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Viewpoint ─ Urban Water Conservation and Sustainability in the Colorado River Basin

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ABSTRACT: Many cities around the world are facing the challenges of freshwater decline and groundwater degradation, compounded by population growth. In the southwestern United States, these challenges are amplified. In that region, many growing cities depend on water from the Colorado River Basin, which is faced with aridification and record-low surface water supplies. Despite these unprecedented trends in Colorado River flows, however, many basin cities are enhancing their water security through a combination of supply diversification and water conservation. We draw from key academic and practitioner studies to better understand which conservation strategies are employed, how water providers evaluate the effectiveness of these strategies, and what role urban water conservation has played in the Colorado River Basin. Our examination of the contributions and limitations of urban water conservation under Colorado River Basin drought conditions reveals how the political dimensions of urban water conservation influence the ability to fully realise the potential of conservation in broader basin governance and sustainability. We call for improved assessment and monitoring of conservation efforts, advancement of holistic approaches, and the addressing of key political and equity dimensions as ways to improve urban water conservation efforts and, more realistically, situate them in the context of basin wide sustainability.

KEYWORDS: Urban water conservation, Colorado River Basin, water governance, water demand management, transboundary water governance

INTRODUCTION

For the past two decades, the Colorado River Basin in the western United States (US) and northern Mexico has faced pervasive drought and increased aridification due to climate change (Hoerling et al., 2019; Overpeck and Udall, 2020). Lake Powell and Lake Mead – the two major water storage reservoirs on the river – recently reached their lowest levels since being filled (US DOI, 2022), threatening water supply, hydropower production, and environmental health throughout the basin. Despite significant rainfall in the spring of 2023, prolonged drought conditions have exacerbated the overallocation and overuse of the river's water. This has led to conflict between the diverse users of the basin's water including farmers, municipal water suppliers, industries, and tribes (Wheeler et al., 2022; Davis, 2023).

Since the 1990s, there has been an increase in attention to demand management strategies such as water conservation in the US. Despite population growth, this has led to declines in per capita water use in many of the Colorado River Basin's cities (Richter et al., 2020). In a recent study that reviewed demographic and water use trends, Colby and Hansen (2022) concluded that, over the last 20 to 30 years, many basin cities have experienced both notable population growth and a decrease in per capita water use; indeed, in some cases such as Salt Lake City and Phoenix, total water use has declined. To achieve these reductions, municipal water utilities and water providers have adopted a diversity of programmes such as awareness campaigns, rebate programmes for high-efficiency indoor fixtures, and mandatory water use restrictions for landscaping. Most recently, the Metropolitan Water District of Southern California, the nation's largest water supplier, declared a drought emergency for all of Southern California, clearing the way for mandatory water restrictions (*AP News*, 2022), and the state of Nevada banned all ornamental, or 'non-functional', grass in the southern part of the state (Government of Nevada, 2021). Other states in the basin have followed a similar trend in limiting decorative turf (Government of California, 2023; Government of Colorado, 2024).

Throughout history, cities have been engines of growth and economic development (Kaplan et al., 2009); more recently, however, they have become significant global actors in climate change governance (Lin, 2018). In the Colorado River Basin, cities are often first in line for cuts during water shortages, since in the western US the water rights system first allocates water to senior rightsholders, who are often agricultural users (Getches, 1997). Cities in the western US, thus, have been forced to explore adaptive strategies to help them build resilience to drought and on-going aridification. Globally, among rapidly growing cities, demand management is a key strategy for avoiding critical imbalances in water supply and demand (Ahmadi et al., 2020). Many cities have turned to water conservation as a way to maintain economic and population growth in the face of climate change (Loomis, 2022). Multiple different water conservation strategies are being pursued in cities around the world (Saurí, 2013; Zapana-Churata et al., 2022; Ray Biswas et al., 2023). Cities often have greater financial resources than other water use sectors; they are thus able to advance the development of innovative technologies and can pursue experimentation to shape climate change adaptation strategies that are necessary for their long-term sustainability (Hondula et al., 2019; Bulkeley and Castán Broto, 2013). Examining trends in urban water conservation in cities of the Colorado River Basin can increase awareness of this shared concern and, on a global level, can inform strategies that are being implemented in different urban areas.

Although some suggest that the conditions on the Colorado River constitute a crisis for the basin's cities (Pearl, 2017; Hondula et al., 2019; Swanson, 2023), municipal water use accounts for just 15% of the basin's overall water use (Cohen et al., 2011). Agriculture, in contrast, is responsible for about 80% of water withdrawals in the basin (Hung et al., 2022), where it irrigates nearly 5.5 million acres (2.2 million hectares) of land (Cohen et al., 2013). Among the uses of Colorado River water, however, municipal water has been the fastest-growing sector (Cohen et al., 2011). Water conservation can be the most cost-effective way to increase available water as it can help suppliers delay or avoid the need to invest in new water sources (Danelski, 2022; Palmer, 2023).

While urban water conservation alone cannot solve the basin's water scarcity challenges, it plays a role in advancing water conservation across sectors (Cohen et al., 2013). It is recognised that the majority of water use reductions will need to come from agriculture (Frisvold and Duval, 2023), which may include transfers of water from agricultural to urban use. Implementing agricultural-to-urban water transfers, however, is not without challenges. Reducing water use in the agricultural sector may require investments in technologies to enhance irrigation efficiency; it may also require temporary or permanent fallowing or decreased crop production (Frisvold and Duval, 2023). These strategies may have negative impacts on the environment through reduced groundwater recharge and degradation of wildlife habitats (Pitt, 2023; Fleming et al., 2014). They may also have significant social and economic impacts on rural communities in the form of threatened farmer livelihoods, income instability for tenant farmers and farm labourers, and reduced employment opportunities for Indigenous populations, all of which raise important questions regarding equity (Robbins, 2019; Frisvold and Duval, 2023). Legal and institutional barriers also complicate agricultural-to-urban water transfers (Frisvold and Duval, 2023). Recent studies suggest that farmers may be reluctant to accept such agreements due to concerns about inadequate financial compensation and concerns that their water rights may be permanently reduced or lost (Bennett et al., 2023; Taylor et al., 2019). Urban water conservation may help to reduce the impacts on farming communities and may possibly encourage participation from the agricultural sector in basin wide conservation efforts.

If we are to better understand the role of urban water conservation in addressing basin wide water scarcity, we need to understand the impact of urban water conservation approaches and how to improve on these strategies. In this *Viewpoint*, we review the contributions and limitations of urban water conservation practices in the Colorado River Basin. We draw from key academic and practitioner studies to better understand three distinct questions: which conservation strategies are employed by municipal utilities and water providers in the basin; how water providers evaluate the effectiveness of these strategies to better understand their impact; and what the appropriate role of urban water conservation is in basin wide water sustainability. We begin with a brief review of the evolving water conservation practices in cities in the basin, focusing on the most populous cities that are utilising Colorado River water. We then examine what is known and what is not known about the impact of these efforts to reduce water consumption. Finally, we reveal the political dimensions of urban water conservation that can influence the impact of these efforts, and the role of politics in basin governance and sustainability. We offer some key recommendations for how to improve water conservation practices and research. These are meant to situate urban water conservation more appropriately within broader Colorado River Basin governance and sustainability efforts but also provide lessons for the implementation of water conservation strategies in arid cities around the world.

We conclude that there are limitations to urban water conservation under the basin's drought conditions. We call for improved assessment and monitoring of conservation efforts, advancement of holistic approaches, and the addressing of key political and equity dimensions. All of these recommendations are meant to help fully realise the potential of conservation in growing cities of the western US and globally while acknowledging its limitations in terms of long-term water sustainability.

THE GROWING AND EVOLVING ROLE OF URBAN WATER CONSERVATION PRACTICES

Rapid urban growth contributes to water resource challenges in the Colorado River Basin. Four of the ten fastest-growing states in the US are states in the southwestern US that utilise Colorado River water, that is, Nevada, Arizona, Utah and Colorado (US Census Bureau, 2021) (Figure 1). From 2005 to 2015, population in this region grew at least 15%, with most growth occurring in cities (Feng et al., 2018). Water from the Colorado River Basin contributes to municipal supply for approximately 40 million people (U.S. DOI, 2012), 70% of whom live outside of the basin's boundaries (Cohen et al., 2011). Some 100 water providers, municipal utilities, and special districts, both within and outside the basin, use Colorado River water (ibid). The river also supports about US$1.4 trillion in economic activity annually (Obringer and White, 2023) and is associated with more than US$1 billion in annual tourism revenue (Sullivan et al., 2017).

Water suppliers in the basin are facing enormous challenges in meeting the water demands of a growing urban population (Richter, 2023). Conventional urban water management approaches (or hard-path approaches, see Pahl-Wostl, 2020) are focused on large infrastructure projects that aim to enhance supply or reduce variability through "predict-and-plan" management (Gober, 2013: 955). These are no longer suitable to meet the challenges of climate change, overallocation, and urban growth in the basin (Forrest et al., 2020). Such regimes are stymied by path dependence and by lock-in to technological or infrastructural commitments (White et al., 2019; O'Neill and Boyer, 2023). Municipal utilities and water providers are, therefore, turning to soft-path approaches such as demand-side management; this includes water conservation, efficiency improvements, and reallocation, which are often implemented at the household level (Obringer and White, 2023).

Figure 1. Map of the Colorado River Basin.

Source: United States Bureau of Reclamation. 2015. Colorado River Basin Stakeholders Moving Forward to Address Challenges Identified in the Colorado River Basin Water Supply and Demand Study. May.

A diversity of urban water conservation approaches

As in many cities around the world, municipal utilities and water providers in the Colorado River Basin employ a mix of educational, market-based, and regulatory measures to promote water conservation. The *educational measures* promoted by Denver Water, for example, focus on outdoor irrigation check-ups for large customers, low water use landscaping design for single-family residential homes, and indoor audits for multifamily and public housing (Denver Water, 2007). In the 2000s, Denver Water launched an educational campaign using the slogan, '*Use Only What You Need*' (Denver Water, 2024); a new campaign that began in 2023 features additional clever phrases on billboards, buses, and social media (Proctor, 2023). The City of Phoenix Water Services Department has promoted cultural change around water use through on-going educational efforts such as the '*Water – Use It Wisely*' campaign, which promotes efficient indoor plumbing fixtures and low water use landscaping (City of Phoenix, 2021). In Los Angeles, the Department of Water and Power (LADWP) provides low water use landscaping education that targets single-family residential customers, and it also provides guidance for reducing water use in businesses (LADWP, 2013). In Las Vegas, the Southern Nevada Water Authority (SNWA) – the water wholesaler for the region's municipal utilities – tailors outreach to individual customer needs through site appraisals for high water use customers, and it also reaches out to homeowners associations (SNWA, 2019).

Market-based approaches such as rebates are commonly offered for residential and commercial indoor fixture replacement, and incentive programmes are used to promote improvements in outdoor irrigation efficiency. In Los Angeles, the LADWP sponsors rebates for high-efficiency indoor plumbing fixtures (LADWP, 2013). In southern California, a turf replacement programme encourages homeowners to remove existing grass and replace it with drought-tolerant landscaping. Rebates to homeowners are sponsored by SoCal Water$mart; this is a programme that is provided by the Metropolitan Water District of Southern California, which is the wholesaler that provides water to 19 million people in Los Angeles and other counties (SoCal Water$mart, n.d.). In southern Nevada, as part of its Water Smart Landscapes programme, SNWA offers a substantial rebate (up to US$5 per square foot in 2024) for single-family residential turf that is removed and permanently replaced with desert-appropriate vegetation (SNWA, 2024). Since 1999, the programme has helped to convert nearly 190 million square feet (1760 ha) of turf (SNWA, 2019). SNWA also offers rebates for smart irrigation controllers, pool covers, and leak detection units (ibid).

To help reduce residential water use, municipal utilities, and water providers may use pricing to encourage conservation. LADWP employs a four-tiered volumetric water rate to discourage overuse; this includes water allocations that are based on individualised water budgets which are calculated for customers by using their lot size and temperature zone (LADWP, 2021). Municipal water suppliers in the Las Vegas area set their own water rates; as member agencies of SNWA, however, they follow shared principles that include employing increasing block rates and a usage-based commodity charge that supports system enhancements (SNWA, 2019). The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) employs surcharges to encourage the conservation of irrigation water; it also uses numerous rebate programmes to promote indoor and outdoor water use efficiency (ABCWUA, 2018).

Municipal utilities and water providers may also use *regulatory measures* to increase conservation. In Los Angeles, for example, city ordinances integrate water efficiency into building codes and mandate the installation of high-efficiency plumbing fixtures in new constructions, renovations, and newly purchased existing buildings (LADWP, 2013). Denver Water's regulatory measures similarly require retrofitting of indoor fixtures when residential properties are sold. New single-family residences and new commercial developments are also required to have efficient indoor fixtures as well as metered irrigation systems (Denver Water, 2007). Since the 1990s, city ordinances in Phoenix have controlled water use on golf courses, parks, and other facilities with large turf areas, limiting them to an annual water allotment; they also require low water use vegetation in public rights-of-way (City of Phoenix, 2021). The City of San Diego has had permanent, mandatory water use restrictions since 2016 (City of San Diego, 2023). In 2022, these were enhanced by statewide emergency water conservation measures that, among other restrictions, ban irrigation of decorative turf at commercial, industrial, and institutional (CII) facilities (California Water Boards, 2022). Nevada was the first state to ban non-functional turf in the southern part of the state (Government of Nevada, 2021).

A shift to outdoor conservation efforts

Increasingly, researchers and practitioners are shifting attention from indoor water use to the role of outdoor landscaping in urban water conservation in the western US (Mayer et al., 2015; Gober et al., 2016a; Western Resource Advocates, 2017; Yue et al., 2022; Richter, 2023). In arid regions of the western US, outdoor water use accounts for 65 to 70% of residential water use (Mayer, 2016; Hogue and Pincetl, 2015). It thus presents significant potential for water savings. In recent years, several municipal utilities and water providers have begun to address the challenge of reducing outdoor water use. In Tucson, Arizona, golf courses and parks are required to use reclaimed water for turf irrigation. An ordinance passed in 1991 in Tucson requires the use of desert vegetation in multifamily, commercial, and industrial developments. This has reduced turf area and has considerably decreased the demand for potable water, such that outdoor water use in the city is only 40% of total water use, which is about 25 to 30% lower than in other cities in arid regions (Zuniga-Teran and Tortajada, 2021).

In Denver and other cities, voluntary water efficiency improvements for landscaping are promoted by financial mechanisms such as rebates for the installation of efficient irrigation systems. Denver Water follows a targeted approach whereby it provides tailored recommendations and technical assistance to customers to help them become more efficient; these include outdoor water use audits and water budgets for residential and multifamily units (Denver Water, 2017). In Las Vegas, the SNWA sponsors rebates for the replacement of residential turf with drought-resistant shrubs and trees at rates of up to US$5 per square foot in 2024 (SNWA, 2021a; SNWA, 2024). In Albuquerque, the ABCWUA is shifting its conservation strategy towards a greater focus on outdoor water use. To achieve this, there will be a reduction in indoor rebates on, for example, water-conserving toilets and showerheads, and the money thus saved will be used to fund new rebate programmes that are focused on irrigation efficiency (ABCWUA, 2018). Urban water suppliers in California are required to follow the state's Model Water Efficient Landscape Ordinance, which limits outdoor water use for new developments and retrofitted landscapes (California DNR, 2023). The current implementation of California's statewide 2018 conservation legislation includes the development of water efficiency standards for outdoor residential and CII water use (California Water Boards, 2023).

Non-functional turf has become a recent focus of regulatory measures aimed at reducing unnecessary water use. Colorado River water makes up 90% of southern Nevada's water supply; a Nevada state bill prohibits the use of river water for irrigation of non-functional turf in government, commercial, and multifamily properties in southern Nevada, starting in 2027 (SNWA, 2021a). The state of California, in 2023, made its emergency measures permanent including prohibiting the use of potable water to irrigate non-functional turf on CII properties (Government of California, 2023); Colorado recently followed suit, banning the installation of new non-functional turf in CII properties (Government of Colorado, 2024). Commitments to reduce non-functional turf have also been made by individual water suppliers across Arizona, California, Nevada, New Mexico, Utah, and Colorado (SNWA, 2022).

The impact of water conservation efforts

Despite continued population growth, declines in municipal per capita water use have been reported over the past two decades in many cities that utilise Colorado River water (Colby and Hansen, 2022; Richter et al., 2020; Richter, 2023). Based on data obtained from 28 water utilities in the Colorado River Basin, Richter (2023) found that total and residential median per capita water use declined by approximately 30% between 2000 and 2020, and that changes in total per capita water use ranged from

+2% (in Chandler, Arizona) to -50% (in the Eastern Metropolitan Water District of California). While the service populations of water utilities grew in cities such as Los Angeles (+9%), Phoenix (+15%), San Diego (+16%), Denver (+29%), Albuquerque (+40%) and Las Vegas (+59%), total per capita water use declined by between 21 and 47% in these locations (ibid). The study notes that indoor plumbing retrofits and rebates, water pricing, and turf removal were the most-used conservation strategies in locations throughout the Colorado River Basin (ibid: 7). Other strategies contributing to per capita water use declines in Colorado River Basin cities include programs that incentivise the use of greywater, effluent and captured rainwater for outdoor water uses (Colby and Hansen, 2022). Improvements in the efficiency of residential plumbing fixtures in new developments, as required by the 1992 Energy Policy Act, are estimated to have contributed to an approximately 15% reduction in per capita residential indoor water use nationwide (DeOreo et al., 2016; Mayer, 2016). In the western US, some states (such as California) have exceeded these federal requirements by retrofitting existing fixtures; others, such as Colorado, have done so by requiring that new fixtures meet a higher level of efficiency, as indicated by the WaterSense label (Richter et al., 2020; U.S. EPA, 2024).

For many Colorado River Basin water providers, total water deliveries (which includes residential and non-residential) declined in parallel to reductions in per capita water use. Tucson Water, for example, saw an increase in service area population from 635,073 in 2000 to 743,881 in 2020, a 17% increase, while total per capita water use per day declined by 29% and total water deliveries also declined by 17% (Richter, 2023: 4). Other cities in Arizona experienced more rapid growth, which led to increased water deliveries despite improved water efficiency in new developments. This trend can be found in cities in the Phoenix metro area such as Gilbert and Avondale. Richter (2023) reports that between 2000 and 2020, the Gilbert Utility Division experienced a 140% increase in service area population, a 14% decrease in total per capita water use per day, and a 105% increase in total water deliveries; similarly, Avondale experienced a 124% increase in population, a 15% decrease in total per capita water use per day, and an 89% increase in total water deliveries (ibid: 4).

Evaluating water conservation practices

Despite the prominence and variety of water conservation measures in the water resource strategies of many cities around the world, much is still uncertain about the effectiveness of any particular strategy, programme, or policy. Assessment of water conservation is often limited to noting the presence or absence of certain programmes or policies (see, for example, Hess et al., 2017) or the prevalence of conservation attitudes and behaviours, that is to say, what increases customer participation in conservation programmes (Koop et al., 2019). Less attention has been paid to comparing the effectiveness of conservation strategies across different contexts (Wichman et al., 2016).

In looking broadly across this research, we see that the effects of conservation programmes depend on multiple social, economic, political, and environmental factors, and that results thus tend to be site-specific (Neale et al., 2020; Barta, 2004). Researchers have generally found that regulatory or mandatory approaches to water conservation are the most effective and that incentive- and rebate-based or voluntary approaches are less effective (see, for example, Maggioni, 2014; Garcia-Valiñas et al., 2015; Inman and Jeffrey, 2006; Hughes, 2012). The effectiveness of economic-based methods is debated, as price increases may not be easily accepted by customers (Wichman et al., 2016); however, pricing may be effective for reducing outdoor water use as it tends to be more responsive than indoor water use to price changes (Griffin and Chang, 1991; Renwick and Green, 2000). The effectiveness of non-price strategies varies, and these approaches are typically more expensive for utilities to implement (Olmstead and Stavins, 2007).

It can often be difficult to obtain the data needed to evaluate the impact of various conservation programmes, especially when multiple strategies are implemented concurrently (Kenney et al., 2008; Inman and Jeffrey, 2006). In California, Stokes and Hunnicutt (2018) found that conservation messaging positively impacted water savings, but that the addition of pricing mechanisms did not substantially increase these results. The effectiveness of household-level measures such as conservation-based rates or mandatory water use restrictions can also vary among customers based on their water use behaviours (Kenney et al., 2008). Significant water savings can be garnered by installation of water-efficient indoor plumbing and appliances (Mayer, 2016; DeOreo et al., 2016), however user behaviour can reduce these positive impacts over time (Campbell et al., 2004). Some studies showed no clear effects of educational strategies (Campbell et al., 2004) or found that education resulted in only a temporary positive impact on water-saving behaviour (Koop et al., 2019); other studies, however, indicated that public education influenced conservation behaviour more in water-scarce areas than in areas where water was not in short supply (Inman and Jeffrey, 2006). Overall, the scholarship underscores the highly contextual nature of conservation strategy effectiveness.

This is especially true for outdoor conservation. Despite recent shifts towards outdoor conservation programmes, limited research has been conducted on these strategies, and uncertainty persists regarding their effectiveness (Mayer et al., 2015; Brelsford and Abbott, 2021; Radonic, 2018). Assessing actual water savings that result from particular outdoor water conservation measures is difficult due to the challenges of measurement, variability of local conditions, the influence of climate, and the complicating effect of human behaviour. All of these factors make it difficult to do more than estimate potential water savings (Mayer et al., 2015; Glenn et al., 2015; Gober et al., 2016a; Blount et al., 2021; Kong et al., 2022).

Studies conducted on urban water conservation efforts in cities in the Colorado River Basin demonstrate that, in general, these programmes can help reduce per capita water use. Mandatory water use restrictions in Colorado and Arizona were more effective (that is, conserved higher volumes of water per capita) than voluntary measures (Kenney et al., 2004; Campbell et al., 2004). In further research, Kenney et al. (2008) found that, in Colorado, the effect of mandatory measures varied depending on the customer class, which characterises the type and volume of water use. In Los Angeles, mandatory measures combined with pricing mechanisms were found to be most effective, resulting in a 23% decrease in single-family residential water use (Mini et al., 2015). Even with pricing mechanisms, reductions can take a long time to be realised in Southern California (Baerenklau et al., 2014). A review focusing on incentive-based conservation programmes found that most of the large cities in the Colorado River Basin have used water pricing structures to incentivise reduced per capita water use (Colby and Hansen, 2022). In general, less is understood about the effectiveness of non-price strategies such as public education and voluntary retrofits (Garcia-Valiñas et al., 2015).

Outdoor programmes are key in multiple locations, including Denver, Las Vegas, and Tucson; however, conservation strategy effectiveness varies according to local climate conditions, land development, and population (Neale et al., 2020). In Las Vegas, the conversion of turf to lower water use xeriscaping decreased annual residential water use by 20 to 30% (Sovocool et al., 2006; Brelsford and Abbott, 2021; Baker, 2021). Results of education campaigns also varied depending on weather conditions, customer type, and time since implementation (Wang and Chermak, 2021). In Utah and Colorado, public education was found to be moderately effective (Coleman, 2009; Kenney et al., 2008).

In large cities such as Las Vegas, San Diego, and Denver, municipal utilities and water providers have invested in detailed programme evaluations to assess the performance of conservation strategies; in this, they have used either in-house staff, industry-specific tools, or specialised consultants. These studies are able to estimate the annual water savings and programme costs that can be expected from the implementation of particular conservation strategies; these studies, however, may use varying levels of data and assumptions. One such recent programme evaluation conducted by SNWA in Las Vegas reports estimates of water saved by, and cost of, each conservation strategy (SNWA, 2019); however, it does not clearly present the methods and processes that were followed to arrive at these values. Water utilities use estimates of conservation programme performance to help them decide which measures to continue implementing and which programmes have outlived their usefulness. Many cities, however, especially those with smaller utilities, may not have the resources and capacity to conduct such detailed studies and may instead rely on more general guidance. Such guidance can be found in publications such as Colorado WaterWise's *Best Practices for Municipal Water Conservation* (Colorado WaterWise and Aquacraft, Inc.; 2010); American Water Works Association manuals (such as AWWA G480-13 *Water Conservation Program Operation and Management*); and the US Environmental Protection Agency's 2016 *Best Practices to Consider When Evaluating Water Conservation and Efficiency as an Alternative for Water Supply Expansion*. These documents include best practices for water conservation, and they help guide water suppliers in the selection and evaluation of water conservation programmes.

As the supply of water in the Colorado River Basin becomes increasingly constrained, and as many cities have already captured significant conservation gains, there is a need for a better understanding of the impact of urban water conservation programmes. Investments by municipal utilities and water providers in future conservation programmes should be guided by realistic assessments of what potential gains are still available from current or new conservation efforts. To this end, there is a need for improved monitoring programmes to assess the water savings that are attributable to site-specific conservation measures, especially those targeting outdoor water use, and to project the long-term sustainability of programme impacts (Mayer et al., 2015: 64; Glenn et al., 2015). A better understanding of urban conservation across the Colorado River Basin will also contribute to understanding the broader role of urban water conservation in addressing basin wide water scarcity.

The search for new supplies

Despite efforts to conserve, municipal utilities and water providers in the Colorado River Basin continue to need supply-side expansion and alternative water sources to meet future water demands. Many of these strategies require the construction of new infrastructure or facilities, which are likely to increase consumer water bills. California's new Water Supply Strategy, as of August 2022, calls for both demand management and supply expansion, including wastewater reuse and desalination. In terms of total water volumes, the overall goal of water conservation strategies constitutes just 10% of the total projected water supply for 2030 (California Water Boards, 2022). This means that future increases in water demand will be met primarily by expansion of supply and in only a limited way by water savings that result from conservation measures. Supply-side projects can be found in every major city in the basin. The City of Los Angeles plans to expand groundwater remediation and replenishment projects to supplement potable supplies and expand recycled water use for irrigation and industrial purposes (LADWP, 2021). Denver Water is expanding water recycling, raising reservoirs to increase storage capacity, and exploring aquifer storage and recovery (Denver Water, 2023). While the City of Phoenix holds senior water rights to Salt and Verde River water, it is also considering various options for supply augmentation. These include: adding more storage capacity on the Salt and Verde Rivers, expanding the use of recycled water, recovering banked surface water, and utilising groundwater allocations (City of Phoenix, 2021). The SNWA is considering options for future water supplies that may include in-state groundwater sources, bi-national desalination water exchanges with Mexico, and water exchange partnerships with other Colorado River water users (SNWA, 2021b). Tucson has been replenishing its aquifers with Colorado River water since the 1990s; more recently, efforts have been made to infiltrate stormwater, greywater, and reclaimed water through programmes and initiatives related to green infrastructure that have been undertaken by multiple organisations at the city and county level (Zuniga-Teran and Tortajada, 2021). The City of San Diego has invested in potable water reuse infrastructure, with a plan that this should provide up to 40% of the city's total water demand by 2035 (City of San Diego, 2021). Cities such as San Diego and Phoenix are also considering plans to utilise direct potable reuse (Paredez, 2023; *Reuters*, 2023). Clearly, conservation is insufficient to address the growing water demands of the basin's cities.

REVEALING THE POLITICAL DIMENSIONS OF URBAN WATER CONSERVATION

The numbers associated with urban water conservation – from percentages of water saved to the number of shower fixtures installed, to acres of lawns removed – can hide or even distort the more political dimensions of urban water conservation. All water management and policy actions have political implications, however researchers are revealing additional political dimensions by calling attention to the unknowns around the effects of water conservation, the trade-offs associated with urban water conservation, the winners and losers of conservation policies, and how framings can privilege particular actions. Taken together, these findings suggest a growing awareness of the politics associated with urban water conservation at the basin scale.

First, research highlights some significant unknowns associated with the effects of urban water conservation. Although water conservation can help reduce demand for water supplies, some proponents of economic growth contend that water conservation may act as a disincentive to growth (Brown and Hess, 2017). While studies have suggested that growth control may be necessary to secure long-term water supplies in arid cities such as Phoenix (see, for example, Gober et al., 2016b), few cities have implemented limits on growth (Hirt et al., 2017). Indeed, some argue that in certain cases, decision-makers may only be amenable to conservation measures when they do not inhibit economic growth (Boyer et al., 2021a). Others warn of demand hardening, which is "the concern that policies that encourage consumers to use less water can effectively reduce the 'slack' in the system and thereby undermine the ability of those consumers to further reduce consumption during droughts or other supply emergencies" (Kenney, 2014: 37).

Second, researchers are uncovering some fiscal realities for urban water providers that may serve as disincentives to water conservation. Water providers rely on revenue from the sale of water to help finance their operations; reduced water use can, therefore, cause revenue loss. "Because many of a utility's costs are fixed (e.g.; the capital costs of existing infrastructure), conservation can drop revenue (income) faster than costs, leading to budgetary shortfalls that necessitate rate increases unpopular with customers, utilities, and political leaders" (Kenney, 2014: 37). Reduced indoor water consumption can also cause changes in wastewater quality, possibly requiring modifications to treatment processes; this can also reduce the volumes of wastewater that are available for reuse (Schwabe et al., 2020). In the wake of the coronavirus pandemic, household water bill debt has been rising in many communities across the US (Walton, 2020). In California, for example, a recent survey[1] by the state's water regulator estimates that about 1.6 million households have a combined water debt of US$1 billion (Walton, 2021). Many experts also suggest that we might expect water rates to increase further in the coming years in parts of the basin (Garrick, 2022; Weiser, 2022). This suggests that there are dual, and perhaps contradictory, pressures to both ensure that water utilities are financially sound and recognise the growing water debt and consumer financial burden that exist in many communities.

Third, there is a growing body of research that reports inequities in access to urban water conservation programmes and their benefits. In Tucson, Arizona, rainwater harvesting incentive programmes have largely benefited well-organised middle-class communities at the expense of poorer and more vulnerable communities (Gerlak et al., 2021). Understanding who benefits from conservation programmes and who is burdened by them is a key question. Indeed, there are differentiated water insecurities and vulnerabilities at play in the urban space. Water conservation programmes directed at outdoor water use may be related to green infrastructure projects at the household, neighbourhood, and city level. Studies have found that the presence/absence of green infrastructure affects urban resilience in the form of, for example, heat abatement, reduced flooding, and enhanced air quality (Staddon et al., 2018); this, in turn, affects the quality of life of residents. The unequal distribution of green infrastructure thus represents an

[1] https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/covid-19watersystemsurvey.html

environmental justice issue, with underlying factors that are rooted in legacies of redlining and disinvestment in neighbourhoods where minority populations prevail (Zuniga-Teran et al., 2021).

Water justice issues within the Colorado River Basin are more pronounced for Native American Tribes. Even though Indigenous peoples have been using water in the basin since time immemorial, they were not engaged in the creation of the Colorado River Compact or the development of the basin's governing institutions and they therefore do not have reliable access to a sufficient supply of clean water (McKinney et al., 2023). According to Wilson et al. (2023), about 40% of Navajo Tribal members do not have access to running water in their homes and must haul water from distant sources. Water insecurity among Native Americans results from a combination of a lack of physical infrastructure for delivering water and entitlements to water that exist only on paper. In this way, Indian water settlements and the resulting water law in the Colorado River Basin replicate colonial dispossession (Curley, 2021). Basin-level justice issues thus emerge when examining water conservation in cities: for what purpose are cities conserving water and for whom?

Finally, there are a growing number of critiques suggesting that framing the crisis in the basin as a problem of urban areas and urban consumption is incomplete and misleading. We know from research in other communities that the framing around water challenges strongly influences the strategies pursued (see, for example, Jones et al., 2022). Historically, narratives around water are often quick to disregard the human element and overemphasise technological or infrastructure solutions (Mesmer et al., 2022; Nickels and Clark, 2019; Olivier et al., 2021). In the case of Guaymas, Mexico, for example, research has shown how framing water security around a water scarcity crisis instead of aging infrastructure led to the implementation of an expensive desalination plant; this approach was adopted even though repairing the aging infrastructure would have significantly reduced water use (as more than 50% is lost to leaking) and would have helped solve the scarcity problem (Varady et al., 2021). Other studies have argued that urban water conservation efforts can be used to justify new infrastructure projects (Welsh and Endter-Wada, 2017). A crisis framing may inspire all sorts of new expensive infrastructure projects in the urban water domain that are loosely vetted and economically infeasible. The recent approval of a desalination plant by the Water Infrastructure Finance Authority of Arizona is one such example. Criticised as an energy-intensive, environmentally harmful, and expensive proposal by environmental groups and questioned as a backroom deal by some legislators, the plan was approved quickly and without much process or oversight in the final days of an outgoing state administration (Partlow, 2022). New desalinisation plants are being framed as a solution for cities; they are touted as ways to provide new water supplies for the cities in Arizona that may likely face cuts in Colorado River supplies (Davis, 2024). Path dependencies promoting such infrastructure-based solutions as desalination often overlook the political and financial challenges associated with them and fail to acknowledge how such 'solutions' can impede future adaptation (O'Neill and Boyer, 2023).

Others argue that conservation messaging as it is portrayed in the news media has framed water conservation as being necessary to support economic growth (via population growth) in desert cities of the US Southwest (Boyer al.; 2021a). As the water conservation narrative aims to change people's behaviour, it can be interpreted as a scalar fix (Cohen and Bakker, 2014) that shifts responsibility for a regional problem from regional actors to individuals at the household level (Boyer et al., 2021a). This framing promotes a "weak sustainability model" that avoids questioning embedded political and social structures and instead supports an approach that maintains the status quo (ibid: 16).

CONCLUSIONS: THE ROLE OF URBAN WATER CONSERVATION IN A CONSTRAINED COLORADO RIVER

In this *Viewpoint*, we reviewed the contributions and limitations of urban water conservation practices in the Colorado River Basin. Drawing from key academic and practitioner studies, we examined which urban conservation strategies are employed in the basin, how municipal utilities and water providers evaluate the effectiveness of these strategies, and what is known and unknown regarding the impacts of urban water conservation efforts. Going forward, there is no question that urban water conservation can play an important role in the Colorado River Basin. There are clear financial benefits of water conservation as it is often less expensive than acquiring new supplies or reallocating water from rural uses to urban ones (Rupprecht et al., 2020). There are also notable savings associated with urban water conservation, including lower energy costs (Chini et al., 2016), reduced air temperatures, and reduced carbon emissions (Sowby and Capener, 2022).

Additional savings through conservation and efficiency are possible. Estimates suggest that, nationwide, an additional 37% decrease in indoor water use is possible (compared to 2010-2013 figures) through full market saturation of high-efficiency indoor water fixtures and appliances (Mayer, 2016). In terms of outdoor water usage, a report by the Alliance for Water Efficiency suggests that a reduction in outdoor water use by 15 to 65% can be achieved through the implementation of strategies such as low water use landscaping and water rates designed to encourage conservation (Mayer et al., 2015: 63). Recent research also suggests that a further reduction of urban water use by 30 to 48% could be achieved in California through the implementation of available water-efficient technologies across residential, commercial, industrial and institutional sectors (Cooley et al., 2022: 2). The capture of these additional savings is challenged by data gaps, difficulties in monitoring, and the site-specific nature of conservation programme performance.

In our review of urban water conservation strategies, however, we also reveal the more hidden challenges of these approaches. 'Political dimensions', in our report, include the unknowns around the effects of water conservation, the trade-offs associated with urban water conservation, the winners and losers of conservation policies, and how framings can privilege particular actions. This suggests that the impacts of conservation measures need to be better understood if they are to more effectively guide decision-making.

We conclude here by cautioning against the over-reliance on urban water conservation to solve basin wide water supply and demand imbalances. Urban water conservation will likely not be enough to balance the current water deficit in the Colorado River Basin and to address the water needs of a growing population. We need to move the conversation beyond urban water conservation, such that it also examines the relationship between the basin's cities and farms and agricultural water conservation.

To help guide future urban water conservation in the basin, we outline key steps forward for research and practice. These recommended steps can also inform approaches in cities around the world that are facing similar challenges. Experiences in other cities have demonstrated the need to consider the differential impact of water conservation policies on different subsets of the urban population (Zapana-Churata et al., 2022; Muller, 2020; Ray Biswas et al., 2023). There is also a need to ensure that water access is maintained while employing conservation practices (Tortajada et al., 2019; Muller, 2020). Cities around the world also share challenges regarding demand hardening due to over-reliance on water conservation measures (Muller, 2020) and the possibility that utilities will face new operational and financial hurdles with reduced water use (Stavenhagen et al., 2018). Based on our review of urban water conservation trends in Colorado River Basin cities, we call for improved assessment and monitoring of conservation efforts, advancement of holistic approaches, and the addressing of key political and equity dimensions. All of these recommendations are meant to help fully realise the potential of urban water conservation while acknowledging its limitations for long-term water sustainability.

Beyond urban water conservation in the Colorado River Basin

The progress that has been made on urban water conservation in the basin will still not be enough to address the Colorado River Basin's water challenges. Water conservation in agriculture is essential. Agriculture represents about 80% of water withdrawals in the Colorado River Basin (Hung et al., 2022); municipal use, in contrast, accounts for only 15% of Colorado River water use, including in the residential, industrial, commercial, and institutional sectors (Cohen et al., 2011). A central tension in the basin today

– and a matter that is at the heart of current negotiations – is how to balance water cuts between urban and farming regions, as farmers hold the most senior water rights but cities contain the majority of the population (Partlow, 2023).

Reduced cropland productivity (for example, through temporary or permanent fallowing of active cropland) has been explored as a potential alternative for states holding junior water rights, that is, those whose rights are subordinate to senior water rights under the western US water rights system (Norton et al., 2021). Some municipal utilities and water providers in the basin have shifted water allocations from agricultural to municipal uses as one of their first strategies for addressing water scarcity. This approach was adopted by Tucson, which acquired water rights by purchasing farmland on the outskirts of the city (Zuniga-Teran and Staddon, 2019). Water reallocation from agricultural land to municipalities is a common strategy, particularly in cities of the Global South (Garrick et al., 2019).

Conserving water through reducing agricultural use can be attractive because the cost per unit is lower than in other sectors such as municipal. Relatively small marginal changes can create large savings, and water supply can be expanded faster in this way than by infrastructure-based solutions such as the construction of new desalination plants (Frisvold and Duval, 2023). Conserving water by reducing agricultural use, however, comes with its own challenges and potentially unjust impacts. Reallocating water from agriculture to other water uses can impact crop productivity and farm incomes, and payments for voluntary reductions do not always include paying compensation to local farmworkers and other third parties who may be affected by fallowing (ibid). Urban expansion onto formerly agricultural land can lead to a decline in water use; such transitions, however, can reduce flexibility in the system since municipal water use is fairly constant, whereas agricultural users have the option of fallowing fields if necessary (Hirt et al., 2017). Ag-to-urban water conversions are also rife with institutional and political challenges (Larson et al., 2009; Frisvold and Duval, 2023), and farmers in the basin have become powerful actors who have negotiated, "institutional arrangements that enable them to mediate the risks associated with intersectoral competition, as well as the perceived political, economic, and hydrological risk" (York et al., 2020: 434). These arrangements effectively buffer the effects of overallocation and drought while helping farmers defend their water rights against the claims of other sectors. Among the latter are Indigenous peoples, the resolution of whose water rights farmers perceive as potentially reducing agricultural water allocations (York et al., 2020).

Outlining key steps forward for research and practice

As discussed above, urban water conservation will not be enough to achieve sustainability in water resource management in the basin, and ag-to-urban water transfers also have their constraints and limitations. Here, we outline key steps for future research and practice that can advance sustainability in the basin. First, there is probably more that can be done to improve existing programmes and to inform the design of new urban conservation strategies. Some studies have argued that Phoenix's passive approach, which emphasised creating a "culture of conservation", was undermined by weakened regulations, a continued focus on supply expansion (Larson et al., 2009: 108), and the city's dependence on growth for economic development (Hirt et al., 2017; Boyer et al., 2021a). It is argued that messaging around the city's '*Water – Use It Wisely*' campaign promotes a concept of sustainability that does not challenge the status quo (Boyer et al., 2021b). Indeed, the City of Phoenix notes in its recent water plan that even with the reductions in per capita water use, "in the face of prolonged, severe shortage, Phoenix should proactively develop strategies to reduce per-capita demand to levels lower than those that would be achieved passively over time" (City of Phoenix, 2021: 113). In Las Vegas, the SNWA recognises that many of its current programmes may have already reached their maximum feasible impact. As stated in a 2019 document,

> It also is important to note that the SNWA has reached many of the community's most willing participants through its incentive programs and other offerings over the years. It also follows, that the well of opportunity

> has diminished through the success of prior efforts (i.e. there is less available turf to convert/pools to cover, etc. due to prior program enrolment). While future gains are anticipated, the SNWA recognizes they are likely to come slower than in prior years, and potential participants may be harder to compel towards change (SNWA, 2019: 43).

Additional potential conservation savings will likely require new approaches and more holistic programmes. This may involve thinking beyond traditional conservation approaches and considering new models such as '*Net Zero Urban Water*', which aims to meet the water needs of a city using local water supplies such as surface water, groundwater, stormwater, rainwater, and reclaimed water (Crosson et al., 2020). Water self-sufficiency at the city level would require moving away from siloed water management approaches and more towards a 'One Water' approach that manages water holistically to safeguard future water availability and avoid damage to interconnected systems (ibid). This holistic concept has been implemented at the household level, and research suggests that water-independent single-family housing offers the potential for sustainable outcomes (Forrest et al., 2019). Scaling up this household-level approach, however, may include challenges such as reduced revenues for the water utility. This may, in turn, translate into difficulty in maintaining infrastructure, issues around social justice and equity, and dependence on suburban development as the main form of future growth (ibid).

Second, there is the need for improved monitoring and metering to better track the benefit of particular conservation strategies in their local context. Not all municipal utilities and water providers, however, have the capacity to carry out detailed evaluation studies or improve monitoring. State and federal governments can thus offer funding to help municipal utilities and water providers collect and analyse data. This can especially benefit smaller utilities or communities that are burdened with a level of water debt that limits their ability to implement effective conservation programmes (Maggioni, 2014; Richter, 2023). The 2022 Inflation Reduction Act could provide some support as it allows for spending on water conservation and efficiency projects for both urban and agricultural water uses (Alliance for Water Efficiency, 2022). Researchers can partner with municipal utilities and water providers on these efforts and can provide valuable accountability checks in interrogating the data.

There are unknowns around the impacts of urban water conservation programmes, and there are inequities in terms of who enjoys their benefits; there are also misleading or incomplete framings of the basin's water crisis. All of these elements have a related political dimension that influences who benefits, what investments are made, and how water allocations and reductions are distributed across basin water users. Our third key point for future research and practice is thus that we should not be afraid to dig deeper to reveal how the benefits and burdens of conservation efforts are shared.

Finally, we need to work harder to think more holistically about the basin and to consider all Colorado River water users as part of the same system. The historic 'oasis in the desert' model of developing cities in the western United States is insufficient in today's time of increasing basin wide aridification. While cities seem able to create a sense of water security amid basin wide scarcity, they still influence and are influenced by the broader socio-ecological system. In addition to honing urban water conservation programmes, we need to seriously consider the role of water conservation across all sectors in the basin and critically evaluate the cross-sectoral impacts and trade-offs of these strategies. Ultimately, accurately perceiving who wins and who loses and understanding the more political dimensions of urban water conservation are key to more sustainable, fair, and just water governance across the broader Colorado River Basin.

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