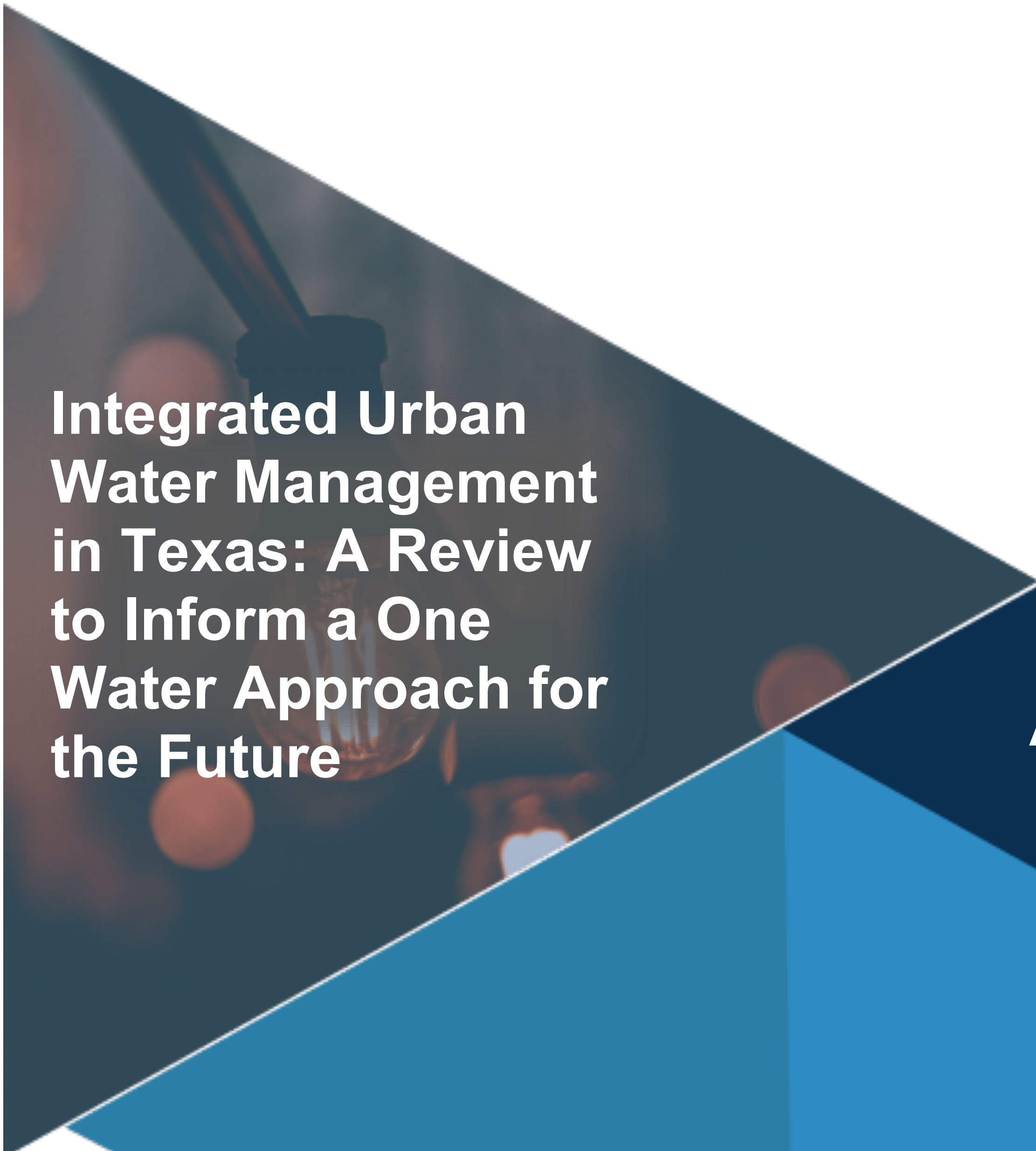

Integrated Urban Water Management in Texas: A Review to Inform a One Water Approach for the Future

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Boston University Institute for Sustainable Energy

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Abstract

Texas has considerable experience grappling with historic droughts as well as flooding associated with tropical storms and hurricanes, yet the State's water management challenges are projected to increase. Urban densification, increased frequency and severity of droughts and floods, aging infrastructure, and a management system that is not reflective of the true cost of water all influence water risk. Integrated urban water management strategies, like 'One Water', represent an emerging management paradigm that emphasizes the interconnectedness of water throughout the water cycle and capitalizes on opportunities that arise from this holistic viewpoint. Here, we review water management practices in five Texas cities and examine how the One Water approach could represent a viable framework to maintain a reliable, sustainable, and affordable water supply for the future. We also examine financial and business models that establish a foundational pathway towards the 'utility of the future' and the One Water paradigm more broadly.

Introduction

The availability of and access to freshwater resources in US cities is becoming less reliable due to pressures from urban densification, water scarcity and flooding, aging infrastructure, and management systems that do not reflect the true cost of water. In recent years, water stakeholders have begun to consider fundamental changes to management practices that increase water use efficiency and enhance conservation. One such change is moving away from historically siloed management techniques and towards adoption of integrated urban water management approaches, such as “One Water”. There are many definitions of One Water; therefore, for clarity, we provide a working definition. For the purposes of this review, the One Water approach emphasizes the interconnectedness of water throughout the water cycle, and focuses on opportunities that arise from this holistic viewpoint. Two key aspects of One Water are coordinating water management processes across the water stakeholder community, and accounting for the true cost of water. The outcome of One Water management is sustainable and resilient urban water systems. We identify the utilities as playing a central role in water planning, maintenance, and operations that positions them uniquely to drive change in the business models for integrated urban water management.

In order to meet the water needs of growing urban populations in rapidly developing cities across the US, utilities are now undertaking long-term planning that accounts for the risk and uncertainty of droughts and flooding, while also ensuring that sufficient reserves are maintained to refresh groundwater supplies and freshwater flows for the environment. These planning exercises are especially critical to urban populations residing in the state of Texas. Texans endured an historic drought in the 1950s as well as a notable recent drought in 2011. The state also faces periodic, sometimes catastrophic, flooding associated with tropical storms and hurricanes that approach from the Gulf of Mexico. Further, water managers strive to protect sensitive freshwater bays, estuaries, and aquifers while also procuring sufficient potable water supplies to meet demand in rapidly growing metropolitan areas across the State. The challenge is compounded by the aged state of water infrastructure systems and the increasing impact of climate change. This review investigates how best to affect a successful transition to a One Water management approach in the Texas cities of Austin, San Antonio, Houston, and Dallas-Fort Worth. Here, we analyze water management data, stakeholder interviews, and utility financial and business models across these four urban areas in order to help inform water management planning processes within the state of Texas and across other US cities faced with similar water management challenges, as well as promote a transition towards the One Water management paradigm more broadly.

1. Texas Today

1.1 Water Demand in Texas

Key sectors that sustain the Texas economy, from agriculture to manufacturing, require water for direct or indirect use; therefore, water supply disruptions have potentially devastating consequences for the State (Fig. 1). Studies on the impact of the 2011 drought, the worst drought year on record, reveal a startling cost. Texas' State Comptroller detailed losses of $5.2 billion in agriculture alone, though other studies model a total direct and indirect cost of $16.9 billion, including a loss of approximately 100,000 jobs (Combs 2012; Ziolkowska 2016). Effects of the drought were observed globally, in the price of cotton and cattle (Galbraith 2011). If a "Drought of Record"-length drought occurs, overall State economic losses could amount to $116 billion. Most of the direct losses come from the agricultural and recreational sectors, though declining manufacturing, infrastructure breakage, and ecological damage contribute as well. In addition, energy generation shortages could create significant indirect effects.

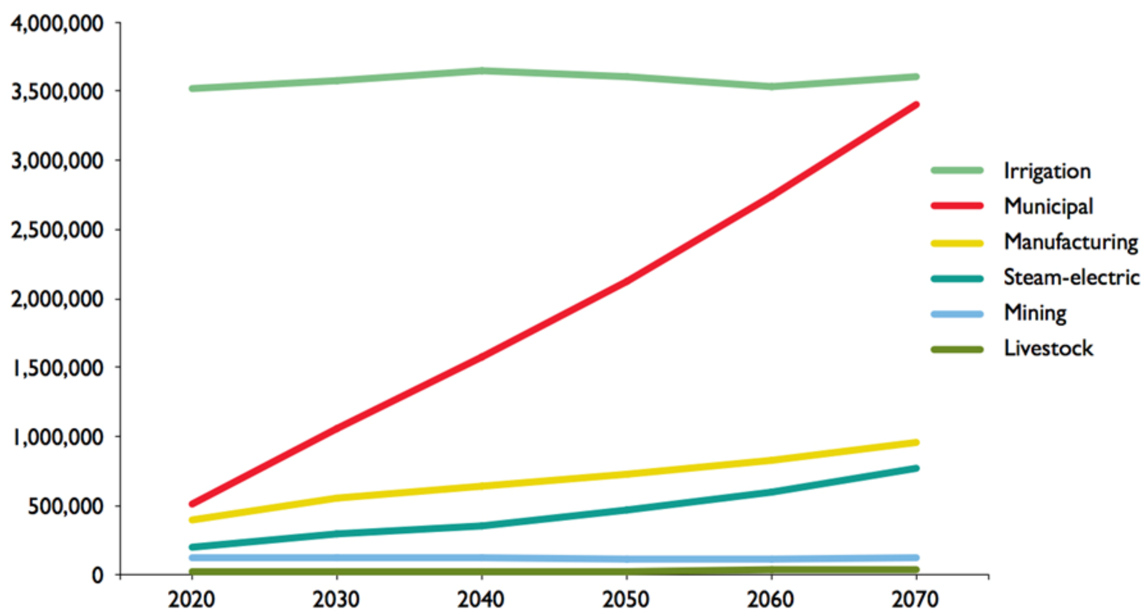

Figure 1. Rapidly rising population in Texas is causing municipal water demand to grow. Annual water need by water use category (acre-feet) is represented on the y-axis and year is depicted on the x-axis. Figure adapted from the Texas Water Development Board's 2017 State Water Plan (TWDB 2016a).

Looking forward, Texas is projected to increase its population by 70% in the next 50 years (Fig. 2), accounting for the substantial increase in municipal demand shown in Fig. 1. This trend will place significant stress on the State's water resources at a time when existing water infrastructure is aging. Simultaneously, existing water supplies are decreasing overall and becoming more variable, as the climate changes. Recognition of the stark consequences of these dynamics have prompted calls for a new way to manage Texas' water (TWDB 2016a; ASCE 2017).

1.2 Why Urban Water?

In cities across the globe urbanization continues to rise at a dramatic rate, and Texas is no exception (United Nations 2015; TWDB 2016a). Several studies of US cities found that some of the most vulnerable cities in the US are in the central south, including Texas, where water shortages owing to increased demand pose a substantial risk to human health and local economies (Padowski and Jawitz 2012; Pickard et al. 2017). The challenge of increased demand is compounded by changes in precipitation patterns associated with climate change, which threatens the reliability of traditional water sources (Vörösmarty et al. 2010).

Cities place stress on local water supplies, but also function as hubs of economic and political power. They can leverage that power to draw water from a wide area (Harris and Ullman 1945; McDonald et al. 2011). Of particular concern in Texas, urban irrigation is a major consumer of municipal water supplies (Cabrera et al. 2013). Another concern is drainage: as cities increase their impervious cover, the local hydrological cycle is disrupted, which places stress on both natural systems and manmade drainage systems (Walsh et al. 2005). To address these challenges, cities need to spend more money on water management infrastructure maintenance and also invest in new infrastructure; however, there are concerns about the cities' ability to finance infrastructure at a rapid pace that matches demand, as well as balance the ecological, economic, and residential needs of their stakeholders (Vörösmarty et al. 2010; McDonald et al. 2011; VanLandeghem et al. 2012; TWDB 2016a).

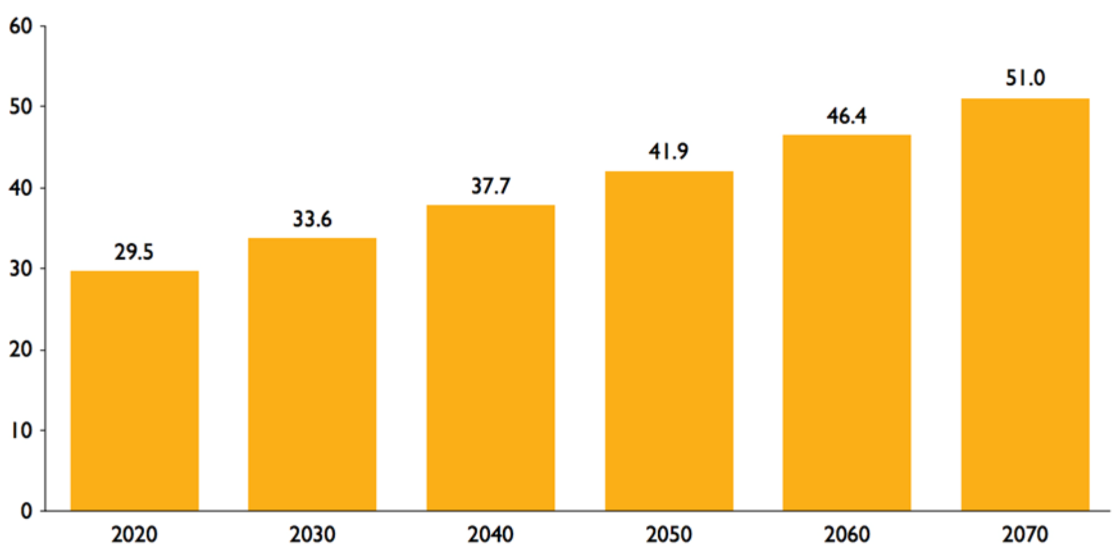

Figure 2. Texas population projected (in millions of people, y-axis) through the year 2070 (x-axis). Figure adapted from the Texas Water Development Board's 2017 State Water Plan (TWDB 2016a).

2. Moving to the Water Utility of the Future

In order to meet the water needs of growing urban populations in rapidly developing cities across Texas, water utilities must now grapple with long-term planning that accounts for the risk and uncertainty of droughts and flooding, while also ensuring that sufficient water reserves are maintained to refresh groundwater supplies and provide sensitive, critically important freshwater ecosystems with adequate flows. This long-term planning necessarily includes envisioning revenue and business models that will ensure stable, long-term generation of revenue to make much-needed capital expenditures, like revitalizing aging infrastructure and investing in innovative infrastructure that will help meet growing demand by improving conservation and efficiency, while also maintaining affordable access to water services by municipal ratepayers. Given the environmental pressure of climate change, the declining state of American infrastructure, and the rapid uptick in urban densification, now is the time for water utilities in the state of Texas to move to the "water utility of the future."

For the purposes of this review, we define the water utility of the future as:

1. Reflective of the 'true cost of water;"
2. Sustainable;
3. Resilient; and
4. Integrated.

These principles are integral to the One Water philosophy and, if adopted, will allow water utilities in Texas to implement a more holistic approach to integrated urban water management.

2.1 Reflective of the True Cost of Water

Water sustains life, human and otherwise, making it one of the most valuable commodities on the planet. However, there is no other commodity whose true value so far exceeds its nominal price, and whose price is so low compared to the real cost of providing it (Maxwell 2012). Water utilities must source, clean, treat, distribute, drain, and recover water supplies, and these services require significant operating, maintenance, and capital improvement costs. US residents pay significantly less for water and use significantly more compared to most other countries (Table 1). Canada, which is water-rich and only moderately populated, is the only other country that is more water intensive than the US.

Table 1. Table adapted from Maxwell (2012) that depicts the average water prices and per capita consumption for various countries according to the Global Water Intelligence's 2011 Water Tariff Survey.

Country	Average Price— *cents per gallon*	Average Consumption— *gallons per capita per day*
Denmark	1.64	30.2
Germany	1.26	39.8
France	1.23	61.2
Australia	1.19	160
United Kingdom	0.78	36.7
Canada	0.73	205
Japan	0.56	98.4
Spain	0.56	90.2
Turkey	0.52	62.8
United States	0.48	163
Italy	0.37	127

While the cost of water in the US today is nowhere near close to being reflective of its true value, the price of water is slowly increasing. The price of water in the 30 major US cities increased by 4% in 2017, which reflects a longer-term increase of 52% since 2010 (Walton 2017). This historical rate of increase amounts to a difference of only a few dollars in monthly water bills from year to year (Fig. 3; Maxwell 2012). However, projected increases in water pricing that reflect water scarcity adjustments and infrastructure investments will be much steeper in the near-term future. It is estimated that at least $1 trillion will need to be invested to refurbish aging water infrastructure over the next 25 years and $36 billion will need to be invested by 2050 to adapt water systems to deal with the impacts of climate change (Wharton et al. 2013; Mack and Wrase 2017). Pricing water towards full cost recovery is essential to ensuring revenue stability for water utilities in the face of water scarcity and much-needed infrastructure investments.

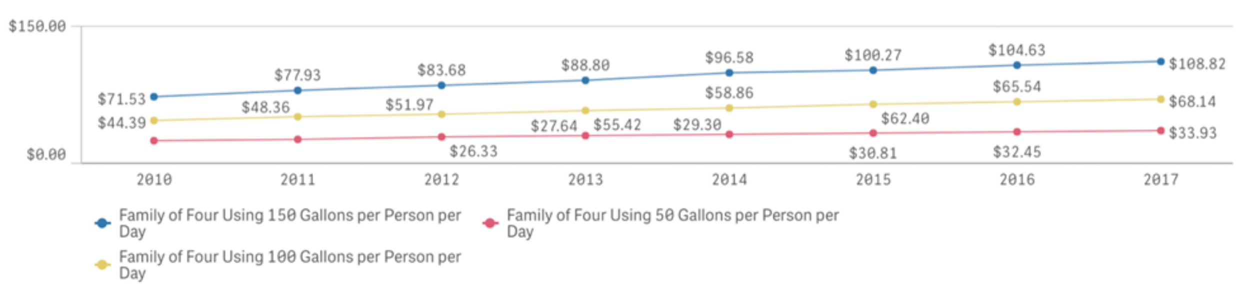

Figure 3. Infographic adapted from Circle of Blue (Walton 2017) that depicts the increase in average monthly residential water bills for three tiers of water consumption in 2010-2017 for 30 US cities that participate in Circle of Blue's annual water pricing survey.

However, raising the price of water has been difficult in the past because of concerns regarding water affordability and rate shocks (Maxwell 2012; Dinar et al. 2015; Mack and Wrase 2017; Walton 2017). Water prices are projected to increase to four times current levels over the next few decades, and at this rate, the percentage of US households that find their water bills unaffordable could triple from 11.9% to 35.6% in the next five years (Mack and Wrase 2017). The EPA defines an "affordable water bill" as one that costs less than 2.5% of a small community's median household income (AWE 2014). Cities are expected to experience the greatest difficulties with water affordability issues in the future, as 81% of high-risk and 63% of at-risk tracts are currently located in census-defined urbanized areas (Fig. 4; Mack and Wrase 2017). While there is general agreement that water is at once essential to life and a commodity, there is less agreement on how to regulate pricing of this commodity, especially with regards to lower income households across the US (Dinar et al. 2015). The water utility of the future must strike a balance as it assesses how best to structure revenue and business models to meet dual needs.

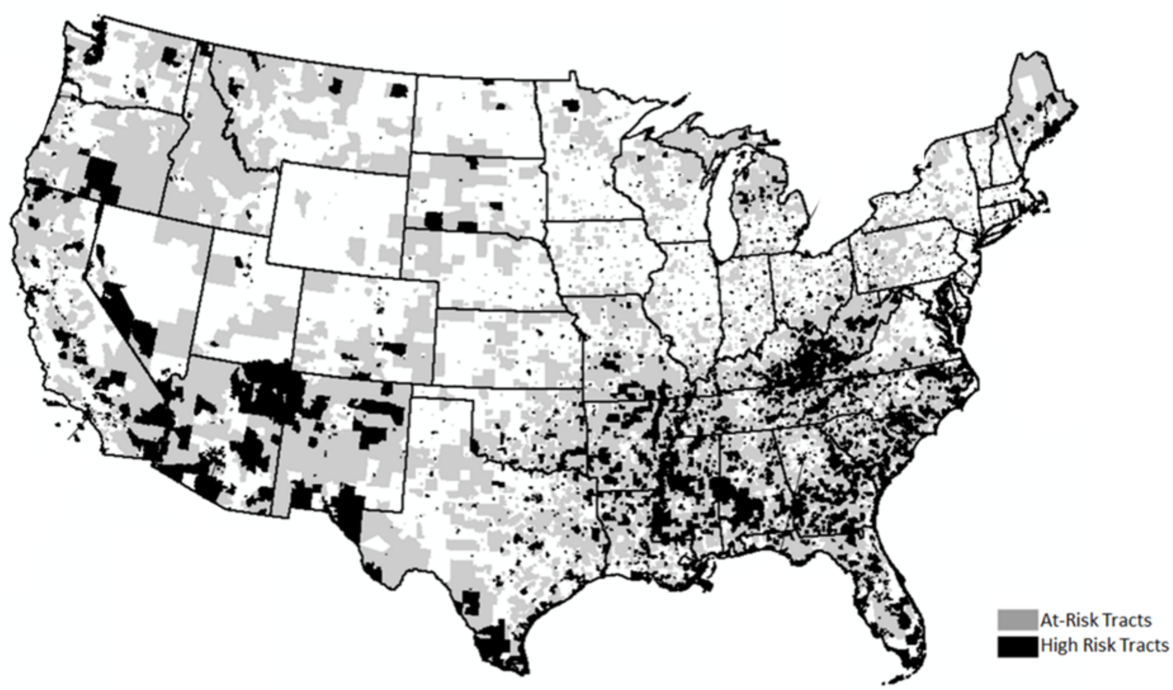

Figure 4. Figure adapted from Mack and Wrase (2017) that depicts the distribution of at-risk (grey; people located in census tracts with median incomes of $32,000-$45,120, with concentrations of people with median incomes below the minimum income thresholds needed to afford future increases in water rates) and high-risk (black; people located in census tracts with median incomes < $32,000, with likely concentrations of people who face affordability challenges based on current water rates) census tracks.

2.2 Sustainable

A sustainable urban water utility can generally be defined as one that effectively manages the urban water cycle to deliver the most appropriate use of water across all stages, and in doing so, enhances social, ecological, and economic stability at various scales (Marlow et al. 2013). Sustainable management practices adopt long-term visioning as well as a holistic approach to understanding systems and their broader impacts. The juxtaposition between sustainable yields and safe yields when considering groundwater management is an excellent example of the value added by adopting a sustainable approach to resource planning (Christian-Smith and Abhold 2015). Safe yields aim to match groundwater withdrawal with groundwater recharge. However, it has been demonstrated that this approach often oversimplifies the hydrological, ecological, and social aspects of groundwater management, leading to insufficient recharge over time (Christian-Smith and Abhold 2015). Alternatively, sustainable yields employ metrics that can ensure the long-term resilience of a groundwater system, explicitly incorporating the needs of the environment (Christian-Smith and Abhold 2015). The water utility of the future must integrate sustainability into its day-to-day operations and capital investment planning in order to appropriately manage the urban water cycle, especially in light of the environmental perturbations associated with climate change.

2.3 Resilient

A resilient urban water utility is one that is able to withstand, respond to, and quickly adapt to shocks and stresses, resulting in the capacity to robustly recover during difficult times and vigorously thrive during good times (Arup 2015). Water utilities of the future must be resilient in order to overcome and flourish in the face of the significant environmental, financial, and social challenges that lie ahead. The US counties forecasted to experience the largest increases in water demand through 2090, all of which are identified as being near or adjacent to metropolitan centers, are located in California, Texas, and isolated portions of the Mid-West, Southeast, and Mid-Atlantic (Pickard et al. 2017).

The Rockefeller Foundation (Arup 2015) defines resilient cities as those that embody seven core qualities: reflectiveness, resourcefulness, robustness, redundancy, flexibility, inclusiveness, and integration. Beyond adopting these qualities, water utilities of the future must also conceive of business models that will facilitate financial resiliency. Financial resiliency with respect to water utilities is defined by the Environmental Protection Agency and the Water Research Foundation (Hughes et al. 2014) as the ability for a utility to thrive under fiscal stresses that threaten to temporarily or systematically move the utility off-balance or out of fiscal equilibrium. Achieving resiliency will require water utilities to embrace long-term planning that considers the impacts of climate change, future infrastructure requirements, and customers’ responses to changing revenue and business models.

2.4 Integrated

Integration is a fundamental component of the One Water philosophy and a core determinant of success for the water utility of the future. Integration must occur across water systems (water, sewer, stormwater, and waste), water sources (desalination, new or alternate groundwater, new or alternate surface water, recycling, and/or rain collection), and infrastructure systems (especially at the water-energy nexus). The concept of integrated urban water management has been an active area of research for over 30 years, and advances in this field remain critically important today (Bach et al. 2014).

Traditional water systems are centralized and often managed in silos according to the service provided: water treatment, distribution, sewerage and storm drainage, and wastewater treatment. Water experts now advocate for a hybrid approach that combines centralized and decentralized systems and integrates management across these systems (Ferguson et al. 2013). While privatization of water services has been suggested as a way to manage water utilities of the future, serious concerns regarding the potential for enhancement of existing silos as well as a decrease in ratepayer confidence remain (García-Rubio et al. 2015).

The diversification of water sources that supply urban residents is essential to maintaining a sustainable and resilient water utility of the future. Successful adaptation to climatic extremes, especially with regards to drought, requires long-term contingency planning, water source diversity, and adaptive management (Ferguson et al. 2013). Towards meeting this goal, the water utility of the future must make strategic capital investments and advance new regulatory approaches and programmatic solutions that support improved supply- and demand-side management. For example, green infrastructure, low-impact development, efficiency programs, and novel water, waste, and sewer treatment can all complement traditional water sourcing strategies like transmission pipelines, reservoirs, and aquifer storage and recovery.

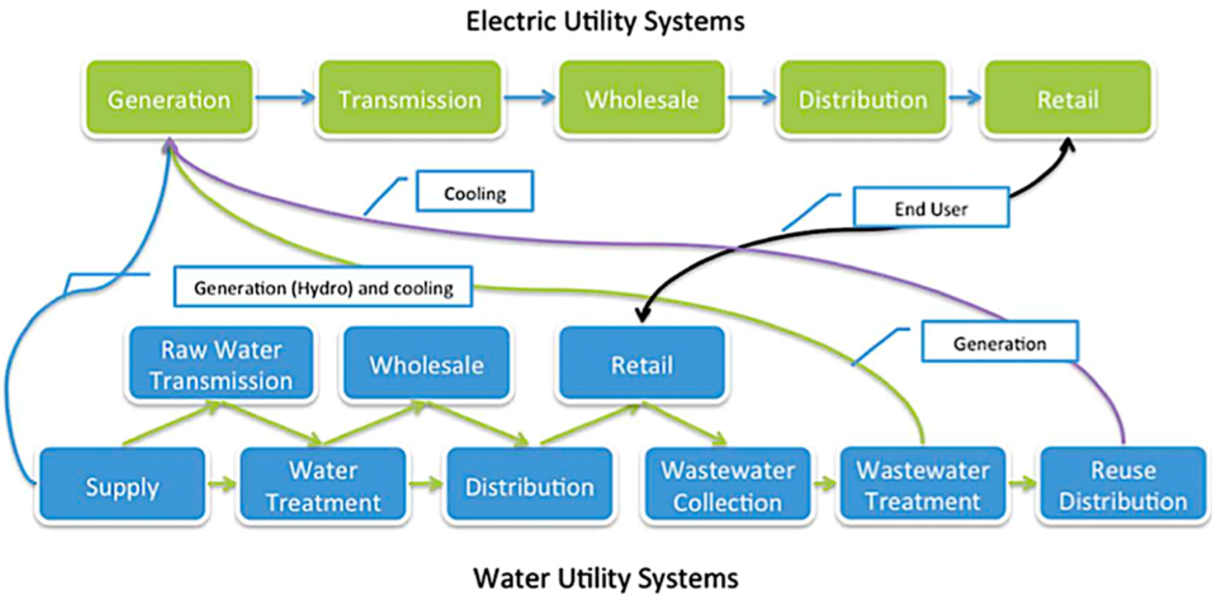

Figure 5. Figure adapted from Conrad et al. (2017) that depicts 'water and electric utility integrated planning' pathways and interconnections. This planning framework illustrates how water and electric utilities must collaborate in the future to harness the water-energy nexus.

The water-energy nexus is increasing in importance as global temperatures rise, the length and severity of drought intensifies, and the demand for freshwater and energy resources increases. Power plants are hugely water intensive (Zhang and Vesselinov 2016), and in times of water scarcity they draw down critical freshwater resources in order to maintain energy production (Averyt et al. 2011; Rogers et al. 2013). Conversely, the pumping energy required for urban water utility operations is significant (Wong et al. 2015), with urban water supply, water use, and wastewater services accounting for 13-18% of state electricity use (Kenway et al. 2015). As such, the water utility of the future must work with electric utilities to develop plans to maintain and/or improve the delivery of water and electric power services (Fig. 5; Conrad et al. 2017).

3. Illustrative Water Management Scenarios in Texas

In this section, we convey descriptions of various water management scenarios in Texas to provide insight into how situations can evolve on the ground. These illustrative examples were identified through interviews with experts and stakeholders in the Texas water community. The aim is to illustrate important dynamics that affect water management – positively or negatively – in Texas today. Focusing in on Austin, Dallas-Fort Worth, Houston, and San Antonio, we note that the specifics of both opportunities and challenges around water management vary notably even across five major cities in Texas, and these scenarios highlight some of those differences.

3.1 SAWS/BexarMet Assumption

In 2011, Senate Bill 431 passed, initiating a process for the assumption of Bexar Metropolitan Water District (BexarMet) by San Antonio Water System (SAWS) within five years. Following the passing of the bill, BexarMet ratepayers voted to incorporate into SAWS. BexarMet had a complex history, and it served customers in numerous small geographically distinct service areas scattered across the greater San Antonio region (Fig 1. in TCEQ 2012). BexarMet had different isolated water sources for the different geographical pockets that comprised their disjointed service territory, and it did not provide sewer service to these customers.

The logistics of supplying water from multiple sources across a highly fragmented service territory was a systemically flawed foundation, with the inevitable inefficiencies resulting in service being both unreliable and costly – with BexarMet suffering poor fiscal health. It was not possible to make the necessary investments in infrastructure.

The assumption took several years to accomplish. It required addressing:

- Legal and governance issues: how can an entity be disbanded? Which body oversees the new entity, and how do people get involved in the oversight body?
- Financial issues: transitioning the rates, and merging the management bond obligations for capital projects.
- Operational issues: inheriting infrastructure in poor condition and investing in substantial improvements.
- Cultural issues: absorbing employees and customers.

Adding the demands of a utility the size of Corpus Christi, Texas, posed challenges. However, both the financial transition and the operational/capital improvement efforts were conducted with care to avoid impacting SAWS' favorable financial rating.

After the assumption, a cross connection between SAWS and the former BexarMet system was created, enabling former BexarMet customers to receive supplies from original SAWS sources.

This proved to be a very timely change: in the 2011 drought, former BexarMet customers would have probably lost their water supply, or at least been under stringent drought restrictions, were it not for the changes in access to sources that occurred after the assumption, since some of the original BexarMet wells and Medina Lake were not able to supply water during the drought.

3.2 Google's Net Zero Water Goal: Efficiency, Demand Reduction, and Reuse

In 2017, Google moved to new offices in Austin that accommodated approximately 600 employees. During the development process, Google worked hard toward a goal of net zero or net positive water management. Their choice of architect for their new office space, CTA, was driven in part by CTA's willingness to pursue novel water management arrangements. Ultimately, the goal proved to be elusive, although Google did end up with a notably low consumption arrangement.

The technology and systems were not lacking: for example, CTA designed a filtration system that could make the rainwater potable, and determined how to configure water storage tanks in the building's basement. Austin Water, the municipal water utility, was also involved and very supportive of exploring the opportunities to create a net zero space – with an Austin Water staff member engaged with Google and liaising with senior management at Austin Water in the process.

The primary obstacle became evident in communications with the Texas Commission on Environmental Quality (TCEQ) about regulatory issues. The Google space is leased, with no long-term hold. Questions emerged relating to what entity would manage the operations of the water system that supplied the office space. The building owner did not want to take responsibility for managing the system. Austin Water could not carve out the dedicated staff time to manage the operations owing to fiscal constraints. Creating a separate utility for a single space was burdensome, and raised questions about competition with Austin Water. Fundamentally, the question of who would manage the operations stymied the project.

As the effort to create this novel management system for Google's new office space was waning in the face of these challenges, Austin's Mayor learned of the effort and engaged with Google to try to help. In this case, the discussions came too late, although the city's willingness to try to help may be cause for hopefulness for the next player who attempts to accomplish an ambitious water consumption goal.

Today, Austin Water is considering moving to a new building (that they will own) in Highland Mall and they may target a net zero water goal there. In this case, the operational questions are much more straightforward, although questions around whether the substantial capital investment required is manageable come into play.

3.3 Austin's CodeNEXT: Stormwater Management and Green Infrastructure Development

The City of Austin has proposed a code (City of Austin 2017) that requires beneficial use of a specific portion of captured stormwater runoff. There is a base level of capture for stormwater quality management purposes that applies uniformly, and then as impervious cover increases above a certain threshold, additional stormwater capture is required by the code. The captured water is detained on site for a period of time: the duration depends on the type of control being used. E.g., for rainwater harvesting the detention time may be up to 120 hours. In addition to capture and detention, the code requires that a portion of the water is used on site in a beneficial way: e.g., for outdoor irrigation, or for flushing toilets.

The benefits of low impact development practices requiring onsite use of stormwater are:

- Support flood hazard mitigation by limiting impervious cover and requiring more stormwater capture at sites where there is more impervious cover;
- Offset demand on potable supplies;
- Distributes the water capture and use process across a large number of small structural and non-structural systems, which results in increased redundancy and decreased likelihood of a single system failure.

Potential developer concerns about the financial implications of the new land development code were addressed by coupling this change with proposed code reducing mandatory minimum onsite parking requirements. A reduction in onsite parking corresponds to increased area for profit-generating buildings and reduced total impervious cover generating stormwater runoff to treat. When the implications of these two code changes together were evaluated, there was an increase in the developer pro forma profit estimates. An advantage of the wholesale code redesign process involved in CodeNEXT (City of Austin 2017) is that these changes could be introduced simultaneously to improve water management practices and air quality simultaneously, in a way that benefits developers.

More generally, a net zero water ordinance project (AWE et al. 2017), providing guidance for establishing water neutral ordinances based on offsets, has been developed very recently, with the first communications to the general public launching in June 2017. This effort is led by the national Alliance for Water Efficiency, the Environmental Law Institute, and the River Network; the larger group involved in its development includes Austin water experts. The ISE team will incorporate learnings from the water neutral ordinance reporting into its future work.

3.4 Building Reservoirs in the Dallas Area

The major drought that occurred in Texas in the 1950s and the corresponding water shortages spurred an intense period of reservoir construction lasting several decades. Some reservoir construction met a genuine need for water storage to ensure sufficient supply during drought years. However, the success of the construction industry for reservoirs ultimately outgrew the actual need, and the construction companies became embedded in the planning and decision-making process in a way that enabled them to advance plans for reservoirs – that they then profited from building – even when there was not a true need. This does not represent violation of the conflict of interest rules.

For example, Toledo Bend Reservoir was built 15 years ago on the border between Texas and Louisiana, and it inundates 186,000 acres. Yet very little water has ever been used out of it for water supply aside from a small amount for hydroelectric power. The economic benefit associated with the small amount of water used is small compared to the cost of taking 186,000 acres of mostly high quality land out of production.

Activists have come to understand this dynamic, and discussions around reservoir construction are now often different. Fifteen years ago a plan was developed to build the Marvin Nichols Reservoir that would flood 70,000 acres and, according to the original plan, it would have been built by now. However, concerned citizens organized and communicated the plan and their opposition to it broadly, shining a negative light on any politician who supported the reservoir construction plan. Today, there is still no permit application for the reservoir and it is unclear that it will actually be built.

Opponents of reservoir construction sometimes but do not always prevail. Currently, there are plans to build the Lower Bois d'Arc Creek Reservoir in spite of objections from the affected community and organized efforts to overturn the plan. While what unfolds on the ground is a mix, with some reservoirs built and then little used and other plans for reservoir construction thwarted, what is notable is the shift from a consistently favorable political attitude to reservoir construction, with no vocal community opposition to a more considered approach based on the merits of building, with some opportunity to prevent unnecessary reservoir construction.

4. Water Availability and Ownership

Water in Texas is defined by its point of origin. Water can be surface water or groundwater. The ownership rights and laws for each vary.

4.1 Texas Drought Planning and Impacts

Given the costs of water pipelines and pumping, water is a local issue. Yet, these systemic drivers of local management are intensified in Texas by local variability in water supply dynamics and water sourcing. Therefore, the Texas state legislature created a grass roots, bottom up mechanism by which local plans are compiled into a state planning process (Rochelle et al. 2016). The state of Texas is split into regional planning areas, roughly corresponding with the major river basins of the State (Fig. 6). Each of these areas must convene Regional Water Planning Groups every five years and use the best available hydrologic and population based models to demand for the next fifty years, and identify supply to meet it. This input is combined with an intense stakeholder outreach process, during which fourteen or more representatives from various water using/supplying groups give input on the overall plan (TWDB 2016a).

The State Water Plan must address drought contingency, normally based on Texas' 1950-57 Drought of Record conditions, as well as propose means to meet the projected demand growth. The Texas Water Development Board (TWDB) reviews the regional plans, recommends changes, and approves them for inclusion in the State Water Plan. The State Water Plan is then the nonbinding, guiding document for allocation of water development financing, such as State Water Implementation Funds for Texas (SWIFT; TWDB 2016a).

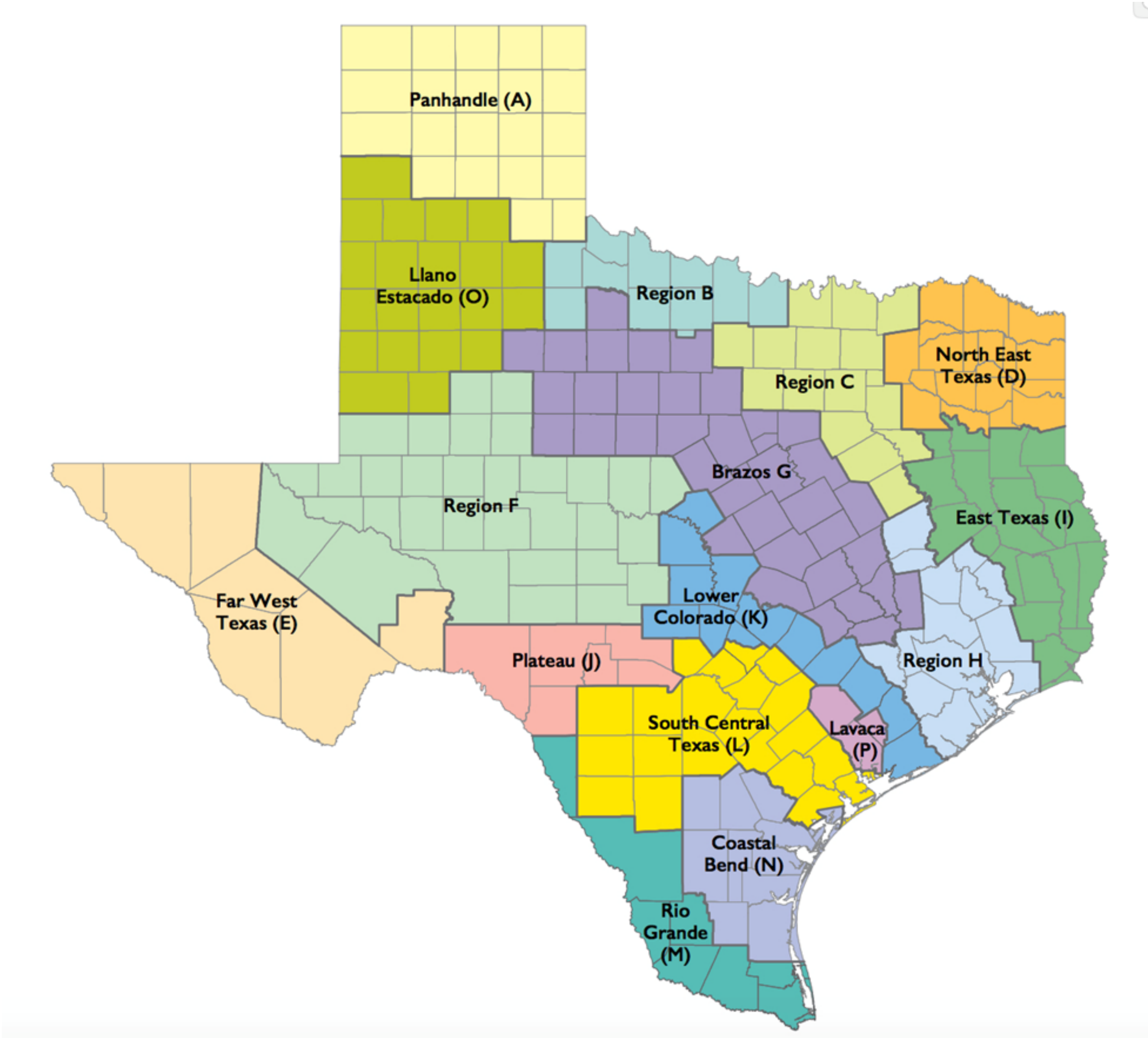

Figure 6. Figure adapted from the Texas Water Development Board's 2017 State Water Plan (TWDB 2016a) depicting the Regional Water Planning Areas

Due to its long history of drought, Texas has a robust drought mitigation planning process at the State, regional, and local level. Most plans are tested to the standard of the Drought of Record, though Regional Water Planning Regions A, B, C, F, G, and K have different standards based on locally significant historic droughts. Some regional plans also include municipal drought management strategies, although this is not required. Finally, local governments must have drought plans which are triggered by supply and shortages (TWDB 2016a).

The State monitors conditions using a variety of indexes including: the US Drought Monitor as well as the Crop Moisture Index, Keetch-Byram Drought Index Reservoir Storage Index, Stream Flow Index, and Standardized Precipitation Index (Drought Preparedness Council 2005). The

State defines drought as one of four types depending on the specific nature of the resulting water shortage. Meteorological drought is a period of prolonged dry weather, though not necessarily with a supply impact. Agricultural drought is due to irrigation demands increasing to compensate for lack of precipitation. Hydrological droughts occur when stream flow and aquifer levels dip below average, and are the main focus of regional water planning. Finally, socioeconomic droughts occur when the needs of all stakeholders cannot be met, threatening health, safety, and quality of life of the population (TWDB 2016a).

Currently, Texas uses various national monitoring systems (TWDB 2016a). On top of those, the TWDB developed a rainfall monitoring system to predict summer droughts with between four and six months lead time, with approximately 60% degree of certainty (Fernando et al. 2015). This allows emergency planners to anticipate water needs and preemptively conserve. However, this type of modeling does not predict drought length, nor does it address the increased likelihood of severe multi-decade droughts, beyond the drought of record (Venkataraman et al. 2016). Current drought response models are concerned with drought crisis management rather than solidifying system resilience through the water system (Drought Preparedness Council 2005). Furthermore, precipitation is not a proxy for drought, as anthropogenic and climate change factors have considerable effects on local water availability (Dai 2011; AghaKouchak et al. 2015; Awal et al. 2016).

4.2 Surface Water

4.2.1 Ownership Rights and Regulation

Surface water is defined as the waters passing through a defined watercourse. The definition of a defined watercourse is quite broad, and subject to ruling by the Texas Commission on Environmental Quality (TCEQ; Hoefs v. Short 1916; Domel v. City of Georgetown 1999; Porter 2014; Eckstein and Hardberger 2016). In general, a watercourse has a bank and bed, current and a somewhat regularly occurring source of water. This definition extends to manmade canals and reservoirs (Eckstein and Hardberger 2016). Surface water is property of the State, and a permit, called a Water Right, must be obtained from TCEQ for its use (Fehlis and Fipps 1998). Water Rights are classified by their year of issuance; older rights getting priority over newer in the event of shortage in a system called prior appropriation (also known as 'first in time, first in right') (Jarvis 2016; TCEQ 2017a). The usage purpose of the water receives no consideration in this process, except in the Middle and Lower Rio Grande (Porter 2014). There are two notable exceptions to the water right system. Firstly, for domestic, wildlife management, or livestock use, a reservoir with 200 acre-feet annual withdrawal capacity may be built on private property. Secondly, petroleum and natural gas drilling may use up to one acre-foot per day (Porter 2014). River authorities are established to address development and water planning needs in river basins. These do not consume water, but sell use rights to customers (TWDB 2003).

4.2.2 Sourcing Issues

Water in Texas has been essentially fully appropriated (Porter 2014). Due to differences between the appropriation of water and the use of appropriations, TCEQ also issues Limited-Term Rights, which allow use of water that is technically already allotted, but remains unused. For example, a municipality may hold a water right that it does not use, and a construction company may apply for a limited term right to use part of that water. These rights have lowest priority in the event of drought (TCEQ 2017a). Stormwater, or water from rain, is the State's property if it is flowing into a defined watercourse. If the water is not in a defined water course, it is called "diffused surface water" and property of the land owner (Eckstein and Hardberger 2016). Some new rights have provisions to allow municipalities to exercise water sourcing options in events of drought (Porter 2014).

Surface water sources are shared by different political entities: rivers flow across state or national borders. This can cause complications in surface water regulation, especially in more water-stressed regions (Nava et al. 2016). Along with other entities outside of Texas who are drawing water, there are environmental needs of surface water. Senate Bill 3 defined environmental flow requirements, determined through a multi stakeholder engagement process (Eckstein and Hardberger 2016; Jarvis 2016). While this ultimately concluded with defined levels, environmental stakeholders maintain that these are too low (Roach 2013).

4.3 Groundwater

4.3.1 Ownership Rights and Regulation

Groundwater refers to water trapped in underground aquifers. Unlike surface water, groundwater is not owned by the State. Instead, groundwater is usually owned by the land holder, though recent case law allows separation of water ownership from the land (Johnson and Sahs 2016). Like many Western states, Texas follows the 'Rule of Capture', sometimes called the 'rule of the biggest pump' where few restrictions can be placed on a landowner's right to pump water (TWDB 2003; Johnson and Sahs 2016). Some level of coordination is achieved through Groundwater Conservation Districts (GCDs), which are the State's favored form of groundwater management. These GCDs are intended to control and prevent waste, subsidence and maintain pumping and drilling permits (Johnson and Sahs 2016). Mostly, their power depends on the specifics of their founding charter, but generally involve permitting drilling, withdrawals and revising transfers of groundwater outside the district (Porter 2014;

Johnson and Sahs 2016). GCDs must also submit plans to manage groundwater resources, to ensure their future use (Booth et al. 2016; Johnson and Sahs 2016).

GCDs are not mandated across the state, and have to be created either by an act of legislature, TCEQ, or voluntarily at the local level (Booth et al. 2016). The borders of a GCD often do not follow the aquifer, instead are often on county lines (Porter 2014). In order to more efficiently manage water supplies, GCDs are agglomerated into Groundwater Management Areas, which monitor the aquifer, plan for the future and send modeled projections to the TWDB (TCEQ 2017a). GCDs can be small and underfunded, and the scope of their powers can vary greatly (Bolhassani 2014; Booth et al. 2016).

Certain aquifers are regulated by special districts, such as the Edwards Aquifer Authority (EAA). These are established by the Texas Legislature and have special powers as defined by that body. For example, the EAA can restrict water use to protect endangered/threatened species at the spring, wildlife, domestic/municipal water supplies, and the quality of the aquifer.

4.3.2 Sourcing Issues

The primary concerns with groundwater use in Texas are, dormant rights, over use in dry conditions, salinization and contamination, replenishment, and subsidence.

Dormant rights are the ownership rights of landowners that have not tapped into the aquifer supply. In effect, the landowner is also the owner of the water, and Edwards Aquifer Authority v. Day denied the ability of state entities to restrict access to that water without compensation (Edwards Aquifer Authority v. Day 2012; Malewitz 2015; Harder 2016). This increases uncertainty and risk of shortage (Harder 2016).

Furthermore, groundwater is often a substitute for surface water during times of drought, especially in rural regions. This spike in demand can lead to overdrawing, harming the ability of the aquifer to replenish (Ho et al. 2016). Groundwater salinity increases as water levels fall, something that is already a concern in parts of Texas (Chaudhuri and Ale 2013; Chaudhuri and Ale 2014). It has been established for many years that extensive groundwater withdrawals causes subsidence (Chi and Reilinger 1984). Subsidence is of particular concern for Texas' municipal areas, especially in the Houston-Galveston area (Khan et al. 2014; Qu et al. 2015).

4.3.3 Aquifer Storage and Recovery

One innovative means of water management currently being explored in Texas is Aquifer Storage and Recovery (ASR). ASR refers to storing, and sometimes treating, excess surface water, groundwater, and stormwater in an aquifer system in order to use it at a later time (Missimer et al. 2011; Webb 2015). Scouting a project involves rigorous scientific and economic studies. Afterwards, permitting from TCEQ and any relevant ground water conservation districts must be secured on a case-by-case basis before construction can begin which has slowed ASR adoption (Webb 2015). Though this technology has been explored in Texas at some level since the 1960s, there is increasing interest in ASR technology across the state. The water is stored without evaporation losses, though the geological limits of each aquifer may constrain storage. ASR projects are a key component of the 2017 State Water Plan, contributing 2% of water management by 2070 (Webb 2015; TWDB 2016a). In an urban context, ASR is often suggested as a means to store and partially treat stormwater (Page et al. 2017). SAWS' ASR program is the largest groundwater-based ASR in the country.

4.4 Auxiliary Waters

New technologies have required new legal status with regards to water ownership. Beginning with rainwater capture, Texas law classifies stormwater not in a water course as diffuse surface water. While only relevant at large scale, diffuse surface water belongs to the land owner and can be stored without a permit, as long as the diversion does not cause harm to other land owners (Porter 2014; Eckstein and Hardberger 2016). Another interesting case involves Aquifer Storage and Recovery. Water pumped into ASR in Corpus Christi is limited by ground water migrating away and being used by other users (Webb 2015). ASR waters are still subject to the right of capture, and so measures must be taken to protect the stored water (Malcolm Pirnie Inc et al. 2011; Webb 2015).

Technological improvement in desalination has unlocked saline waters as potential water resources in Texas (Mezher et al. 2011; Eckstein and Hardberger 2016; TWDB 2016b). While still a minority of water supplies, Texas currently desalinates sea water and brackish groundwater and plans to expand as other, cheaper water sources are consumed (Davis et al. 2015, Arroyo et al. 2016; TWDB 2016b). Desalination also provides a drought proof source of water, making it attractive to municipal water planers (TWDB 2016b). Legally, brackish groundwater follows the same rule of capture as fresh groundwater, and, were applicable, is regulated by GCDs. Thusly, any desalination projects must own land above the target aquifer (Arroyo et al. 2016). Costs are relatively variable, depending on the salinity of the source water and capital costs, however it is generally cheaper to desalinate groundwater than seawater (Arroyo and Shirazi 2012; Arroyo et al. 2016). Another major barrier to desalination is the permitting process, which can be extensive involving federal, state, GCDs and local permits (Arroyo et al. 2016).

Recycled waters, such as greywater and reclaimed water, do not have ownership issues, but are subject to more stringent regulation. Greywater, as defined by Texas Law, is wastewater from showers, bathtubs, sinks not used for food preparation, and clothes washing machines. The precise nature of the definition excludes water that may have come in contact with toxic or biohazardous materials. Domestic use is limited for 400 gallons per day or less as long as a grey water system is in place and in compliance with various building specifications. The permissible uses are for minimizing foundation damage, gardening and composting (Austin Water 2016; TCEQ 2017b).

Reclaimed water (so called “purple-pipe water”) by contrast, is water that has been treated to safe levels and reused, either as potable or non-potable water. There are strict regulations as to the use of reclaimed water and its integration back into the water supply; however, it is treated like any other water source (TWDB 2017).

5. Water Treatment and Use

A general diagram of key aspects of the water treatment and use cycle is depicted in Fig. 7. This shows water sources (surface, ground, storm), the different streams they occupy (sewage, graywater), and water lost to consumptive use. The diagram also indicates key institutions with regard to operations: the water utility, the stormwater management agency, and different customer classes. Finally, different pathways for water re-use are indicated.

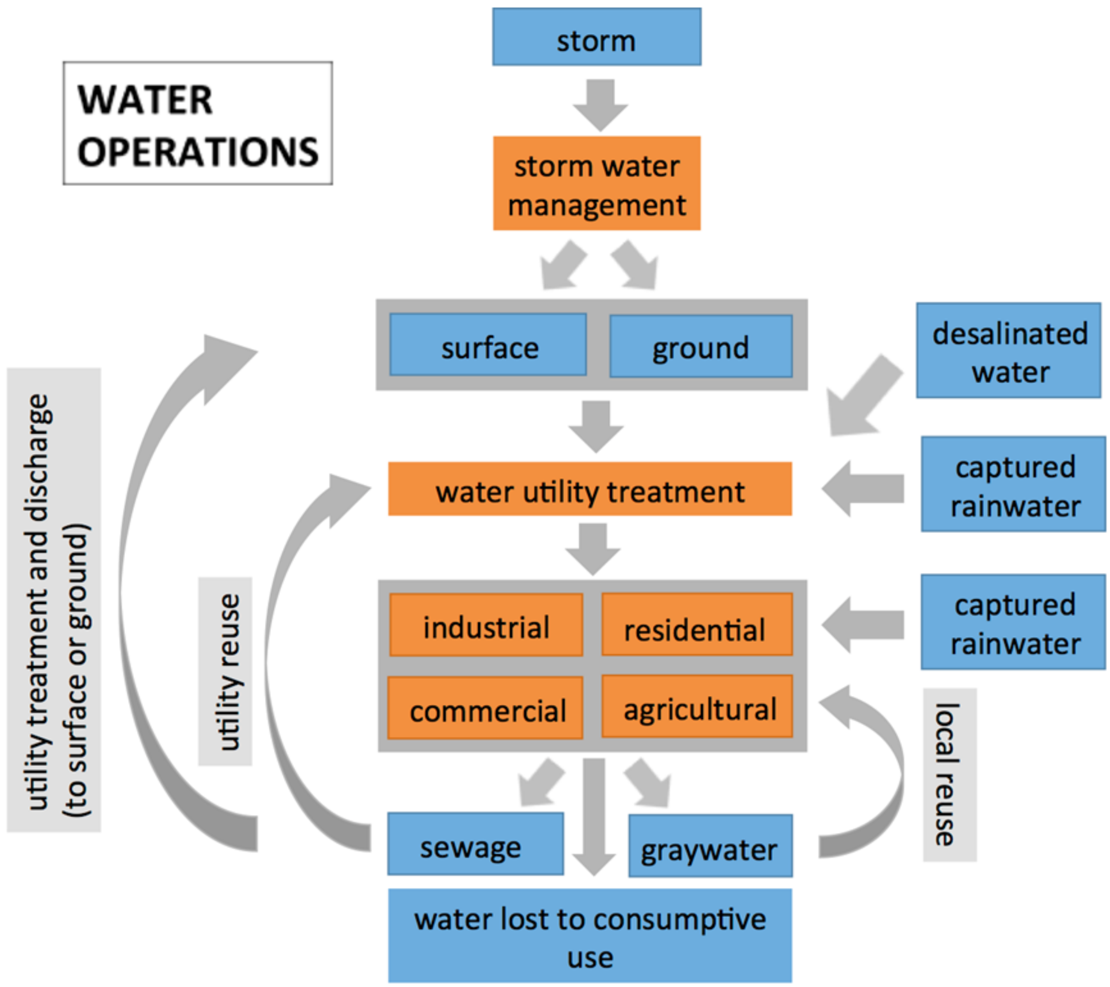

Figure 7. A diagram representing sources of water, entities involved in the treatment and distribution of water, key customer classes, different classes of wastewater, and viable pathways for water re-use.

The five cities that are the focus of this study are each served by a municipally controlled water and sewer utility and a municipal stormwater organization (summarized below in Table 2).

Table 2. Listing of primary water sources and the water service entities for each of the five major Texas cities that are the focus of this study.

	Austin[a]	Dallas[b]	Fort Worth[c]	Houston[d]	San Antonio[e]
Primary sources	Surface water from the Colorado River, Highland Lakes	Surface water from area reservoirs: Lake Ray Hubbard, Lake Lewisville, Lake Grapevine, Lake Ray Roberts and Lake Tawakoni	Surface water from Cedar Creek and Richland-Chambers reservoirs, and Lake Bridgeport, Eagle Mountain Lake, Lake Worth, and Benbrook Lake	Surface water from the San Jacinto River through Lake Conroe and Lake Houston, and from the Trinity River, through Lake Livingston	Groundwater from the Edwards aquifer
Water & sewer	Austin Water - municipal	Dallas Water Utilities - municipal	Fort Worth Water Department - municipal	City of Houston Water & Wastewater Utility - municipal	SAWS - municipal
Storm	City of Austin Watershed Protection Department - municipal	City of Dallas Trinity Watershed Management (Stormwater Management team) - municipal	City of Fort Worth Transportation & Public Works Department (Stormwater Management Division) - municipal	City of Houston Stormwater Maintenance Branch - municipal	SAWS - municipal

[a]Source: http://www.austintexas.gov/department/water-sources-city-austin
[b]Source: http://dallascityhall.com/departments/waterutilities/Pages/water_quality_information.aspx
[c]Source: http://fortworthtexas.gov/water/drinking-water/supply/
[d]Source: https://www.publicworks.houstontx.gov/pud/drinkingwater.html
[e]Source: http://www.saws.org/Your_Water/WaterResources/Projects/edwards.cfm

The primary water sources for each city are also listed in Table 2. This is one aspect that drives differences in each city's approach to water management: notably, since San Antonio receives the vast majority of its water from the Edwards Aquifer which has very beneficial geological and hydrological characteristics in addition to a unique regulatory structure, water rates in San Antonio are unusually low. However, the potential for the water supply from the Edwards Aquifer to drop by as much as 44% under drought of record conditions necessitates that San Antonio diversify their water sources. Similarly, Austin is assessing opportunities to diversify its supply instead of relying only on surface water from the Colorado River in order to address projected demand. Each city has to consider the costs and the benefits of diversifying the water supply compared to those of various forms of water re-use, demand reduction, and other management strategies, and this will be a strong dynamic in the implementation of integrated urban water management.

5.1 Water Utility Operations

Focusing in on water utility rates, since 2013 the Public Utility Commission (PUC) has assumed a lead role in regulatory approval of rates. Current rate structures for key customer classes are outlined in Tables 3 and 4. Customer classes not listed in this table include multiple occupancy residences and high volume or industrial customers. The rate structure for these groups is typically similar to those for residential customers and commercial customers, respectively.

The summary of rate structures presented indicates a fundamentally traditional rate structure across most classes in most major Texas cities. There are a few places where rate structures may motivate certain usage behaviors: Austin has seasonal charges for commercial customers that may help to motivate efficiency, and San Antonio has a “base excess use” rate to discourage peaks in monthly usage. Seasonal variations in water use for irrigation are of course large and water managers in Texas described a notable level of interest in encouraging reductions in water use for irrigation, although not all cities meter water for irrigation separately.

Stormwater rates are structured similarly across different cities and rate classes, generally based on the amount of impermeable cover. Specifically, residential rates typically have 2-5 tiers, with the tier reflecting the number of square feet of impervious cover; commercial rates also scale with the amount of impervious cover. Austin may offer discounts for stormwater controls that exceed regulatory requirements.

Quantitative details of rates also have implications. San Antonio has been able to keep its rates very low owing to minimal treatment required to provide a high quality water service when sourcing water from the Edwards Aquifer; Austin ratepayers willingly accept relatively high rates in order that the city can support a similarly high quality water service.

There are many options for alternative rate structures that can motivate different consumption patterns. In addition, it is beneficial for the price of water to reflect the true cost of water as much as possible, although it is critical to ensure that all users, regardless of income, have access to at least a basic water service at an affordable price.

Table 3. Summary of structure of residential (single occupancy) water rate structures in Austin, Dallas, Fort Worth, Houston, and San Antonio.

			Austin[a]	Dallas[b]	Fort Worth[c]	Houston[d]	San Antonio[e]
RESIDENTIAL	Water	Fixed	Based on meter size. Additional flat fee.	Based on meter size	Based on - meter size - whether residence is within or outside city limits.	Based on meter size	Based on - meter size - whether residence is within or outside city limits. Additional Edwards Aquifer Authority Permit Fee and small TCEQ fee (both independent of meter size)
RESIDENTIAL	Water	Variable	Volumetric charge has 5 tiers	Volumetric charge has 4 tiers	Volume charge has 4 tiers, and also varies according to whether residence is within or outside city limits.	Volumetric charge has 8 tiers and ***also*** depends on meter size	Volume charge has 8 tiers, and also varies according to whether residence is within or outside city limits. Also water supply fee to fund acquisition of new water supplies, based on 8 tiers and location within or outside city limits.
RESIDENTIAL	Sewer	Fixed	Flat fee	Based on meter size	Based on - meter size - whether residence is within or outside city limits.	Based on meter size	Based on - meter size - whether residence is within or outside city limits.
RESIDENTIAL	Sewer	Variable	2 tiers, with tier chosen according to the lower of average water usage or that month's consuption.	Fixed price per gallon.	Varies only according to whether residence is within or outside city limits.	Volumetric charge has 7 tiers and ***also*** depends on meter size	Volume charge has 3 tiers, and also varies according to whether residence is within or outside city limits.

[a]Source: http://www.austintexas.gov/department/austin-water-utility-service-rates

[b]Source: http://dallascityhall.com/departments/waterutilities/DCH%20Documents/monthly_rate_sheet.pdf

[c]Source: http://fortworthtexas.gov/water/rates/

[d]Source: https://edocs.publicworks.houstontx.gov/division-files/resource-management-division/utility-customer-service/rates/4676-2015-water-and-sewer-rates-1.html

[e]Source: http://www.saws.org/service/rates/

Table 4. Summary of structure of irrigation and commercial water rate structures in Austin, Dallas, Fort Worth, Houston, and San Antonio.

			Austin[a]	**Dallas**[b]	**Fort Worth**[c]	**Houston**[d]	**San Antonio**[e]
IRRIGATION (where seprately metered)	**Water**	**Fixed**				Based on meter size	Based on - meter size - whether residence is within or outside city limits.
		Variable			3 tiers	Volumetric charge has 2 tiers and ***also*** depends on meter size	Volume charge has 4 tiers, and also varies according to whether residence is within or outside city limits.
COMMERCIAL	**Water**	**Fixed**	Based on meter size. Additional flat fee.	Based on meter size	Based on - meter size - whether business is within or outside city limits.	Based on meter size	Based on - meter size - whether business is within or outside city limits.
		Variable	**Seasonal Charges**: peak and off peak rates. Also a volumetric reserve fund surcharge that is used to offset water service revenue shortalls.	2 tiers - but apply a third higher rate if monthy usage is in higher of two tiers and is more than 1.4 x average use	Varies only according to whether business is within or outside city limits.	Fixed volumetric price	**Base excess use structure** - volume charge has 4 tiers based on the month's volume used relative to average monthly use, and also varies according to whether residence is within or outside city limits.
	Sewer	**Fixed**	Flat fee		Based on - meter size - whether business is within or outside city limits.	Based on meter size	Based on - meter size - whether business is within or outside city limits.
		Variable	2 tiers, with tier chosen according to the lower of average water usage or that month's consuption.	Fixed volumetric price Surcharges depending on waste composition	Volumetric rates based on location and composition of waste water	Fixed volumetric price	**Base excess use structure** - volume charge has 4 tiers based on the month's volume used relative to average monthly use, and also varies according to whether residence is within or outside city limits.

[a]Source: http://www.austintexas.gov/department/austin-water-utility-service-rates

[b]Source: http://dallascityhall.com/departments/waterutilities/DCH%20Documents/monthly_rate_sheet.pdf

[c]Source: http://fortworthtexas.gov/water/rates/

[d]Source: https://edocs.publicworks.houstontx.gov/division-files/resource-management-division/utility-customer-service/rates/4676-2015-water-and-sewer-rates-1.html

[e]Source: http://www.saws.org/service/rates/

5.2 Planning and Financing Capital Investments

Ultimately, infrastructure development and other capital investment considerations are driven by questions that include:

- The projected population growth;
- Total supply, and also consistency of water supply from current sources under drought of record conditions;
- Rapidity of aquifer depletion and replenishment;
- Balance of cost of supply from new sources compared to cost of development of reuse systems;
- Maintenance and operational costs of existing infrastructure; and
- Frequency and intensity of flooding with regard to stormwater management and capacity of system to absorb floodwaters.

Each regional group contributing to the Texas State Water Plan determines what infrastructure is necessary to meet projected water needs, with future efficiency and reuse measures factored in. Infrastructure projects listed in the State Water Plan are eligible to apply to for various state loans, including through the SWIFT fund. This state-wide process couples with various city-based plans, including Austin's 100-year water supply planning process.

An outline of the planning process, including stakeholders and options for choices between traditional and green infrastructure, are included in Table 5 below. Some notable features of the decision making and approval process that pertain to new approaches to urban water management are as follows:

- The choice between different types of infrastructure represents a choice between different capital investment and different maintenance requirements and costs. For example, some green infrastructure projects may require lower capital investment but have higher associated maintenance needs.
- In cases where a ballot measure has been required for bond issuance to cover capital costs of new reservoirs, there have recently been strong advocacy efforts against such measures. In some cases new reservoir infrastructure has been recommended by large engineering firms (who would profit from building that infrastructure), yet broader stakeholders have deemed the additional reservoir infrastructure unnecessary; ballot measures for this category of project have recently been defeated in several situations.

The aim of this table is to highlight who influences planning and what the overall planning and financing approval process is. It highlights that the balance of stakeholders involved in the planning process is critical in influencing the choices made. Since the planning process is a “bottom up” process, the question of who engages in each region’s planning process is important.

Table 5. Representation of key aspects of the water infrastructure planning process that is led by water utilities, including stakeholders and the opportunities for consideration of traditional and green infrastructure.

	Type of project	Sources of financing	Decisionmakers	Stakeholders
Traditional	Infrastructure including reservoirs, pipelines	SWIFT, municipal bonds	Texas Water Development Board must approve plans; Texas Commission for Environmental Quality or Public Utility Commission must approve rate changes to cover capital investments	Construction firms, developers, environmentalists, voters (where ballot measures are involved)
New	Distributed and green infrastructure	Those listed under traditional (above), plus PPPs	Those listed under traditional (above), plus private sector and community/philanthropic investors	Those listed under traditional (above)

Information on the projects planned in each city based on the ten most capital-intensive projects in each region in the 2016 Texas Water Development Plan, sorted by type, are listed in Table 6.

The data captured in the table show the following:

- Investment in source and treatment infrastructure in all urban areas studied.
- Most urban areas are also investing in additional distribution infrastructure, where distribution infrastructure may either open up new water supplies to a given area (e.g., San Antonio’s Vista Ridge project that will pump water from the Carrizo and Simsboro Aquifers in Burleson County) or may enable more efficient use of existing water supplies (e.g., purple pipes for graywater). Clearly, these have very different benefits and impacts on the environment and on water use.
- There is limited major investment into reuse and water efficiency. Note that water efficiency is usually pursued via approaches that do not require infrastructure development, therefore a paucity of listed investments cannot be interpreted as an indicator of cities not pursuing water efficiency.

Table 6. List of high-capital projects by region associated with the cities that are the focus of this study from the 2016 Texas Water Development Plan (TWDB 2016a).

	Austin[a]		**Dallas-Fort Worth**[b]	
	Project	*Budget*	*Project*	*Budget*
Source/treatment infrastructure	Aquifer Storage and Recovery	$312,316,000	DWU - Main Stem Balancing Reservoir Q-35	$674,463,000
Combined treatment & distribution			DWU - Infrastructure to Treat and Deliver to Customers 2035 WTP Expansions Q-40	$1,211,133,000
Distribution infrastructure			TRWD DWU Integrated Pipeline Q-48[e]	$386,752,000
Reuse	Rainwater harvesting Direct reuse	$690,167,000 $536,176,000		
Water efficiency				

	Houston[c]		**San Antonio**[d]	
	Project	*Budget*	*Project*	*Budget*
Source/treatment infrastructure	Allens Creek Reservoir[e] COH Northeast Water Purification Plant Expansion[e]	$221,359,000 $192,838,000	Seawater Desalination Expanded Brackish Wilcox Project	$1,590,590,000 $723,175,000
Combined treatment & distribution				
Distribution infrastructure	East Texas Transfer[e] Luce Bayou Transfer	$388,064,000 $360,005,000	Vista Ridge Project Water Resources Integrated Pipeline	$571,958,000 $205,000,000
Reuse				
Water efficiency	Water Loss Reduction	$701,969,000		

[a]Source: https://www.twdb.texas.gov/waterplanning/swp/2017/doc/2016_RegionalSummary_K.pdf
[b]Source: https://www.twdb.texas.gov/waterplanning/swp/2017/doc/2016_RegionalSummary_C.pdf
[c]Source: https://www.twdb.texas.gov/waterplanning/swp/2017/doc/2016_RegionalSummary_H.pdf
[d]Source: https://www.twdb.texas.gov/waterplanning/swp/2017/doc/2016_RegionalSummary_L.pdf
[e]Cost represents partial costs of larger project assigned to this city

6. Revenue Models of the Future (or, How Utilities Plan on Making Money)

Water utilities strive to meet two primary goals:

1. Provide high quality and reliable water services at the most reasonable rate possible;
2. Generate sufficient revenue through ratemaking in order to sustain delivery of these services.

As such, water rates function as a means to communicate to ratepayers through price signaling the cost consequences of their usage decisions, and they allow the utility to recover the cost incurred to deliver water services, fund daily operations, and invest in system improvements (AWE 2014). Rate setting informs and is defined by a water utility's financial plan development and financial policies (Fig. 8; AWE 2014), which are underpinned by the ratepayers' water usage patterns, regional water availability, and seasonal and annual temperature variation. Structuring appropriate water rates to satisfy customer needs, achieve revenue sufficiency, and effectively manage finite water resources for the near- and long-term future will require novel approaches as water consumption patterns change in response to precipitation regimes altered by climate change and infrastructure systems that require significant revitalization and innovation.

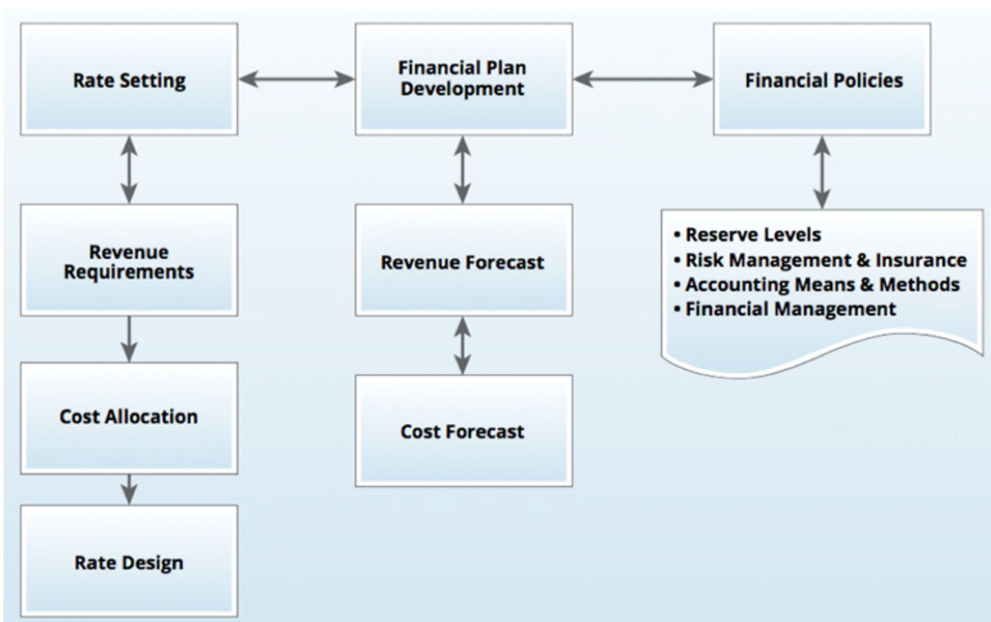

Figure 8. Figure adapted from AWE (2014) that depicts the core components of rate setting, financial plan development, and financial policies.

6.1 The "Conservation Conundrum"

A national trend in water use reduction is currently a focal issue in discussions of water ratemaking. Between 2005 and 2010, total freshwater use in the US dropped by 13% and household water use declined for the first time since the 1950s, with Texas, Nevada, and Nebraska seeing the largest reductions in per capita water use (Fig. 9; Donnelly and Cooley 2015). Efficiency improvements explain household water use decline, but population growth in some of the hottest and driest parts of the country, where per capita water use is relatively high, has offset these efficiency improvements (Donnelly and Cooley 2015). In light of water availability concerns and population growth projections, water utilities are now grappling with how to continue to promote water use efficiency and conservation programs while also maintaining robust revenue streams. Even though efficient water use is in the best interests of society and the environment, declining water sales are traditionally thought to translate to declining revenue, a dilemma which is referred to as the "conservation conundrum" (AWE 2014). The water utility of the future will need to embrace innovative ratemaking that successfully tackles this conundrum.

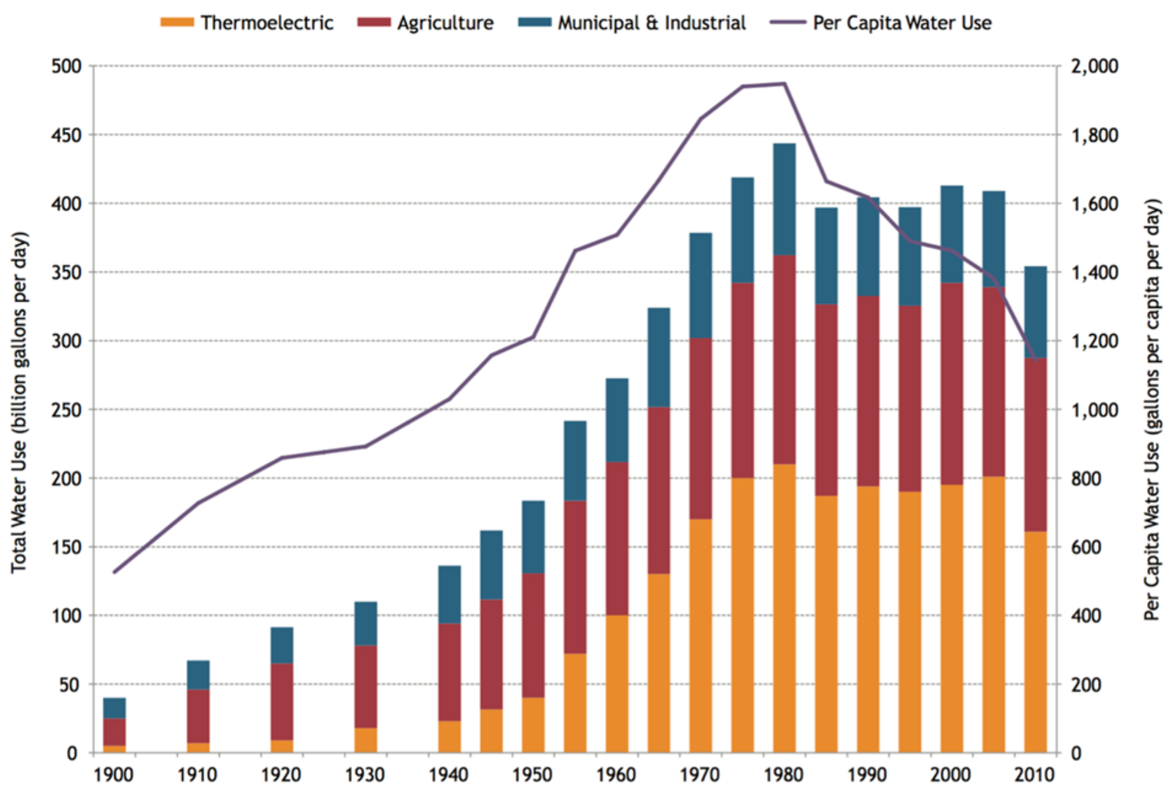

Figure 9. Figure adapted from the Donnelly and Cooley (2015) that depicts total US water use by sector from 1900 to 2010. Total water use includes freshwater and saline water, and municipal and industrial water includes public supply, self-supplied residential, self-supplied industrial, mining, and self-supplied commercial (Donnelly and Cooley 2015).

6.2 Water Ratemaking is not One-Size-Fits-All

No water utility is exactly alike, and as a result there are many different strategies and approaches employed when making water rates. Regional variation in climate, water availability, and water sourcing underpin differences in water pricing and water use by states as well as cities (Fig. 10; Eskaf et al. 2014; Walton 2016). In cities that are water rich, like Seattle and San Francisco, water prices are high yet average bill sizes are comparable to other cities because water use is relatively low (Fig. 10; Walton 2016). Alternatively, Phoenix uses twice as much water as Seattle and San Francisco yet has a lower monthly bill (Fig. 10; Walton 2016). Water rates in Phoenix represent a clear disconnect between the true cost of water and the price of water charged to ratepayers, leading to higher usage rates. There is significant variation in water pricing and water use across cities within the same state, as well. For example, the average monthly water bill in Fort Worth, Houston, Austin, and San Antonio is roughly the same size, yet Forth Worth and San Antonio have higher average household rates of use (Fig. 10; Walton 2016). The water utility of the future will need to tailor rate structures to contend with regionally-specific seasonal and annual precipitation regimes and temperature fluctuations as well as water sourcing issues, while at the same time meeting their affordability, efficiency, revenue stability goals.

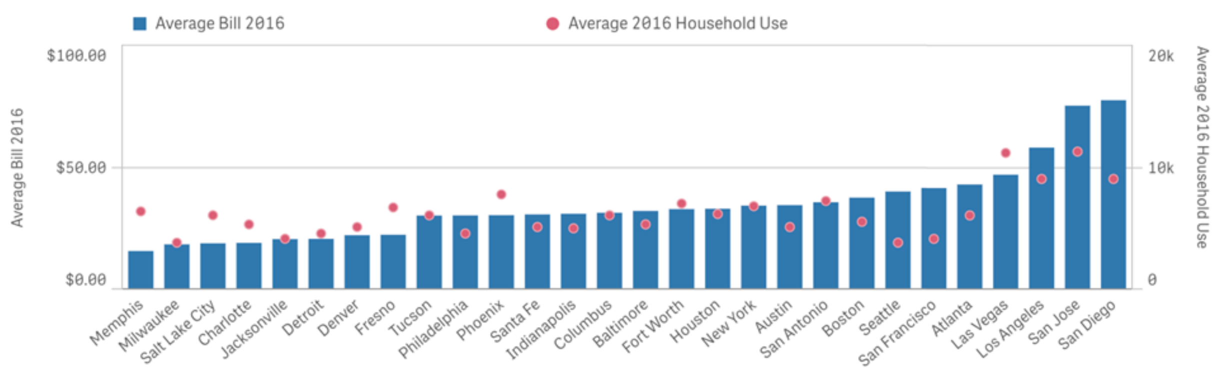

Figure 10. Infographic adapted from Circle of Blue (Walton 2016) that depicts the average household water use (in gallons per month; red) and bills (blue) in 2015-2016 for 30 US cities that participate in Circle of Blue's annual water pricing survey. Median household water use is depicted for Denver, Phoenix, Tucson, and Seattle, and the remaining cities show 'typical use,' as defined by the local utility (Walton 2016).

6.3 Novel Approaches to Water Ratemaking

Water utilities of the future must embrace innovative water pricing structures to overcome the "conservation conundrum" and maintain revenue stability in the face of a rapidly changing environmental and consumer-based landscape (AWE 2014; Eskaf et al. 2014). Water pricing schemes that incorporate financial incentives for water efficiency and mitigate revenue variability, as opposed to traditional one-size-fits-all block rate structures, will help water utilities anticipate how changing water use patterns and rates drive revenue risk (Eskaf et al. 2014). Efficiency-oriented rate design (AWE 2014), as described below and in Fig. 11, is an excellent example of innovative water pricing for the future:

- Choices 1 and 3: value of service/ full cost recovery pricing;
- Choice 2: differences in customer type;
- Choice 4: seasonal change;
- Choice 6: drought contingencies;
- Choice 5: variation in usage rates.

Models and tools such as the Alliance for Water Efficiency's Sales Forecasting and Rate Model (AWE 2017) and the Environmental Finance Center at the University of North Carolina's Water Utility Customer Assistance Program Cost Estimation Tool (WRF 2013a) and Water Utility Revenue Risk Assessment Tool (WRF 2013b) can help water utilities analyze innovative rate structuring approaches by inputting the unique consumer, climate, water availability, and water sourcing data specific to their service region(s).

PRIMARY CHOICE:	OPTIONS	IMPLICATIONS
1. Recover all costs through rates and charges	External tax support	Some revenue sources from outside the water rate structure.
	No external tax support	Recovers all costs through rates and charges attached to water service.
2. Differentiate rates and charges by customer class	Same rates for all customers	Recovers revenues under a single rate structure for all customers
	Class-based rates	Recovers revenues through different rate structures for different groups of customers (such as residential, commercial, and industrial).
3. Design the fixed component of the customer bill	No fixed charges	Recover all revenues through variable charges.
	Same fixed charge for customers	Recovers metering, billing, and other charges. Reflects no cost variations based on customer-class distinctions.
	Different fixed charge for customers	Reflects cost variations in metering, demand, billing, and other factors based on meter size or other customer-class distinctions.
4. Vary rates by season (Peak Pricing)	Year-round rates	No variation in rates by season of use.
	Seasonal rates	Rates that vary for two or more time periods within a year, reflecting seasonal variation in costs.
5. Vary rates by block of water usage (Block Rates)	Uniform rate	The rate does not vary with usage for all customers or all customers within a class (uniform rates by class).
	Block rates	Requires a determination of: (1) the number of blocks, (2) unit rates for each block. (3) block switchpoints by usage
	Water Budget-based Block Rates	Define block width by a technical definition of efficient water use: a water budget conditional on customer characteristics.
6. Vary rates during drought emergencies (Drought Pricing)	No Drought Pricing	Rates are not integrated into drought management plan.
	Drought Pricing	Rates increase during shortage events to reflect scarcity value.

Figure 11. Figure adapted from AWE (2014) that depicts a decision framework for efficiency-oriented rate design.

Volumetric rate structuring in combination with select service fees (e.g. hook-up fees, etc.) and fixed fees (e.g. meter charges, etc.) are typically used to generate revenue to recover the cost of delivering water services and executing daily operations, while funding for capital investments towards system improvements is generated through usage-related surcharges and/or flat fees that are folded into water rates. For example, a Public Goods Charge is now being applied in California as a means to provide sustainable water financing for public purpose projects, including water innovation (Quesnel and Ajami 2015). However, surcharges may also be applied in order to send efficiency-related price signals to consumers during a specific period of time, such as a hot summer or a drought (AWE 2014). Regardless of the how the revenue generated from rate collection is allocated, public education and communication are vital to ensuring a robust and reliable revenue stream. Customers of the water utility of the future must understand the relationship between rates, revenues, and service quality, in addition to proposed mechanisms to support system improvement and/or efficiency programs, in order to achieve full cost recovery that matches the true cost of water (AWE 2014).

6.4 Business Models of the Future

A water utility's business model dictates the utility's strategy for generating stable and robust revenue streams into the long-term future. Typically, this strategy is built on the premise that revenues collected from ratepayers should cover all water service, maintenance, and operating expenses (Hughes et al. 2014). With the advent of climate change, urban densification, and aging infrastructure, however, this business model is quickly becoming obsolete. Many US water utilities are now faced with funding shortfalls and large capital needs associated with revitalizing aged infrastructure and investing in infrastructure to adapt to climate change, rendering them vulnerable to revenue risk and insecurity in the years to come. In order to overcome this formidable challenge, the water utility of the future must adopt a resilient business model that understands the risk for disruptive revenue fluctuation, makes informed financial decisions, reexamines sales projection methodologies, studies consumer behavior, and considers new pricing models (Hughes et al. 2014). It will be particularly important for the water utility of the future to craft a business model that utilizes data-driven, long-term planning as well as strategies for procurement of financing to supplement rate-based revenue towards ballooning capital needs.

6.4.1 Funding Capital Investments

Public-private partnerships (PPPs) have long been used as a tool to improve the performance and financial stability of water systems in developing countries (WBG 2017). As US water utilities grapple with emerging issues surrounding water scarcity, water security, and infrastructure revitalization and innovation, PPPs are being explored as a means to help bridge the funding gap between rate-based revenue and the capital investment budgets that will be required to pay for the capital needs of the future. There is growing interest amongst investors, policymakers, and water managers alike in harnessing private capital to manage and finance water resource solutions (Culp et al. 2015). While existing regulatory frameworks (water rights and laws, environmental controls, and governance institutions) have historically posed challenges to the investment of private capital in water management, the emerging need for funding has motivated some groups to explore opportunities for investing within existing frameworks. For example, Encourage Capital and Squire Patton Boggs (Culp et al. 2015) have developed private investment strategies for the Colorado River Basin watershed that could be applied to other water-stressed regions in the Western US and function as a template to build strategies for other parts of the country (Fig. 12; Culp et al. 2015). This sort of tailored investment approach is appealing to diverse stakeholder groups and has great potential to work within regionally-specific regulatory frameworks rather than against them.

Watershed Enhancement	Forest Health Environmental Impact Bond	Invest in a pay-for-performance vehicle to reduce the risk of wildfires and increase watershed yield via forest thinning, with investors repaid through savings in fire suppression cost and avoided water risk
	Riparian Restoration Environmental Impact Bond	Invest in a pay-for-performance vehicle to improve ecosystem health and increase watershed yield through invasive species removal and riparian restoration
Muni Water Infrastructure	System Loss Pay for Performance	Invest in a pay for performance vehicle to upgrade municipal water infrastructure to reduce systems losses
	Green Bond with Sustainability Conditions	Provide low-cost financing for municipal water infrastructure tied to environmental and sustainability conditions
Market Development	Next Generation Water Trust	Develop an investment-driven next generation water trust to address environmental and system-wide water supply risks
	Water Storage Trading	Develop, implement, and operate storage trading markets in surface water reservoirs and groundwater aquifers

Figure 12. Figure adapted from Culp et al. (2015) that depicts an overview of private investment strategies, grouped into six "investment tool blueprints," that were developed to finance water resource solutions, generate related environmental benefits, and create financial return in the Colorado River Basin watershed.

Bonds are a typical vehicle for private and public funding of water utility capital projects and will undoubtedly continue to factor into the funding schemes of the utility of the future. Cities, states, and private entities all engage in this type of debt investment, in which money is loaned to a water utility for a predetermined period of time and then paid back at a fixed or variable interest rate. Municipal bonds generally take two forms: revenue bonds and general obligation (GO) bonds. Revenue bonds are used to fund targeted projects for specific populations and are repaid by those that benefit directly from the projects (Quesnel and Ajami 2015). GO bonds are used to finance long-term projects through borrowed money from investors and must be initiated through legislation, sent to the ballot box, and then approved by a majority of voters (Quesnel and Ajami 2015). GO bonds are typically invested in public purpose projects that seek to improve management of water systems through efficiency and conservation, ecosystem restoration, and risk mitigation. States also issue GO and revenue bonds, generally through granting programs that are managed by an oversight board and funded through tax revenue, such as the TWDB and the SWIFT Program, respectively. Bond financing through private entities is traditionally tax-exempt and paid back with relatively low interest rates. “Green bonds,” bonds tied to environmental and sustainability conditions (Culp et al. 2015), are gaining popularity with both private investors and issuers, but monitoring mechanisms to ensure compliance with these conditions are not yet robust (Floods 2017). State and federal grants are also an important capital investment funding mechanism, but federal granting towards infrastructure systems in particular remains extremely uncertain in the current political climate.

6.4.2 Long-term Planning is Critical

Data-driven modeling has great potential to inform the water utility business models of the future by providing predictive power towards adapting to the environmental, consumer, and infrastructure challenges ahead. Climate and meteorological data and modeling (Swain and Hayhoe 2015; Tewari et al. 2015; Gelca et al. 2016; Venkataraman et al. 2016) can be employed to understand long-term trends in drought, flooding, and temperature associated with climate change. It can further inform groundwater and surface water availability given changing precipitation regimes and usage rates. Vulnerability and resilience data and modeling (Hughes et al. 2014; Aydin et al. 2015; Beh et al. 2015; Gonzales and Ajami 2017; Trindade et al. 2017) can be used to assess drought vulnerability with respect to urban water source management. Water-sensitive urban design data and modeling (House-Peters and Chang 2011; Olmos and Loge 2013; Kanta and Berglund 2015; Lottering et al. 2015; Sharma et al. 2016) has the potential to inform water use efficiency strategies, including parsing trends in urban water demand. It is crucial that water utilities build their financial and investment strategies with the long-term future in mind, and regionally specific data and modeling can help reduce the uncertainty that surrounds such long-term thinking.

8. Conclusions

This review is focused on four urban areas in Texas – Austin, Dallas-Fort Worth, Houston, and San Antonio – each with its own set of unique water management challenges and opportunities. Differences across these urban areas are grounded in projected population growth, patterns of water availability, water source variation, and the extent to which cities have engaged with best management practices for the future. These situational differences between cities ensure that each will adopt different strategies towards achieving One Water. The specific financial and economic models adopted will determine what approaches to water systems management the city incentivizes. There is no universal financial or economic model that will be effective for all five cities. Instead, a framework approach is required, with city-specific solutions to guide a pathway to One Water. Nevertheless, the revenue models and capital investment strategies discussed in this review will be useful tools for water managers in determining pathways to integrated urban water management.

The One Water concept centers on coordination across diverse stakeholder groups, including multiple players who are involved in the financial and economic dimensions of water management. However, we identify the utilities as playing a central role in water planning, maintenance, and operations that positions them uniquely to drive change in the business models for integrated urban water management. Our analyses of water management data, stakeholder interviews, and utility financial and business models in Texas highlight several important themes for consideration as utilities adopt business models that align with the One Water paradigm:

- Revenue and cost models should incorporate One Water parameters;
- Demand growth projections should incorporate efficiency mechanisms and economic development as well as population growth;
- It is imperative to consider equity and affordability in any planning process;
- Business models should become flexible towards incorporating alternative sources of capital expenditure and project financing;
- Long-term planning must value the risks posed by climate change, as well as possible mechanisms to address those risks, to ensure supply and fiscal reliability.

Texas is exemplary of many developed regions across the world that are now seeking to overcome the environmental, legal, financial, and demographic barriers to sustainable water management. The risk and complexity surrounding water management practices are projected to mount, with pressures from urban densification, water scarcity and flooding, aging infrastructure, and management systems that do not reflect the true cost of water. As water stakeholders begin to embrace fundamental changes to management practices, this review provides a synthesis of opportunities to integrate One Water strategies into urban water management. Water utilities in particular are poised to make great strides in moving to the utility business model of the future through the integration of novel approaches to water ratemaking and emerging strategies for generating stable and robust revenue streams into the long-term future.

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