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Water policies and their effects on water usage: The case of Tucson, Arizona

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Abstract: As urban population grows and climate change unfolds, water utility companies and city governments are looking for innovative ways to achieve water security. Managing water demand is increasingly considered an efficient way to achieve water security, relying on policies at different levels to make this happen. However, the effects of water demand management policies on actual water consumption are not well documented. The purpose of this study is to analyze water demand management policies and their effects on overall water usage. We analyze the case of Tucson, Arizona, U.S., a city located in a water-scarce region, where population has been growing over the past decades, while their overall water consumption has decreased. We examine water-related policies at different levels (state, county, city, and utility), their caveats, and their effects on water usage. Our analysis shows that policy implementation needs to happen in parallel to management decisions at multiple levels. Lessons learned to reduce their water consumption in cities with water scarcity include the importance of institutional support; the need to collaborate with other organizations; the value of protecting and investing in ecosystem health; and that leveraging and combining existing efforts can result in synergies for water conservation and sustainability.

Key words: Water policy; water demand management; rainwater harvesting; graywater reuse; green infrastructure

1. INTRODUCTION

As urban population grows, and climate change alters precipitation patterns, local governments and water utility companies around the world are looking for innovative ways to achieve water security. Increasingly, scholars point to water demand management as a soft-path approach to achieve water security (Wilder et al. 2016) because decreasing overall water consumption reduces the need to augment water supply and, consequently, the need to fund and build large-scale water infrastructure systems.

Water policies are regulatory tools that support water management, which can be at the constitutional, organizational and operational levels (Rogers and Hall 2003; Zuniga-Teran et al. 2020). At the constitutional level, policies can take the form of legislation at different scales (country, state, county, city, neighborhood, building) along with the institutions established to enforce the legislation. At the organizational level, policies can help harmonize actions between different actors; and at the operational level, policies can be mechanisms that control the use of water to meet specific needs or to be used for specific purposes (Rogers and Hall 2003). At the organizational and operational levels, water policies can be tools, methods, or instruments used to manage water among recipients – societies, communities, organizations, and individuals (Jeffrey and Seaton 2004). At the operational – or utility – level, the most common water policies are economic instruments used to recover the cost of provision and reduce water use (or *conservation*) and reduce pollution (Bazzani 2005). But what do water demand management policies look like? And are these policies effective in reducing water consumption?

The purpose of this study is to analyze different water demand management policies and their effects on water usage. To do this, we analyze the case of Tucson, Arizona because it offers an instructive case study. It is a city located in a desert environment with a growing population, yet the city has managed to reduce not just per-capita, but *overall* water consumption over time. With more than 30 years of water demand management initiatives, people in Tucson use 31% less water in 2015 than they did in 1989[1].

This paper is organized as follows. First, we describe the geographical and institutional context of Tucson followed by the methodology used. We then examine the water demand management policies at different levels – in the state of Arizona, in Pima County, and in the City of Tucson. We also examine the suite of policies developed by Tucson Water – the main water utility of Tucson – to reduce water consumption. Finally, we discuss the policy implications and offer some lessons learned that can be adopted by other cities.

2. GEOGRAPHICAL AND INSTITUTIONAL CONTEXT

Tucson metropolitan area is located in a hot and semiarid region (300 mm average annual precipitation) in Southern Arizona, U.S., that extends through 400 sqmi and is home to about 1 million people (Rupprecht et al. 2020). Administratively, the metropolitan area is located in Pima County and encompasses several jurisdictions, which include the City of Tucson, the City of South Tucson, Oro Valley, Sahuarita, Marana, Tohono O'odham and Pascua Yaqui districts, and the rest is an unincorporated area in Pima County. Tucson Water, the main water utility company in the metropolitan area, provides potable and reclaimed water to about 736,500 people or 75% of Tucson's population (total population of 982,000) – 1/4 of which (about 184,000 people) live in unincorporated Pima County or in another jurisdiction (other than the City of Tucson). The other water utilities that serve the rest of the population (about 245,000 people) include Tucson Metro Water District, Oro Valley Water and Sewer, Marana Water Utility, and Vail Water Company (Megdal and Lacroix 2006).

Currently, there are six water sources in Tucson: (1) groundwater, (2) water from the Central Arizona Project (CAP)[2], (3) effluent (reclaimed water), (4) graywater (at the household level – not metered), (5) rainwater (also at the household level – not metered), and (6) remediated water (contaminated groundwater that has been treated) (Tucson Water, 2018) (Figure 1). Although this diversity in the water portfolio is designed to ensure water availability, sustained drought conditions still pose a threat to water security (Díaz-Caravantes et al. 2020; Varady et al. 2021).

CAP water is not assured since Arizona has junior rights to the Colorado River Water, which means that in case of extreme drought and shortage (Lake Mead and Lake Powell levels dropping beyond a certain limit), Arizona could potentially lose this water, or a portion of their allocation (Jacobs and Holway 2004). As a consequence of climate change, water supply from the Colorado River is expected to decrease between 6 - 20% by 2050 (Western Resource Advocates 2018). In addition, effluent volume production is linked to water use, which is expected to decline during a drought as a response to regulations; and potable water sources may not be available in the same amounts as a backup for reclaimed water production (Arnold et al. 2012). This vulnerable situation has driven water managers to seek water conservation strategies (Radonic 2018b). Water demand management continues to be one of the future strategies to achieve water security in Tucson.

3. METHODS

This study follows a case study approach to examine policies related to water demand management and water consumption. Case study is a methodology that provides an in-depth understanding of complex processes because it allows the examination of multifaceted interactions

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[1] In 2015, the City of Tucson's water use was only 303 liters per capita per day (LPCD) (or 80 gallons per capita per day, gpcd), which is below the state of Arizona's water usage of 553 LPCD (or 146 gpcd), and the U.S.' water usage rate of 314 LPCD (or 83 gpcd) (MAP 2017).

[2] Central Arizona Project (CAP) is a conveyance system and replenishment facilities that convey Colorado River water to Phoenix and Tucson – some 540 km away and 730 m above its point of origin - Lake Havasu (ADWR 2018).

in real-life environments (Radonic 2019; Ragin and Becker 1992). As mentioned earlier, Tucson is regularly affected by severe droughts, which require long-term management of its water supplies and of its demand. Therefore, we analyze water policies since the 1940s, at different levels (state, county, city, and utility), their effects on water usage, and their potential caveats. The study is qualitative in nature. It relied on personal communications from researchers working on the topic, as well as on an extensive survey and analysis of academic and policy literature. Potential limitations of the study, inherent to qualitative case study analysis in the sense that they are case specific, and findings cannot be generalized. However, in our analysis, we extract lessons learned that can be applied to other cities located in arid and semiarid environments.

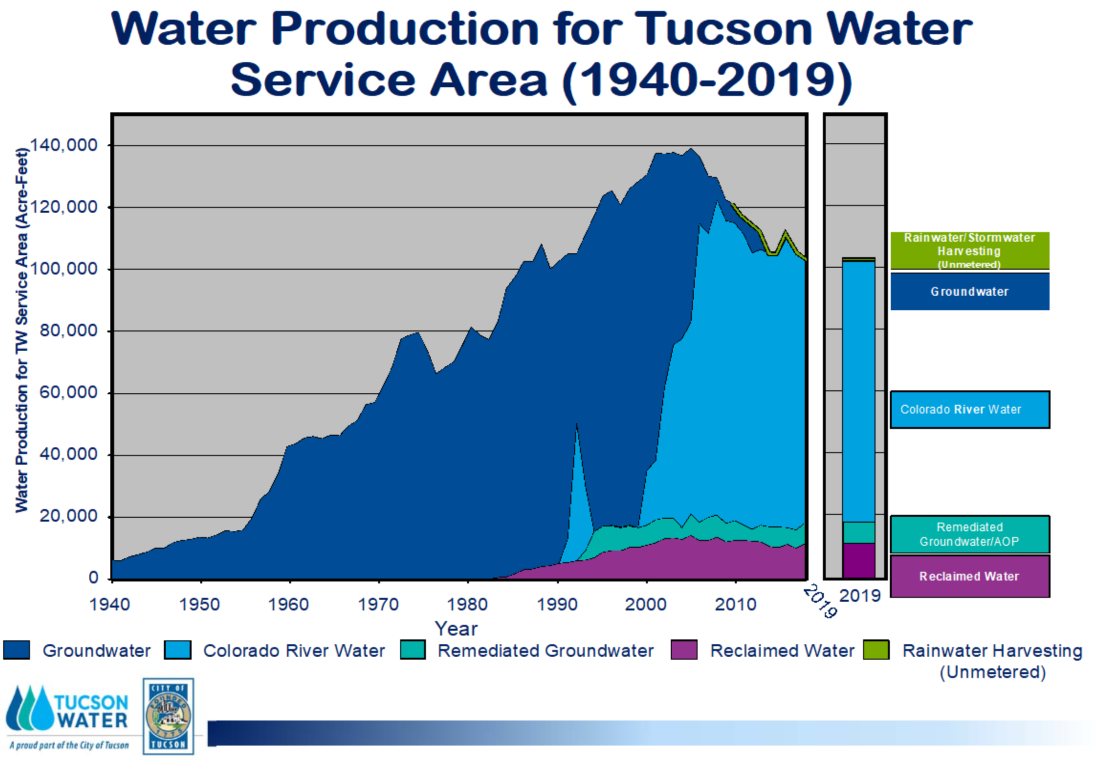

Figure 1. Water use in Tucson according to water source since the 1940s (Tucson Water 2020c).

4. WATER DEMAND MANAGEMENT POLICIES AT DIFFERENT LEVELS

Water demand can be explained by many variables including demographic characteristics (level of education, income, number of household members, age distribution in household, or cultural background). Housing characteristics also play a role in water demand (e.g., lot size, presence of a pool, pool size, greenness of vegetation). In addition, weather (temperature, precipitation and wind speed) is related to outdoor water use (Clarke et al. 2017). However, beyond demographics, housing characteristics and weather, policies also affect water demand. In this section, we examine water demand policies at the state, county, and city level. Potential caveats and assessment results are analyzed whenever possible.

4.1 Water policies at the state level

Water policies in Arizona are widely recognized as an innovative groundwater management approach (Megdal et al. 2018; Petersen-Perlman et al. 2018) (Table 1). This approach originated in 1948 with the enactment of the Critical Groundwater Code (Peacock, 1994). Building on this early policy, in 1980, Arizona became the leader in groundwater management legislation in the world, with the passing of the *Groundwater Management Act* (GMA)[3] (Kyl 1981). Also established in 1980, the Arizona Department of Water Resources (ADWR) is the institution in charge of executing the GMA (ADWR 2019). The ADWR administers water laws at the state level (except for water quality), seeks new water supplies, and creates water policies that promote water conservation (ADWR 2018). A few years later, in 1987, the Arizona Department of Environmental Quality (ADEQ) was created to regulate water quality issues across the state (ADEQ n.d.; Babbitt 2020). These two institutions – ADWR and ADEQ – have been instrumental in the enforcement of water-related policies at the state level.

Table 1. Water policies at the state level, their caveats and the observed effects on water conservation

Water policy	**Description**	**Caveats**	**Effects on water conservation**
Groundwater Management Act (ADWR 2018)	A law created in 1980 that aims to manage groundwater use sustainably. It identifies five Active Management Areas (AMAs) and three Irrigation Non-expansion Areas (INAs)	There is a considerable area in the state outside these AMAs that is not managed by the law. Also, environmental uses are not considered (Babbitt 2020)	These policies combined have significantly improved the condition of the aquifers of AMAs (ADWR 2018)
Groundwater Management Code (ADWR 2018)	Everyone within an AMA who withdraws groundwater from a non-exempt well (a well with a capacity of more than 35 gallons per minute), must report their annual water use and pay a groundwater withdrawal fee. Enforcement action by a civil penalty of $10K per day of violation	This is a “goal” not a mandatory requirement and there is a significant number of exempted wells withdrawing groundwater without control	
Underground Water Storage, Savings, and Replenishment Program (ADWR 2018)	Promotes the savings, storage, and replenishment of water in the aquifers to prevent groundwater overdraft. The program allows recharge in one area and the recovery of the same amount elsewhere. The program also allows users to accommodate seasonal water demand by storing water and using it later on	There is a hydrologic disconnect between the storage and the recovery, facilities which has not been solved	
Assured and Adequate Water Supply Program (ADWR 2018)	Requires developers within an AMA to demonstrate that there is assured water supply for the next 100 years from renewable sources – surface, CAP, effluent	This safe yield is not required outside the AMAs, so overall, Arizona may face aquifer depletion in some areas	
Arizona Department of Water Resources (ADWR)’s Conservation Program (ADWR 2019)	The program’s goal is to encourage the efficient use of water resources. It provides information about conservation regulations and resources through outreach, conservation assistance, and education. They collaborate with other organizations at the regional and national levels (ADWR 2019)	None found	
Reclaimed Water Program (Graf 2016)	Arizona is a leader in the use of reclaimed water for beneficial use with stringent treatment and quality standards regulated and managed by ADEQ	None found	83% of reclaimed water is recharged or used, decreasing potable water demand
Graywater reuse “soft permitting” (Bell 2018)	Regulations to address the potential health risks associated with the use of 4reywater for landscape irrigation and allowing small scale 4reywater reuse without a permit (Bell 2018)	None found.	Graywater reuse is seen as a significant way to reduce water demand

[3] The GMA’s overarching goal is to prevent groundwater depletion through long-term reduction plans (Chapter 2, Article 9), which include present and future withdrawals. In terms of current withdrawals, the GMA outlines five-year conservation plans with stringent conservation measures along with a pumping tax (§45-561); and in terms of future withdrawals, the GMA requires new subdivision development to demonstrate 100 years of assured water supply (§45-576) (Kyl 1981).

The passing of the GMA in 1980 was an impressive action that was possible by a combination of factors (Kyl 1981; Peacock 1994). The 1970s water crisis (severe groundwater depletion and land subsidence) was almost impossible to solve, but the legislature created a statutory process to get a state-wide debate that involved all recognized stakeholders at the time (Babbitt 2020). This democratic process was remarkably effective as it resulted in the passing of a law that has been effective for 40 years.

Although the GMA (or *the Act*) and *the Code* are terms that are often used interchangeably, the Act refers to the legislative package passed in 1980, while the Code refers to the laws compiled in Arizona Revised Statute (ARS), principally Chapter 45. Basically, the Code includes the provisions of the GMA and subsequent legislation relating to groundwater (Megdal 2020). For example, the 1980 GMA designated four Active Management Areas (AMAs) (one AMA was added later on) (Eden 2020). The Code mandates that all users within an AMA, who withdraw groundwater from a nonexempt well (a well with a capacity of more than 35 gallons per minute), must report their annual water use and pay a groundwater withdrawal fee (ADWR 2018).

The Code's main goal is to achieve *safe-yield*, which is defined as "to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in the active management area and the annual amount of natural and artificial recharge" (ADWR 2018: 20). The Code requires the Director to adopt mandatory requirements for water users, including conservation (or demand management) requirements for users withdrawing, distributing and receiving groundwater in the AMAs (ADWR 2018). Today, there are five AMAs in the state that monitor groundwater use, in terms of safe yield in the most populous areas – one of which is Tucson AMA (Figure 2). As mentioned above, the AMAs are ruled by the Code, which aims to avoid groundwater depletion and allow the allocation of groundwater resources to meet the state's needs effectively.

An important caveat of the Code is that safe yield is required within the AMAs, so there may be excessive extraction in one area and the required recharge being done somewhere else. Eventually, this situation can lead to unsustainable results again. Shortcomings of the Code include a policy void in terms of water transfers, where the rural community protests the ongoing water transfers, from agricultural to municipal (Babbitt 2020). The GMA mandates that CAP water provides assured water supply to all member communities in central Arizona (e.g., municipalities, industry, farmers, Tribes), but the fact is that farmers have seen their water rights decrease as cities grow. Gradually, groundwater uses in the state have shifted from agricultural to municipal. So, there is a conflict between legitimate points of view and there is no policy in place to solve this conflict. Another shortcoming of the Code is the lack of water allocated for environmental uses. Historically, water policy in Arizona has been an insider player, with no participation by communities or environmental groups that could advocate for a cut to the river. Babbitt – the governor of Arizona who passed the GMA in 1980 – acknowledges that this situation needs to change (Babbitt 2020).

At the regional level, Arizona has contributed with an innovative water management strategy known as the *Underground Water Storage, Savings, and Replenishment Program* (or water banking) (Díaz-Caravantes et al. 2020; Megdal et al. 2014). To manage CAP water, the state of Arizona developed an institutional and regulatory framework, which allows the storage of water for the neighboring state, Nevada. When Nevada wants to withdraw their share of banked water, they will increase their allotment of Colorado River water and Arizona will have rights to the stored water in their aquifers (Megdal et al., 2014). An unsolved issue for water banking is the hydrologic disconnect between replenishment and the future needed extractions (Avery et al. 2007). Recharge can only take place where the facilities and needed infrastructure were built, but the extractions may be needed elsewhere.

Arizona is one of the leaders in the U.S. in adopting policies that support the use of different water sources for non-potable uses, expanding the water portfolio in the state. For example, Arizona supports the use of reclaimed water – or treated wastewater – to save potable water and distribution costs because of the proximity of treatment plants to potential end users (Chapman 2005). It has been proved that properly treated reclaimed water does not present toxic industrial chemicals, organic materials or endocrine substances (EPA 2012). Arizona also supports the direct use of graywater at the household level, which is not metered. This practice was legalized in 2001 when the ADEQ allowed small-scale graywater reuse without a permit. Graywater reuse is now seen as a significant way to reduce water demand and energy costs in Arizona.

Figure 2. Location of the five Active Management Areas (AMAs) and the three Irrigation Non-expansion Areas (INAs) (ADWR 2018).

4.2 Water policies at the county level

Pima County has promoted and supported water conservation policies through the ongoing collaboration between different organizations and across several jurisdictions (Table 2). These policies address water wasting and the protection of riparian ecosystems that support the hydrological cycle.

The *Drought Response Plan* and *Water Wasting* - Ordinance 10380, Chapter 8.7 (Pima County 2007) are a guidance and regulation respectively to reduce water wasting according to the drought stage that is being experienced (Pima County 2020a). According to the Drought Response Plan there are four drought stages that go from "abnormally dry" to "extreme". Under each stage, the ordinance mandates water use strategies from voluntary (stage 1) to mandated (stage 2-4) (Pima County 2020a). There are policies in place for enforcement of this regulation. Violators get an infraction and are subject for discontinuation of water service. Infractions vary according to the drought stage (Pima County 2020a).

Table 2. Water policies at the county level, their caveats and the observed effects on water conservation

Water policy	Description	Caveats	Effects on water conservation
Drought Response Plan (Pima County 2007)	A four-stage plan drought monitoring system	After years of declared Drought Stage 1 (since in 2006), this condition is the new normal	Decline in gallons per capita per day (gpcd) among Tucson Water's customers (Arnold et al. 2012)
Water Wasting Ordinance (Pima County 2007)	Regulation that is linked to different stages outlined in the Drought Response Plan to avoid water wasting	Very difficult to enforce at the household level	Unknown
GI Action Plan for Pima County (Pima County 2018)	Set of policies designed to support the wide implementation of green infrastructure (GI)	Voluntary policies	Unknown
Sonoran Desert Conservation Plan (Pima County n.d.)	Land use plan that protects riparian habitat from development	None found	Unknown
Zoning Code (Pima County 2020b)	Changes to the code that eliminate barriers to sustainable practices, including rainwater harvesting	None found	Unknown

Pima County has supported legislation and programs that protect and promote ecosystem health at the regional and city levels. Pima County is a leader in environmental land use planning, which protects riparian ecosystems and hence water resources. The *Sonoran Desert Conservation Plan* is used to guide urban growth in Tucson (Pima County n.d.). Although the main motivation of this land use plan is to comply with federal regulations to protect endangered and threatened species (Fish and Wildlife Services n.d.), by protecting riparian habitat from development, it also supports hydrological processes that support aquifer health.

At the city level, support for ecosystem health takes form in green infrastructure (GI). GI is defined as "an array of technologies and practices that use or mimic natural systems to manage rain sand stormwater in situ" (Radonic 2018b: 172). It is thought to reduce potable water for landscape irrigation and infiltrate stormwater into the aquifer, thereby augmenting water supply. However, developing policies for its wide implementation has not been easy. Historically, Pima County has relied on bonds to finance large infrastructure projects and a variety of programs that enhance the quality of life of county residents and provide a large number of construction-related jobs. But the County's credit ratings and low-interest rates are in jeopardy as a consequence of climate disruptions – if the county does not have adaptation plans in place, they do not get the bonds (Pima County 2018). The development of the *GI Action Plan for Pima County* – a plan that promotes GI and fulfils climate change adaptation mandates outlined by the Arizona Board of Supervisors' Climate Resolutions 2017-39 and 2017-51 (Pima County 2018) – was the result of intense collaboration between different governmental and non-governmental organizations. In addition to the economic incentive, implementation of GI meets several goals outlined in the long-range Comprehensive Land Use Plan for the county including water resources. This land use plan, also known as Pima Prospers, has an overarching goal of fostering healthy communities with a focus on the economy (Pima County et al. 2015).

Rainwater harvesting in Pima County and other dry regions is related to GI. In the U.S., rainwater harvesting is associated to water conservation in water-scarce regions, while wet regions promote GI to comply with water quality mandates. GI has proliferated across the U.S. during a time when infrastructure is ageing and funding to upgrade it is declining and is becoming part of water governance system as it transitions from an informal practice to a formal one promoted by water utilities and local governments (Radonic 2018b). For these reasons, Pima County, Tucson Water and other local organizations are collaborating to promote the wide implementation of GI in Tucson.

Pima County recognized the need to promote sustainable practices in Tucson and other municipalities in the county. On Sept 10, 2013, Pima County Board of Supervisors approved changes to the *Zoning Code* to eliminate barriers and allow voluntary green building practices that conserve water including rainwater harvesting systems, cisterns, clothes lines 6 ft or less in height, and vegetated green roofs (Pima County 2020b); all of which were not allowed before the approved changes.

4.3 Water policies at the city level

In this section, we examine the water demand policies, most related to GI, that have been developed by different organizations in Tucson (Table 3). One of the earliest policies aimed to reduce water demand for irrigation is the *Xeriscape Landscaping and Screening Ordinance 7522*, which was effective in 1991 (City of Tucson Water Department 2013). This regulation mandates that all new (after 1991) multifamily, commercial, and industrial development in Tucson use desert plants in their landscape design. This land use code is part of Tucson City Code and allows only 2.5% of turf in commercial facilities, and 5% in multifamily facilities. This regulation also requires the introduction of trees in yards and street frontages, in parking lots (one for every 15 spaces), and requires dust control through ground cover (e.g., gravel) (City of Tucson n.d.). Because irrigation is the largest use of municipal water, this ordinance has played a major role in the overall reduction of water consumption in Tucson. According to Rupprecht et al. (2020), a reduction of the peaking factor from 1.6 to 1.4 is a consequence of a decrease in outdoor use during the summer season, which is equivalent to water savings of 81.6 mgd (Rupprecht et al. 2020).

On June 1, 2010, the City of Tucson passed the *Commercial Rainwater Harvesting Ordinance 10597*, which mandates commercial development to meet 50% of irrigation demand with rainwater (City of Tucson 2013; City of Tucson Planning and Development Services Department 2008). Because of the mandate, this ordinance has likely resulted in 50% of water savings in commercial development.

The *Rainwater Harvesting Rebate Program* was launched by Pima County Cooperative Extension / Smartscape Program in collaboration with Tucson Water. The rebate program aims to reduce water consumption by using rainwater and stormwater for landscape irrigation (Radonic 2018a). However, an internal evaluation of the program shows that water consumption did not decrease, instead it increased in households that participated in the program[4]. Program participants perceived the program as successful, not so much in terms of a reduction of potable water consumption, but more as an enabler of a desert oasis that enhances their quality of life (Radonic 2018a). An econometric analysis conducted by Montgomery & Associates on the same rebate program found that, over time, the program is significantly associated to a reduction in water demand in Tucson of an average of 748 gallons per month, averaged across the year (Weiser 2018). From talking to the customers, the author found that the program has caused a change in behavior – people are more aware of their irrigation patterns and their use of potable water, and they are now more involved in this practice (Weiser 2018). An important caveat of the rebate program is that it has shown equity issues at the city scale. The funds for this program come from a conservation fee

[4] Participants of the program, in average, use more water monthly than the single-family average – low water users who participated in the program used up to 7.99 centum/hundred cubic feet (ccf) (equivalent to 748 gallons), while medium water users consumed up to 14.99 ccf, and high water users consumed up to 30 ccfs (Radonic 2018a).

charged to every Tucson Water customer on their water bill (described below). However, mostly wealthy customers have applied for this program (Elder and Gerlak 2019). Reasons for this lack of participation from low-income families are complex, but these include land tenure (low-income families are more likely to rent their homes), language barriers, immigration status, and more pressing issues to attend to (Gerlak and Zuniga-Teran 2020).

Table 3. Water policies at the city level, their caveats and the observed effects on water conservation

Water policy	Description	Caveats	Effects on water conservation
Xeriscape Landscaping and Screening Ordinance 7522 (City of Tucson n.d.)	Regulation that mandates the use of drought-tolerant plants in landscape design	Only applicable to multifamily, commercial, and industrial development	Water used for landscape irrigation has been reduced
Commercial Rainwater Harvesting Ordinance 10597 (City of Tucson Planning and Development Services Department 2008)	Regulation for commercial development to use passive rainwater systems to irrigate landscapes	None found	50% of water savings for outdoor uses in commercial development
Rainwater Harvesting Rebate Program (City of Tucson 2020)	Applicants get reimbursed for installing rainwater harvesting systems in their homes	This program has shown equity issues	Average saving of 748 gallons per month (Weiser 2018)
Residential Graywater Ordinance 10597 (City of Tucson 2018)	New homes are built with a plumbing dual system that allows users to use graywater for landscape irrigation, with potential water savings of 40%	The ordinance does not require the installation of the system, only the possibility of installing the system	Only about 10.5% of the new homeowners use the system, some 72,000 lt (or 19,000 gallons) per household per year (Bell 2018)
Stormwater Management Program (TDOT n.d.)	Promotes the use of GI along the rights-of-way and boulevards in the transportation network	Difficult to get curb cut permits for GI	Unknown
Stormwater quality Ordinance 10209 (Mayor & Council and City of Tucson 2005)	Ensures that non-point source pollutants do not enter the drainage system	None found	Unknown
Conserve to Enhance (C2E n.d.)	Funding opportunity for GI at the neighborhood scale	May result in equity issues	Unknown
Low-Income Rainwater Harvesting Program (SERI n.d.)	Provides financial support (grants and loans) to low-income families to implement residential rainwater harvesting	Only funds active systems that require space and maintenance	Unknown
Land Use Code (City of Tucson 1995)	Land use regulation body that requires stormwater harvesting to be used for irrigation	None	
National Standard Plumbing Code (IAPMO 2020)	Instructions for the construction of efficient plumbing systems	None found	Unknown
Green buildings (USGBC 2020)	Demonstrate water savings from calculated baselines and monitor water use using subsystem metering	Green building certification is expensive, so it is not pursued by most developments	From 30 to 100% of water savings for outdoor uses, and from 20 to 50% of water savings for indoor uses

The *Residential Graywater Ordinance* (11089 §P2601.2.1) aims to reduce extraction and increase recharge (City of Tucson 2018). Graywater provides an additional water source at the household level, which can be used for non-potable uses, such as irrigation (Bell 2018). In Tucson, landscape irrigation represents 40% of the residential water use, which is less than the state's (60%), because in Tucson, most landscapes use desert plants since the 1990s (see Xeriscape Ordinance above). Therefore, using graywater for landscape irrigation at the household level can save up to 40% of water.

Retrofitting existing homes for graywater use for toilet flushing entails a large cost, but new homes can easily be designed with dual plumbing systems that include laundry-to-landscape and using gravity at a low cost. This practice can save up to 19,000 gallons (72,000 lt or 19,000 gallons) of water per household (2.5 people) per year (Bell 2018). With a simple plumbing modification, graywater from the allowed fixtures (clothes washer, bathtub, shower, and sink) can be directed to the landscape instead of the sewage system (Little 2016). Even though new constructed homes (after 2010) in Tucson have the plumbing for graywater reuse in place, most residents do not use it. An assessment of this ordinance indicates that only 10.5% of the sample population actually used their graywater. Barriers range from policy, community, organizations, interpersonal, and individual (Bell 2018). Most of the sample population (89.47%) reported not using their graywater system because they were unaware of this possibility (Bell 2018). The main caveat found is that the ordinance does not require the installation of the system, only *the possibility* of installing the system.

The *Stormwater Management Program* was launched by the City of Tucson, Department of Transportation (TDOT) (Hester et al. 2012; TDOT n.d.), to promote the use of rights-of-ways and boulevards as vegetated spaces designed to capture runoff and infiltrate stormwater. Although the focus of the program is to keep non-point source pollutants out of the drainage system, this practice helps to augment aquifer levels, hence water supply for Tucson. In addition, as this practice is complemented by trees and other plants that require no irrigation, this lack of irrigation of urban forestry reduces water demand. Results of this program in terms of the precise amount of recharged water are uncertain.

A related policy is the *Stormwater Quality Ordinance 10209* (Tucson Code Chapter 26, Article II) (Mayor & Council and City of Tucson 2005), which mandates that business, facilities and construction sites do not contribute with non-point source pollutants (oil, grease, trash, and sediment) to the drainage system (TDOT n.d.). However, this practice of GI has been found to be difficult to implement because of stringent regulations on width of right-of-way that result in the denial of curb cut permits (Gerlak and Zuniga-Teran 2020). Indeed, transportation engineers have been known to be the last adopters of GI practices, mainly as a consequence of maintenance requirements (Gerlak and Zuniga-Teran 2020).

Conserve to Enhance (C2E) is a grant program to fund GI in Tucson that is possible through a collaboration between Tucson Water, local non-profit organizations, and the University of Arizona's Water Resource Research Center. This program provides grants (of about $10,000) for the implementation of GI in neighborhoods located in close proximity to a natural drainage system (C2E n.d.). The partner organizations raise funds every year to promote GI in neighborhoods whose residents are well-organized and committed to GI maintenance (Zuniga-Teran and Staddon 2019). A caveat of this program is that it is not equitable, since low-income communities in Tucson are less likely to be organized and they seldom apply for funds (Gerlak and Zuniga-Teran 2020).

The City of Tucson is working hard to address equity issues in collaboration with local NGOs. They launched the *Low-Income Rainwater Harvesting Program* to provide grants and loans to low-income families to be able to apply to the rebate program. This program is administered by the local NGO, Sonora Environmental Research Institute (SERI) (SERI n.d.). However, a caveat is that it is focused on active systems (cisterns, tanks) that require space and maintenance, and low-income households usually have less space in their yards and less time available for maintenance, reinforcing injustices (Gerlak and Zuniga-Teran 2020).

The City of Tucson follows the *National Standard Plumbing Code* (IAPMO 2020), which ensures the correct installation of plumbing systems to promote sustainable practices. In Tucson, this code is known as Plumbing Code (Ordinance 7178), and mandates efficient plumbing fixtures (1.6 gallon flush toilets, and 2.5 gallon per minute showerheads), which are related to lower water consumption (City of Tucson 2013).

In Tucson, 60-70% of the municipal water use is related to residential buildings (Bell 2018), so buildings are big actors in water-saving initiatives. In 2006, the City adopted the Leadership in Energy and Environmental Design (LEED) silver standards for all new city-owned buildings and renovations over 5,000 square feet. Since 2008, the city and other organizations and developers in Tucson have built 289 LEED certified buildings in this city[5]. To be LEED certified, buildings have to include water conservation strategies including both outdoor and indoor water use reduction, and building-level water metering.

4.3 Water utility's suite of water demand management policies

Tucson Water has over 110 years of experience, produces 90K acre-feet (AF) of water annually and serves around 710,000 residents within its service area (Clarke et al. 2017). Overall, Tucson Water's production declined 23.3% from 2005 to 2015 as a result of water conservation programs, community outreach campaigns, tiered rate structures, national plumbing code changes, technology improvements and other policies (Rupprecht 2020). Amidst success in water savings, Tucson Water believes that all of the conservation outcomes can still be enhanced. Water demand management is still listed as one of the recommendations for the 2012 Updated Water Plan 2000-2050, which include the expansion of conservation programs, leak reduction (lost and unaccounted water), rainwater harvesting, and public information programs (City of Tucson 2013).

The diversification of the water portfolio in Tucson has played a key role in decreasing groundwater use and avoid aquifer depletion and land subsidence. In Tucson, projections for the use of reclaimed water have increased substantially, from 12,500 acre-feet per year in 2010 to about 15,000 acre-feet per year by 2030 (City of Tucson 2013). In addition, remediated water can also save potable water. It refers to contaminated groundwater that has been treated up to drinking standards[6]. After treatment, remediated water is discharged into the distribution system, where it is blended with other waters and served to the customers (Tucson Water 2018). Tucson Water aims to fully utilize their effluent with additional treatment and recharge (City of Tucson Water Department 2013).

One of the ways that Tucson reduces demand is through avoiding waste. In 1984, the City of Tucson passed the *Water Waste and Theft* (Ordinance 6096) (City of Tucson Water Department 2013) (Table 4). This policy defines waste and penalties for wasting water. Tucson Water employees investigate reported cases of water waste and patrol the streets of Tucson looking for water waste cases. Customers have five days to solve the problem and pay the fine (up to $1,000) (Tucson City Code 1984).

The *Emergency Water Conservation Ordinance* (8461) prohibits certain water uses under emergency situations (e.g., car washing, refilling swimming pools) (City of Tucson Water Department 2013). In the case of an emergency when the utility cannot deliver service (e.g., the loss of a well field, a treatment plant, or a transmission line), water use is regulated for non-essential uses.

Most of the funding used for the different programs comes from water bills for Tucson Water customers, which include a *Conservation Fee*. The fee is 10 cents per ccf and is charged to all potable water sales. Money collected through this economic instrument is placed on the Water Conservation Fund, established by Mayor and Council in 2008 (Ordinance 10555). Programs funded by the conservation fee in FY 2018-2019 have resulted in 52.1 million gallons of water saved; and to date, after 11 years of implementation, it is estimated that conservation programs have saved 2.6 billion gallons (8,014 acre feet) of water (Rupprecht 2020).

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[5] For a list of LEED certified buildings in Tucson see https://www.usgbc.org/projects?Search+Library=%22tucson%22&State=%5B%22Arizona%22%5D

[6] Contaminated groundwater exists near the Tucson International Airport. The Tucson Airport Remediation Project/Advanced Oxidation Process (TARP/AOP) Treatment Facility started operations in 1994 to remove contaminants from groundwater in this area (Tucson Water 2018).

Table 4. Tucson Water's water demand policies, their caveats and effects.

Water policy	Description	Caveats	Effects on water conservation
Water Waste and Theft Ordinance (6096) (Tucson City Code 1984)	Customers who waste water are penalized with fees	Difficult to identify all water waste cases	Unknown
Emergency Water Conservation Ordinance (8461) (City of Tucson Water Department n.d.)	Prohibits non-essential water uses during emergency situations	None	Unknown
Conservation fee (Rupprecht 2020)	All Tucson Water customers are charged a fee for conservation programs in their water bills	Everyone pays the fees but not everyone benefits from the programs, resulting in inequities	52.1 million gallons of water saved in FY2018-2019
Increasing Block Rate Structure (City of Tucson Water Department 2013)	Customers who consume more water pay a higher unit price	Wealthy people may not react to this incentive (Radonic 2018a). There is a time lag between consumption and billing that makes consumers ill-informed about their consumption level (Clarke et al. 2017)	Varied by household
Water Conservation Rebates (City of Tucson Water Department 2020b)	Rebates for multiple water conservation features	Low-income families may not be able to apply to most programs	2,611 million gallons of water saved from 2008-2019
Green Stormwater Infrastructure Fund (Sayers 2020)	$1 fee is charged to every Tucson Water customer to fund the 1 Million Tree campaign	Potential equity issues if greening does not happen in low-income neighborhoods	Unknown
Tucson Audit Program (City of Tucson Water Department 2020a)	On-site examinations for industrial and commercial customers on water features and water use data from billing records	Residential customers are not included in the program	115 million gallons of water saved in 2015, or 26% of water savings per audit
Zanjero Program (Tucson Water 2020b)	Free individualized survey (audit) for residential customers to help them lower water bill	None found	Varies by household
WaterSense Program (EPA n.d.)	Environmental Protection Agency (EPA)'s label or certification used in water-saving fixtures and water-efficient homes	None found	Varies from individual fixtures to entire home
Water Conservation Kits (Tucson Water 2020a)	Free water conservation materials or water fixtures	None found	Varies by household

As part of the metering system to promote water conservation, Tucson Water implemented the *Increasing Block Rate Structure* in 2019 (City of Tucson Water Department 2013). This pricing mechanism raises the price of water with consumption at different blocks, or intervals; so, consumers pay a different price depending on their water consumption (Clarke et al. 2017). A base-rate summer surcharge is also applied to larger users, such as commercial and industrial users during the peak months: If users exceed the base rate during the summer, they pay more (City of Tucson 2013). The increased block rate structure is probably one of the easiest ways to promote water savings – the more you use, the more you pay. But a study by Clark et al. (2017) found that there is a distinction in the way consumers perceive water pricing – discretionary consumption, and consumption that consumers are not willing to reduce no matter the pricing. However, many consumers do not know this information – consumers learn their level of consumption after they are billed. This time lag makes consumers ill-informed to make decisions on water consumption based on pricing. For this reason, timely communication and education initiatives are very important in water conservation efforts. Communication must include real-time data on water consumption and an estimate of the water bill to make water pricing policies more relevant.

Tucson Water offers *Water Conservation Rebates* for multiple water conservation features including high-efficiency toilets (HET) (for single-family, low-income, multi-family and commercial users), clothes washers, irrigation upgrade, commercial upgrade, and rainwater harvesting and graywater systems (from $75 to $2,000) (City of Tucson Water Department 2020b; Rupprecht 2020). Cumulative water savings from these incentives are shown in Figure 3 with an approximate total amount of 2,611 million gallons from 2008 to 2019 (Rupprecht 2020).

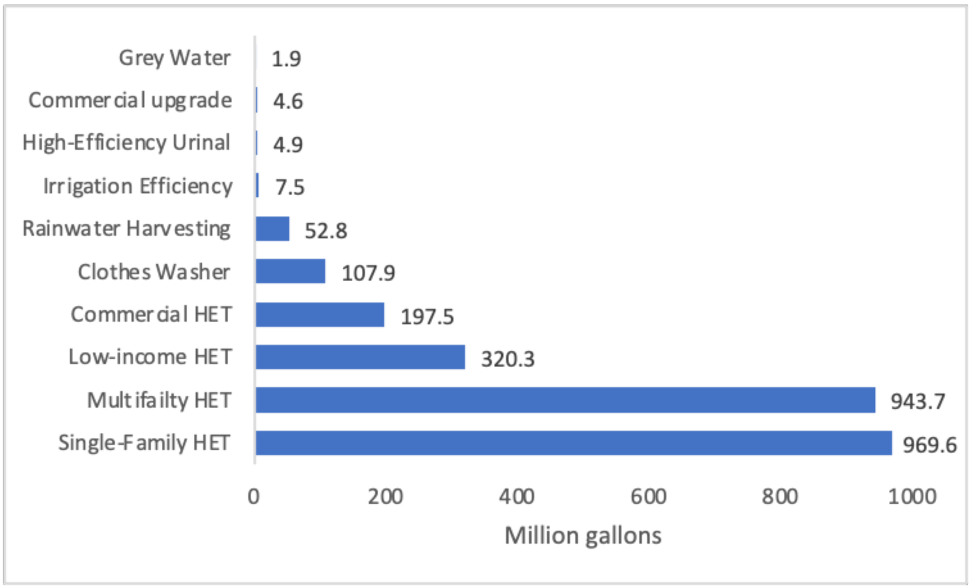

Figure 3. Cumulative water savings by program (from 2008–2019) (adapted from Rupprecht, 2020).

In May 2020, Tucson Water launched the *Green Stormwater Infrastructure Fund*, charging $1 per month to every customer. This program will generate about $3 million dollars annually and will be used to support the city's 1 Million Tree campaign and maintain new and existing GI projects (Sayers 2020). However, there are equity concerns on the use of these funds, because similar funds have typically supported wealthy neighborhood (Gerlak et al. 2021a,b). Neighborhoods without GI are not likely to benefit from the maintenance funds, yet they will be contributing through their water bill.

Water audit programs are free and individual consultations are provided by Tucson Water to their customers, which have resulted in positive results. In 2015, Tucson Water launched the *Tucson Audit Program* (TAP), targeted to commercial and industrial customers. In one year (2016), the program was used by 71 customers in Tucson and achieved 115 Mgal in total annual water savings. On average, a TAP audit equates to 1.6 M gallons in annual water savings, and an equivalent to 26% in annual water savings (Tucson Water 2016). Tucson Water also provides free water audits to residential customers under the *Zanjero Program*. Customers request an audit and schedule a visit from a Tucson Water employee, who will check for excessive water use, will measure flow rates, and look for inefficiencies (Tucson Water 2020b).

The U.S. Environmental Protection Agency (EPA)'s *WaterSense* program was adopted by Tucson Water (Rupprecht 2020). The U.S. federal government passed a law in 1992 that forced toilets purchased in the country to be ultra-low-flow (ULF) models that use 1.6 gallons per flush or less (Water CASA 2010). The WaterSense program provides a pathway to meet this law by a third-party certification of bathroom fixtures, which accounts for about 50% of indoor water use. A WaterSense shower head, for example, can save 4 gallons of water per shower, WaterSense faucets and aerators can save 700 gallons of water per year, or 30% more efficient than standard faucets (EPA n.d.). Tucson Water offers *Water Conservation Kits*, which are free water fixtures, some of which are certified by WaterSense. These include low-flow showerheads, 5-minute shower timer, toilet tank bag, toilet leak detection dye tablets, and bathroom faucet aerator (Tucson Water 2020a).

5. DISCUSSION AND CONCLUSIONS

Overall water savings vary as a result of the interdependencies between policies, which are very difficult to tease out. Recognizing important gaps, caveats and learning opportunities, Tucson is an example of effective water demand management. Our findings suggest that water demand in Tucson has been successful because it has been a team effort, they have invested in ecosystem health, and they have leveraged existing efforts that have resulted in synergies for water conservation.

5.1 A team effort

This analysis suggests that collaboration between different levels of government (state, county, city), organizations, agencies, and of course, utility companies, has resulted in progress toward water conservation. At the local level, Tucson Water collaborates with Pima County and other local organizations to design, implement, educate and communicate their policies. In turn, some of these policies have emerged from collaborations and have been supported by strong institutions that carry out and enforce legislation (e.g., ADWR, ADEQ, Water Banking Authority). Likewise, water management in Tucson has been supported by changes in land use planning, zoning, transportation, and other urban development practices. It is necessary to bring all of these built environment actors to the table to strengthen efforts toward water conservation and sustainability.

5.2 A healthy ecosystem

Probably the best strategy to reduce water demand in Tucson has been to support a healthy ecosystem. Tucson Water, the city, county, and local organizations have recognized their dependence on ecosystem health and have invested heavily in GI programs. Although GI initiatives may not have yielded direct water savings to individual customers (Radonic 2018a), enhancing the quality of life and developing a conservation ethic eventually pays off. For example, rainwater harvesting programs combined with xeriscape regulations and the use of reclaimed water for landscape irrigation have significantly reduced outdoor water use – the larger municipal use in Tucson (Rupprecht 2020). Likewise, GI initiatives, considered climate change adaptation strategies, have allowed Pima County to be eligible to receive bonds to fund large infrastructure projects (Pima County 2018).

Similarly, through the protection of ecosystems, organizations and local governments have been able to comply with federal regulations. For example, the Sonoran Desert Conservation Plan is intended to comply with the Endangered Species Act, but at the same time, allows hydrological processes to occur. Also, water quality standards mandated by the Clean Water Act and implemented locally by ADEQ have led to the use of GI along transportation routes to reduce non-point source pollutants in water systems. It is in the interest of many stakeholders (if not all) that ecosystem function is supported in cities.

5.3 Leveraged efforts can turn into synergies

Tucson Water and other organizations interested in sustainability and water conservation have joined efforts that have resulted in synergies for water demand management. For example, Tucson Water's rebate programs use the EPA's WaterSense certification for water fixtures. This way, Tucson Water does not have to certify fixtures themselves. Likewise, using the green building certification (LEED) saves resources to the local government and ensures buildings save water. Learning from others and harnessing existing tools can save time, effort, and funding.

In conclusion, water demand in the desert cannot be looked in isolation. Demand policies are intrinsically linked to aquifer recharge and to the diversification of the water portfolio, including reclaimed water, graywater, and rainwater for non-potable uses. This aligns with the *net zero urban water* concept that advocates for the consolidation of all water resources and related management approaches (Crosson et al. 2020). In addition, it is critical to avoid waste and to have plans and policies in place on how to act during different drought stages and emergency situations. Communication of water consumption data in real time is needed to foster water conservation at the household level, and this is something that sensors can provide in a smart and connected community.

Our analysis shows that it is the sum of water-related policies and those related to land use, urban development, and even buildings, which have been reviewed, revised, and re-invented over decades, accompanied by strong state level legislation and institutions, that have yielded positive results in reducing water demand. Successful water demand management depends on the collaboration between different actors and institutions at multiple levels, and on the protection of ecosystems that sustain the hydrological cycle. It is important to leverage parallel sustainability efforts, maintain the transparency of data, foster inclusive processes, and provide the necessary funding to accomplish all of these activities. Finally, continuous monitoring and constant evaluation of water conservation programs are needed to measure progress toward desired outcomes and ultimately achieve sustainability results.

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