMPLAINTS regarding this project must also be reported promptly to this office.

Continuation Review Requirements

Based on the current regulatory requirements, this project does **not** require continuing review. This project has been assigned a **two-year approval period** requiring communication to the IRB at the end of this approval period to either close the study or request approval for another two years. The two-year approval period will be posted in the Next Report Due section on the IRBNet Submission Details page. During this two-year period, the IRB may also conduct a Post Approval Monitoring visit to evaluate the progress of this research project.

PLEASE NOTE: This project will be administratively closed at the end of a two-year period unless a request is received from the Principal Investigator to extend the project. Please contact the DU HRPP/IRB if the study is completed before the two-year time period or if you are no longer affiliated with the University of Denver through submitting a Final Report to the DU IRB via the IRBNet system.

Study Completion and Final Report

A Final Report must be submitted to the IRB, via the IRBNet system, when this study has been completed. The DU HRPP/IRB will retain a copy of the project document within our records for three years after the closure of the study. The Principal Investigator is also responsible for retaining all study documents associated with this study for at least three years after the project is completed.

If you have any questions, please contact the University of Denver Human Research Protection Program/ Institutional Review Board at (303) 871-2121 or through IRBAdmin@du.edu. Please include your project title and IRBNet number in all correspondence with the IRB.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within University of Denver (DU) IRB's records.

Appendix B: Langa Survey for Chapter 3

Geographies of Day Zero

Do you voluntarily consent to answering this questionnaire? **Yes**

Check here if person provides a verbal voluntarily consent: ____________________

Date: _____________________

Have you previously completed this questionnaire? Yes No

Questionnaire #

Type of Dwelling (circle one)

1. Informal
2. Barrack/hostel
3. Single dwelling house
4. Settler

Household:

How many total family members live in your household? ____________________

How long have you lived in Langa? (circle one)

0-5 years 6-10 years More than 10 years

Water Source:

I get water from (select all that apply):
community tap household tap groundwater borehole

Do you know the source of your drinking water? (e.g. dam, groundwater, desalinated water, etc.)

Do you know who manages water in Cape Town? Yes No
If yes, who?
(Answer is City of Cape Town Water and Sanitation Department)

Should the City of Cape Town supply all citizens with water? Yes No

If yes, how much per day?

Does the City of Cape Town guarantee water to all citizens? Yes No

If yes, how much per day?

I have a rain water tank – Yes No

I have a borehole – Yes No

Do you know of anyone who drilled a borehole during or after Day Zero? Yes No

Do you have access to that water? Yes No

What keeps you from drilling your own borehole? (Money) (Knowledge) (Land) (other)

<u>Water Conservation:</u>

There is a limited amount of water available for use.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

Cape Town is naturally prone to drought.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

I have noticed a change to the rainfall patterns in Cape Town.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

Water conservation is important.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

More attention to water conservation is needed.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

Water shortage issues do not affect me.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

Water conservation is not my responsibility.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

It is important to meter water use so that we know how much water we are using.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

The best way to make sure there is enough water for the future is through government regulation.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

The government has a responsibility to develop policies and laws to make sure that water is conserved.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

There is enough water in the Western Cape to meet the current needs of all the people and businesses.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

There is enough water in the Western Cape to meet the future needs of all the people and businesses for the next 25 years.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

Water Management/Trust

All people and businesses are equally represented when water policies are made.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

The water policymakers understand my priorities for water use.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

I am satisfied with the current system of water management.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

I currently trust _________________ to get information about drought and water availability.
(name of organization, city government, news station, etc.)

Day Zero

Before the forecast of Day Zero, did you have a continuous source of water? Yes No

Did that meet your water needs? Yes No

During Day Zero, did you have a sufficient supply of water? Yes No

Did you have to get it from a source different than before Day Zero? Yes No

If yes, where? (Friend) (Purchase) (School) (NGO) (Church)

I was given a blue meter during the Day Zero crisis – Yes No

I changed my water use during the Day Zero crisis – Yes No

If yes, how? (i.e. shorter showers, collected shower water, started storing water, used hand sanitizer, etc)

I accessed the City's online resources during the Day Zero crisis – Yes No

I followed news updates about Day Zero on the City's Twitter account – Yes No

I discussed water restrictions or Day Zero with my neighbors – Yes No

I reported water wastes during the Day Zero crisis? – Yes No

I have experienced other droughts in Cape Town previously – Yes No

If yes, how did they compare to the Day Zero crisis?

____

I expect my water use to be impacted by drought in the future – Yes No

I would like better communication regarding drought and water use – Yes No

If yes, I would like this in the form of: (workshops, online, paper mail, etc.)

____

The city was never going to reach Day Zero/run out of water.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

Water conservation is an issue that I thought about frequently before Day Zero.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

Water conservation is an issue that I now frequently think about since Day Zero.

Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree

In your opinion, who or what is responsible for the Day Zero crisis?

____

____

Appendix C: IRB for Chapter 4 (Cape Town Tourism)

UNIVERSITY of DENVER
OFFICE OF RESEARCH & SPONSORED PROGRAMS
Research Integrity & Education

DATE:	May 29, 2019
TO:	Meghan McCarroll, Master of Integrated Water Management, Bachelor of Arts in Environmental Studies
FROM:	University of Denver (DU) IRB
PROJECT TITLE:	[1425520-1] Water literacy of Day Zero: The impact of knowledge about the drought on water use and behaviors
SUBMISSION TYPE:	New Project
ACTION:	**EXEMPTION GRANTED**
DECISION DATE:	May 29, 2019
EXEMPTION VALID THROUGH:	*May 28, 2021*
RISK LEVEL:	Minimal Risk
REVIEW CATEGORY:	Exemption category # *2*

Exemption 2: Educational Tests, Surveys, Interviews, or Observations

Research in this category is allowed as long as one of the three criteria is met:

1. Information obtained is not identifiable
2. Disclosure outside of the research would not put subjects at risk of harm
3. Information obtained can be identifiable and a limited IRB review has been conducted which relates to there being adequate provisions for protecting privacy and maintaining confidentiality.

This exemption does not apply to research in the following instances:

When the research is subject to Subpart D and includes children, Category 2 still does not allow:

- Surveys
- Interviews
- Investigator participating in the activities being observed (public behavior observation without intervention is permitted)

Survey cannot be combined or paired with the collection of biospecimens or interventions, as those additional activities would disqualify the research from this category.

Thank you for your submission of Exemption materials for this project. The University of Denver IRB has determined this project is **EXEMPT FROM IRB REVIEW** according to federal regulations. This exemption was granted based on appropriate criteria for granting an exemption and a study design wherein the risks have been minimized.

Exempt status means that the study does not vary significantly from the description that has been provided and further review in the form of filing an annual Continuing Review/Progress Report is not required.

Research Classified as Minimal Risk

Please note that maintaining exempt status requires that (a) risks of the study remain minimal; (b) that anonymity or confidentiality of participants, or protection of participants against any increased risk due to the internal knowledge or disclosure of identity by the researcher, is maintained as described in the application; (c) that no deception is introduced, such as reducing the accuracy or specificity of information about the research protocol that is given to prospective participants; (d) the research purpose, sponsor, and recruited study population remain as described; and (e) the principal investigator (PI) continues and is not replaced.

Implementation of Changes to Protocol or Personnel

If changes occur in any of the features of the study as described above, this may affect one or more of the conditions of exemption and may warrant a reclassification of the research protocol from exempt and require additional IRB review. For the duration of your research study, any changes, including the addition of new personnel in the proposed study, must be reviewed by the University of Denver IRB before implementing those changes.

Unanticipated Problems Involving Risks to Subjects or Others (UPIRTSOs)

Any incident, experience or outcome which has been associated with an unexpected event(s), related or possibly related to participation in this research, and suggests that the research places the subjects or others at a greater risk of harm than was previously known or suspected must be reported to the IRB.

Review Period

This exemption has been granted for a two-year time period. The DU Human Research Protection Program (HRPP)/Institutional Review Board (IRB) will retain a copy of this correspondence within our records and will administratively close this project at the end of the two-year period unless otherwise instructed via correspondence from the Principal Investigator. Please contact the DU HRPP/IRB if the study is completed before the two-year time period or if you are no longer affiliated with the University of Denver.

Study Completion and Final Report

A Final Report is requested, via the IRBNet system, when this study has been completed. All records associated with this study must be retained in a secure location for a minimum of the three years after the completion of the project.

If you have any questions, please contact the University of Denver Human Research Protection Program/Institutional Review Board at (303) 871-2121 or at IRBAdmin@du.edu. Please include your project title and IRBNet number in all correspondence with the IRB.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within the University of Denver (DU) IRB records.

Appendix D: CT Tourism Interview prompts for Chapter 4

Tourism Interview Prompts & Questions:

Introduction first, what is main job/duties

1. How are droughts in the Cape Town region changing in frequency/severity?
2. Is drought communication/conservation something with which you frequently engage tourists?
3. How was the Day Zero drought different than typical droughts in the region?
4. How did your hotel/organization react to the Day Zero drought?
5. Describe the communication strategies used during the Day Zero crisis to encourage conservation among tourists.
    a. Why did you target tourist water conservation?
    b. Did you receive any feedback about these strategies (verbally, observations, follow-up survey)?
2. How did tourists respond to the drought? (willing to conserve, angry, etc)
3. Did you witness tourists engaging with water conservation during their stay?
4. Did your water account reflect a decrease in water consumption because of water conservation strategies?
5. Do you continue to provide communication about water conservation to your customers? If yes, why?
6. Are you noticing any long-term impacts to your business as a result of the Day Zero crisis?

    cost of conserving/marketing efforts, occupancy rates

        If no change, is that a result of your conservation efforts?

Question added on after first couple interviews: How much water does the tourism industry actually use (percentage-wise)?

Appendix E: IRB for Chapter 5 (Aurora)

UNIVERSITY of DENVER
OFFICE OF RESEARCH & SPONSORED PROGRAMS
Research Integrity & Education

DATE:	December 23, 2020
TO:	Meghan McCarroll
FROM:	University of Denver (DU) IRB
PROJECT TITLE:	[1685838-1] Water Literacy in Aurora, Colorado
SUBMISSION TYPE:	New Project
ACTION:	**EXEMPTION GRANTED**
DECISION DATE:	12/23/2020
NEXT REPORT DUE:	*12/23/2021*
RISK LEVEL:	Minimal Risk
REVIEW CATEGORY:	Exemption category # *2*

Exemption 2: Educational Tests, Surveys, Interviews, or Observations
Research in this category is allowed as long as one of the three criteria is met:

1. Information obtained is not identifiable
2. Disclosure outside of the research would not put subjects at risk of harm
3. Information obtained can be identifiable and a limited IRB review has been conducted which relates to there being adequate provisions for protecting privacy and maintaining confidentiality.

This exemption does not apply to research in the following instances:

- When the research is subject to Subpart D and includes children, Category 2 still does not allow:
    - Surveys
    - Interviews
    - Investigator participating in the activities being observed (public behavior observation without intervention is permitted)
    - Survey cannot be combined or paired with the collection of biospecimens or interventions, as those additional activities would disqualify the research from this category.

Thank you for your submission of Exemption Request materials for this project. The University of Denver IRB has determined this project is **EXEMPT FROM IRB REVIEW** according to federal regulations. This exemption was granted based on appropriate criteria for granting an exemption and a study design wherein the risks have been minimized.

Please note that maintaining exempt status requires that (a) risks of the study remain minimal; (b) that anonymity or confidentiality of participants, or protection of participants against any increased risk due to the internal knowledge or disclosure of identity by the researcher, is maintained as described in the application; (c) that no deception is introduced, such as reducing the accuracy or specificity of information about the research protocol that is given to prospective participants; (d) the research purpose, sponsor, and recruited study population remain as described; and (e) the principal investigator (PI) continues and is not replaced.

If changes occur in any of the features of the study as described, this may affect one or more of the conditions of exemption and may warrant a reclassification of the research protocol from exempt and require additional IRB review. For the duration of your research study, any changes in the proposed study must be reviewed by the University of Denver IRB before implementation of those changes.

Informed Consent Process

Informed consent is an important process when conducting human subject research beginning with providing potential subjects with a description of the project and assurance of a participants understanding. The DU IRB has granted this project exempt status with the use of an Exempt Information Letter. Informed consent must continue throughout the project via the use of the approved Exempt Information Letter. If requested, each participant is entitled to receive a copy of the Exempt Information Letter.

Unanticipated Problems Involving Risks to Subjects or Others (UPIRTSOs)

Any incident, experience or outcome which has been associated with an unexpected event(s), related or possibly related to participation in the research, and suggests that the research places subjects or others at a greater risk of harm than was previously known or suspected must be reported to the IRB. UPIRTSOs may or may not require suspension of the research. Each incident is evaluated on a case by case basis to make this determination. The IRB may require remedial action or education as deemed necessary for the investigator or any other key personnel. The investigator is responsible for reporting UPIRTSOs to the IRB within 5 working days after becoming aware of the unexpected event. Use the Reportable New Information (RNI) form within the IRBNet system to report any UPIRTSOs. All NON-COMPLIANCE issues or COMPLAINTS regarding this project must also be reported.

Continuation Review Requirements

Based on the current regulatory requirements, this exempt project does **not** require continuing review. However, this project has been assigned a **one-year review period** requiring communication to the IRB at the end of this review period to either close the study or request an extension for another year. The one-year review period will be posted in the Next Report Due section on the Submission Details page in IRBNet. During this one-year period, a staff member from the Office of Research Integrity and Education (ORIE) may also conduct a Post Approval Monitoring visit to evaluate the progress of this research project.

Study Completion and Final Report

A Final Report must be submitted to the IRB, via the IRBNet system, when this study has been completed. The DU HRPP/IRB will retain a copy of the project document within our records for three years after the closure of the study. The Principal Investigator is also responsible for retaining all study documents associated with this study for at least three years after the project is completed.

PLEASE NOTE: This project will be administratively closed at the end of a one-year period unless a request is received from the Principal Investigator to extend the project. Please contact the DU HRPP/IRB if the study is completed before the one-year time period or if you are no longer affiliated with the University of Denver through submitting a Final Report to the DU IRB via the IRBNet system. If you are no longer affiliated with DU and wish to transfer your project to another institution please contact the DU IRB for assistance.

If you have any questions, please contact the DU Institutional Review Board (IRB) at (303) 871-2121 or at IRBAdmin@du.edu. Please include your project title and IRBNet number in all correspondence with the IRB.

Appendix F: Aurora Survey for Chapter 5

Aurora Water Literacy Survey

Thank you for taking the time to complete this survey about the water knowledge, attitudes and behaviors of the residents of Aurora, Colorado. The results of the survey will help Aurora Water better tailor their education and outreach programs to suit the needs of their community.

Participation is completely voluntary. Even if you decide to participate now, you may stop at any time. If you agree to participate, please continue through this survey in one sitting, which should take roughly 15-20 minutes to complete. You may skip any questions that you don't want to answer.

Anonymous results from the survey may be shared at a meeting, in academic publications, or in reports made available to the public and policymakers. Anonymous data may also be used in future research studies or classroom-based lessons that are yet to be specified. However, we will ensure that your individual identity will be kept private when information is presented or published in any of these forms.

Questions: If you have any questions or concerns about your participation or rights as a participant, you may speak to the Lead Researcher, Meghan McCarroll (meghan.mccarroll@du.edu). This research has also been approved by the University of Denver's Human Research Protections Program (HRPP). If you would like to speak to someone other than the researchers, you may contact the HRPP by emailing IRBAdmin@du.edu or by calling (303) 871-2121.

1. Do you currently own or rent a property in Aurora?
   a. Own a property
   b. Rent a property
2. Do you pay your own water bill?
   a. I pay my own water bill
   b. My HOA pays my water bill
3. What is the name of the neighborhood in which you live? ________________________
4. What is your gender?
   a. Male
   b. Female
   c. Other (please specify)
   d. Prefer not to answer
5. What is your race? *(select all that apply)*
   a. American Indian or Alaska Native
   b. Black or African American
   c. White
   d. Native Hawaiian or Pacific Islander
   e. Asian
   f. Other (please specify)
   g. Prefer not to answer
6. Are you of Hispanic, Latino, or Spanish Origin?
   a. Yes

    b. No
    c. Prefer not to answer
7. What year were you born? ___________________________
8. What is the highest level of formal education you have completed?
    a. Some high school
    b. High school diploma or equivalent
    c. Some college
    d. Associate’s degree
    e. Bachelor’s degree
    f. Master’s degree
    g. Professional degree
    h. Doctorate degree
    i. Prefer not to answer
9. What is your annual total household income?
    a. Below $25,000
    b. $25,000 - $50,000
    c. $50,000 - $100,000
    d. $100,000 - $150,000
    e. Over $150,000
    f. Prefer not to answer

The first section of questions consists of a series of statements about water conservation in Aurora. Please indicate your level of agreement with each statements by selecting a response that ranges from "strongly agree" to "strongly disagree".

10. Aurora is naturally prone to drought. [5-point Likert scale]
11. I have noticed a change in Colorado weather patterns since living in Aurora. [5-point Likert scale]
12. Water conservation is important. [5-point Likert scale]
13. More attention to water conservation is needed. [5-point Likert scale]
14. Water shortage issues don't affect me. [5-point Likert scale]
15. My actions make a difference when it comes to water conservation. [5-point Likert scale]
16. There is a limited amount of water available for use in Colorado. [5-point Likert scale]
17. There is enough water for Aurora to meet the current needs of all the people and businesses here. [5-point Likert scale]
18. There is enough water for Aurora to meet the future needs of all the people and businesses for the next 40 years. [5-point Likert scale]
19. Aurora Water has a responsibility to develop policies and practices to make sure that water is conserved.

The next section asks you to tell us about your experiences and behaviors surrounding water use in Aurora.

20. I am generally aware when Aurora experiences drought.
    a. Yes
    b. No
    c. Not sure
21. I have experienced water restrictions while living in Aurora.

a. Yes
b. No
c. Not sure

22. I have changed my *indoor* water use because of drought in Aurora
    a. Yes
    b. No

Display This Question if 22 = Yes
In which of the following ways have you changed your *indoor* water use because of drought in Aurora?

	Yes	No
Collected shower water in bucket for other use (i.e. gardening)		
Fixed leaks in my home		
Installed a low-flow toilet		
Installed low-flow faucet aerators/showerheads		
Only ran the dishwasher/washing machine when loads are full		
Took shorter showers		
Turned off the tap while brushing my teeth		
Other (please specify):		

23. I have changed my *outdoor* water use because of drought in Aurora.
    a. Yes
    b. No

Display This Question if 23 = Yes
In which of the following ways have you changed your *outdoor* water use because of drought in Aurora?

	Yes	No
Fixed leaks in my sprinkler system		
Increased the efficiency of my sprinkler system		
Installed a smart controller for my sprinkler system		
Removed my grass/turf and installed a water-wise landscape		
Used automated car washes instead of hand-washing car		
Other (please specify):		

24. I have a rain water barrel on my own property.
    a. Yes
    b. No
    c. Not sure
25. I have reported others wasting water during times of water restrictions.
    a. Yes
    b. No

26. Are you aware of or have you participated in the following programs with Aurora Water:

	Unaware of	Aware of, but have not participated in	Have participated in
Rebates for water conserving fixtures (i.e. toilets)			
Conservation classes			
Outdoor Water Assessment for my yard			
Indoor Water Assessment for my home			
Know Your Flow Program			
Aurora Water's Youth Education			
Other (please specify):			

27. Are you aware of Aurora's Water Quality Reports?
    a. I am aware, and I read them every year.
    b. I am aware, and I have read them once or twice.
    c. I am aware, but I have never read one.
    d. No, I am not aware of these reports.
    e.

The next section of questions in an attempt to gauge your general knowledge of Aurora's water system. It may feel like a quiz. Please answer to the best of your ability *without looking up any of the questions* - and if you aren't sure, feel free to take a guess!

28. Which of the following uses the most water in the state of Colorado?
    a. Farms and ranches
    b. Households
    c. Industrial/Commercial businesses
    d. Other (please specify)
    e. Not sure
29. A watershed is an area of land where all the precipitation (rain, snow) that falls on it drains to a single outlet or body of water. True or False: I live in a watershed.
    a. Yes
    b. No
    c. Not sure
30. Aurora receives water from which of the following watersheds (select all that apply):
    a. Arkansas River Watershed
    b. Colorado River Watershed
    c. North Platte River Watershed
    d. Rio Grande River Watershed
    e. South Platte River Watershed
    f. Not sure
31. Aurora Water pipes in water from as far away as.
    a. 60 miles
    b. 100 miles
    c. 180 miles
    d. 240 miles

e. Not sure

32. My drinking water comes from the following source(s) (select all that apply):
    a. Desalinated water
    b. Lakes and Rivers
    c. Groundwater
    d. Recycled Water
    e. Snowmelt
    f. Private Well
    g. Not sure
33. A healthy watershed provides many different benefits. Rank the following benefits in order of importance to you. (I.e. 1 = most importance; 5 = least importance)
    a. Environmental health
    b. Economic activity
    c. Protection against natural disasters
    d. Recreation
    e. Water Quality
34. Treatment is required for water in all of Aurora Water's reservoirs before that water ends up in the public drinking supply.
    a. True
    b. False
    c. Not sure
35. Aurora Water adds flouride to the City's drinking water supply.
    a. True
    b. False
    c. Not sure
36. Aurora residents use an average of ____ gallons per person per day.
    a. 30-40
    b. 80-90
    c. 150-170
    d. 300-320
    e. Not sure
37. I think that Aurora's tap water tastes good. [5-point Likert scale]
38. I prefer to drink bottled water rather than Aurora's tap water
    a. Yes (if yes, please specify why):____
    b. No

This section consists of a series of statements about water management trust and communications. Similar to previous questions, please indicate your level of agreement with each statements by selecting a response that ranges from "strongly agree" to "strongly disagree".

39. I discuss water restrictions with my neighbors. [5-point Likert scale]
40. I am confident I can access information about Aurora's water supply & system.
41. I am confident I can access information about my household water use.
42. I am satisfied with how Aurora Water manages water.
43. I would be interested in an app or online platform that provides more detailed information about my household water usage.
    a. Yes

b. No
c. Not Sure

44. I follow Aurora Water on the following social media accounts:
    a. Twitter
    b. Facebook
    c. Nextdoor
    d. Instagram
    e. I do not have social media accounts
45. I trust the following organizations to get reliable information about Colorado's water situation and water issues (select all that apply):
    a. Aurora Water
    b. Colorado State Government
    c. Federal Government
    d. Environmental or conservation organization
    e. Local City or County Government
    f. Colorado's education institutions
    g. Media
    h. Other (please specify):____
    i. None of these (nobody)
    j. Not sure
46. I would like more communication regarding drought and water use
    a. Yes
    b. No

Display This Question if 46 = Yes

I would like more communication regarding drought and water use in the form of: (select all that apply):

- Emails
- In-person workshops or classes
- Physical mail
- Social media updates (which platform): ________________
- Website updates