frontiers | Frontiers in Water

TYPE Original Research
PUBLISHED 19 November 2025
DOI 10.3389/frwa.2025.1637215

OPEN ACCESS

EDITED BY
Nazmul Huq,
Technical University of Cologne, Germany

REVIEWED BY
Thomas Shahady,
University of Lynchburg, United States
Ayat-Allah Bouramdane,
International University of Rabat, Morocco

*CORRESPONDENCE
Courtney Crosson
ccrosson@arizona.edu

RECEIVED 28 May 2025
ACCEPTED 23 October 2025
PUBLISHED 19 November 2025

CITATION
Crosson C, Pincetl S, Bhushan R, Scruggs C, Zuniga-Teran A, Gupta N, Porse E, Sharvelle S, Boccelli DL, Pierce G, Schuler A, MacAdam J and Piza H (2025) Acceptance of a net zero urban water future: challenges and strategies for a sociotechnical shift of water systems. *Front. Water* 7:1637215. doi: 10.3389/frwa.2025.1637215

Acceptance of a net zero urban water future: challenges and strategies for a sociotechnical shift of water systems

Courtney Crosson[1]*, Stephanie Pincetl[2], Rashi Bhushan[1], Caroline Scruggs[3], Adriana Zuniga-Teran[4], Neha Gupta[5], Erik Porse[6], Sybil Sharvelle[7], Dominic L. Boccelli[8], Gregory Pierce[9], Andrew Schuler[10], James MacAdam[11] and Holly Piza[12]

[1]College of Architecture, Planning, and Landscape Architecture, University of Arizona, Tucson, AZ, United States, [2]Institute of the Environment and Sustainability, University of California, Los Angeles, Los Angeles, CA, United States, [3]School of Architecture and Planning, University of New Mexico, Albuquerque, NM, United States, [4]School of Geography, Development, and Environment, University of Arizona, Tucson, AZ, United States, [5]Arizona Institute for Resilience, University of Arizona, Tucson, AZ, United States, [6]California Institute for Water Resources, University of California Agriculture and Natural Resources, Davis, CA, United States, [7]Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO, United States, [8]Department of Civil and Architectural Engineering and Mechanics, University of Arizona, Tucson, AZ, United States, [9]Luskin Center for Innovation, University of California, Los Angeles, Los Angeles, CA, United States, [10]Department of Civil, Construction and Environmental Engineering, University of New Mexico, Albuquerque, NM, United States, [11]Tucson Water, City of Tucson, Tucson, AZ, United States, [12]Mile High Flood Control District, Denver, CO, United States

The Colorado River supplies over 40 million people in the United States Southwest with their daily water supply and is currently unable to meet these demands. Faced with the challenges of climate change, population growth, and aged infrastructure, urban water systems in the Southwest, as sociotechnical systems, will need to evolve to become more sustainable. A Net Zero Urban Water (NZUW) approach meets the needs of a given community with a locally available and sustainable water supply, without detriment to interconnected systems and long-term water supply. Transitioning to a NZUW future will require considerable changes related to water availability, sources, technology, management, costs, and the urban landscape. Acceptance of these changes is key to a successful sociotechnical shift in urban water systems in the arid Southwest. Our results identify three main actors (institutions, civil society, and the public) and five key factors (public trust, perceived issue severity, infrastructural inertia, cultural preferences, and cost) that influence acceptance of change across the urban water system. Under each factor, we identify strategies that have been used to influence acceptance by each of the three actors (e.g., transparent communication, community engagement, inter-agency collaboration, advocacy campaigns, and financial incentives). To better understand acceptance of the changes necessary for a NZUW future, we examined four case study cities across the Colorado River System to illustrate the dynamics between the identified actors, factors, and strategies: Albuquerque, Denver, Los Angeles, and Tucson. Our results highlight that fostering public trust and understanding, overcoming institutional and cultural barriers, and aligning financial policies are key for advancing a NZUW future. We conclude that cities in the Southwest are in the middle of significant sociotechnical shifts toward

greater water system sustainability. Acceptance of these changes by institutions, civil society, and the public continues to be critical, particularly for a NZUW future to be realized.

KEYWORDS

net zero urban water, sociotechnical systems, public trust, public acceptance, water reuse and decentralization

1 Introduction

The twenty-first century has inherited over 100 years of centralized, highly engineered and material-intensive infrastructures, based on early 20th-century climate assumptions and a utilitarian view of nature. These sociotechnical systems, shaped by extensive rules and regulations, were built to meet agricultural and urban needs, framing expectations of water as reliable and abundant for the 40 million people dependent on the Colorado River. Today, these systems struggle to adapt to a changing climate, marked by higher heat and unpredictable precipitation, and no longer meet current demands in the US Southwest. Water managers of urban water systems in the US Southwest face the urgent need to transition to more sustainable and resilient systems. In this changing sociotechnical context, people who rely on the Colorado River will be asked to accept new understandings of and practices within their urban water systems in an uncertain and more costly future.

Acceptance is the process of consenting to receive or undertake something offered. A sociotechnical shift is the interrelated transformation between people, strategies, and structures to bring about change. Innovations in water systems can include new technologies [i.e., desalination, membrane bioreactors, direct potable reuse (DPR)], efficiency techniques (i.e., sub-metering, leak detection), management techniques (i.e., tiered water rate pricing, water tax, regulation), and new land uses for water management such as infiltration (Kiparsky et al., 2013; Hekkert et al., 2007; Carlsson et al., 2004). A sociotechnical shift involves both technological innovation and social acceptance, where institutions, civil society, and the public demonstrate acceptance of change through action, integrating innovation into urban water systems.

Sociotechnical systems evolve, and, in the urban water system, this evolution depends on acceptance of shifts by various actors. Net Zero Urban Water (NZUW) provides a new lens through which to shape water systems for the twenty-first century. A NZUW approach meets the needs of a given community through a locally available and sustainable water supply, without detriment to interconnected systems or long-term water supply (Crosson et al., 2020). NZUW is an integrative approach using quantitative assessments to adapt to challenges in the urban water system by evaluating strategies at building, district, and city scales over varying timeframes. A NZUW future will require different infrastructure, management systems, new rules, and codes (Crosson et al., 2024). Further, institutions, civil society, and the public must adapt to changes related to water availability, sources, technology, management, costs, and the urban landscape (e.g. landscaping, streetscapes and more). Acceptance of these changes is key to a successful sociotechnical shift in urban water systems in the Southwest.

This paper characterizes the ways in which acceptance of a sociotechnical shift by the actors in the urban water system is crucial for a NZUW future to be possible in the Southwest. First, we combine insights from literature review, workshops, and interviews with water managers throughout the Southwest to identify three main social actors involved in change and acceptance: (1) institutions, (2) civil society, and (3) the public. We outline five dominant factors that influence acceptance: (1) public trust, (2) perceived issue severity, (3) infrastructural inertia, (4) cultural preference, and (5) cost. Ultimately, we synthesize these dynamics in a final section focused on four case study cities of varying size, water availability, and source dependencies along the Colorado River system: Albuquerque, Denver, Los Angeles, and Tucson. The case studies detail how the previously identified actors, factors, and strategies have played out over time and highlight successful strategies to influence acceptance toward a NZUW future for each city. We conclude that, given the significant ongoing sociotechnical shifts in the urban water systems of the Southwest, acceptance of various facets of a NZUW future will be critical in adapting our urban water infrastructure in the face of water uncertainty.

1.1 Defining NZUW

Net zero water, net positive water, and net negative water is measured by the balance of supply and demand of volumes of water for a geographic area and defined scope usually across a year's time period (Figure 1 and see Crosson et al., 2020). Three scopes are outlined under this framework, similar to carbon accounting systems. This paper focuses on the NZUW scope 1 and 2 boundaries within a city and larger watershed (Figure 1). A diverse urban water supply portfolio, including recycled and alternate local sources, with both centralized and decentralized solutions is essential for the NZUW transition (Crosson et al., 2020, 2024). This diverse urban water supply portfolio will require different infrastructure, management systems, new rules, and codes (Crosson et al., 2024). Further, NZUW promotes sociocultural

Abbreviations: NZUW, Net Zero Urban Water; CBOs, Community Based Organizations; NGOs, Non-Governmental Organizations; GSI, Green Stormwater Infrastructure; DPR, Direct Potable Reuse; ABCWUA, Albuquerque Bernalillo County Water Utility Authority; GPCD, Gallons Per Capita Per Day; HOA, Home Owner's Association; PFAS, Per- and polyfluoroalkyl substances; NFT, Non functional Turf; LADWP, Los Angeles Department of Water and Power; LASAN, Los Angeles Sanitation & Environment.

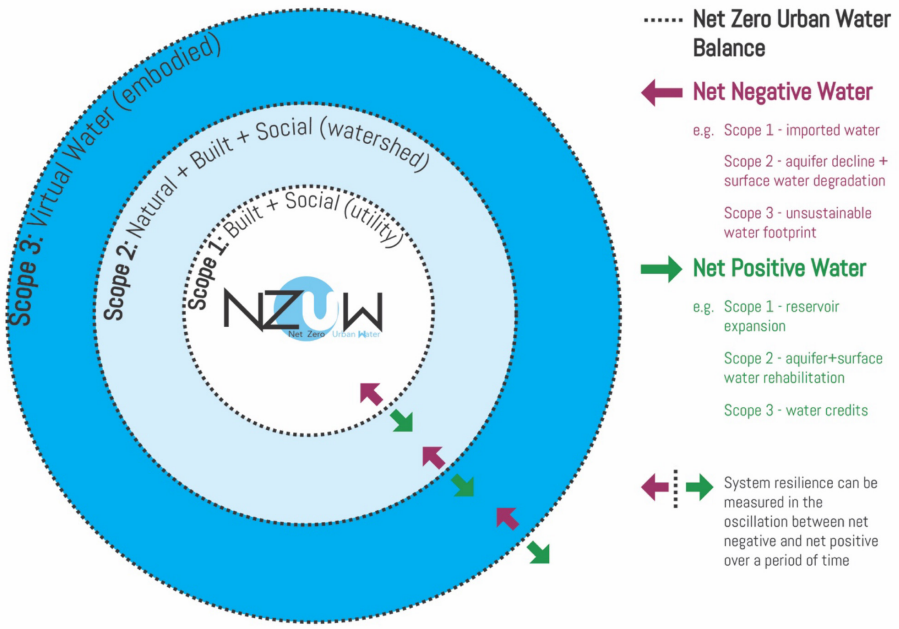

FIGURE 1
Net zero water, net positive water, and net negative water is computed on an annual basis and is the balance between supply and demand within an identified scope (Figure first published Crosson et al., 2020).

shifts in attitudes about water and water scarcity, requiring public understanding and buy-in for successful implementation. Thus, acceptance of these sociotechnical shifts in the urban water system is paramount to achieving a NZUW future.

1.2 Defining actors influencing change and acceptance in the urban water system

Change, and acceptance of change, in urban water systems are affected by numerous influences and barriers, and are addressed by strategies from three social actors: (1) institutions, (2) civil society, and (3) the public (Figure 2). The following sections broadly define these actors and the main factors influencing each actor. To be clear, there may, at times, be overlapping roles between these three groups of actors, and/or variations within these groups (e.g., the public is not a homogeneous group). However, the distinction of these three groups provides a useful framework to understand the complex dynamics of acceptance and how different actors within a society influence one another. Finally, the dynamics between these three actors underline that sociotechnical transitions are inherently political. While understanding these three separate groups, acknowledging the significant dynamics between these three groups is important. For example, acceptance of change can be shaped by power asymmetries, vested interests, and institutional resistance between these three groups.

1.2.1 Institutions: utilities and government

Institutions can be defined as the rules, practices, and norms that govern decision-making (Kiparsky et al., 2013), including formal laws and regulations, as well as behavioral and cultural factors (Scott, 2013). Water institutions are generally stable and resistant to change due to factors such as regulatory frameworks (e.g., the Colorado River Compact, the Clean Water Act), historical success, skilled staff, and large capital investments (Espeland, 1998; Fuenfschilling and Truffer, 2014). However, as climate changes make water resources less reliable, these institutions become difficult to adapt, requiring significant rule changes, new investments, technical training for staff, and public participation. In these instances, leadership becomes critical to overcoming the challenges of social, technical, infrastructural, spatial, and financial change. According to our research results, the main factors influencing institutional change are public trust, perceived issue severity, infrastructural inertia, cultural preference, and cost. The strategies institutions use to influence acceptance by any actor in the urban water system include public messaging and communication, public education, collaboration, leading by example, public engagement, incentives, and regulation and code.

1.2.2 Civil society: NGOs and CBOs

Civil society, including community-based organizations (CBOs) and non-governmental organizations (NGOs), plays a key role in facilitating sustainable community initiatives in the water sector (Reames and Wright, 2021). Civil society engages communities through diverse strategies to support water conservation and practices such as Green Stormwater Infrastructure (GSI). The main factors influencing civil society for acceptance of sociotechnical shifts in urban water systems include perceived issue severity and cultural preference, which are

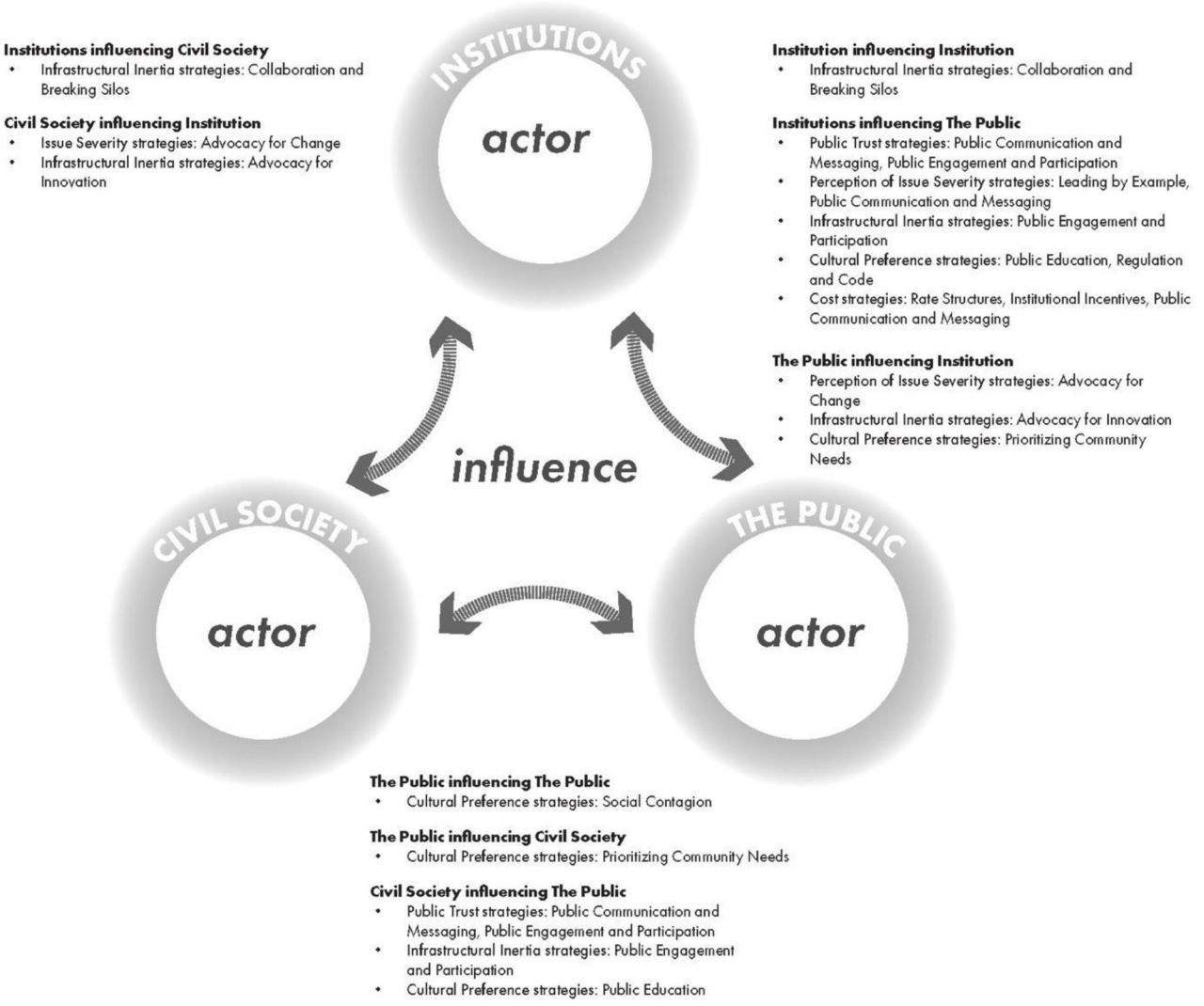

FIGURE 2
Actors in the urban water system influence one another in acceptance of the sociotechnical shift needed to move toward a NZUW future.

addressed using strategies such as communication and messaging, public engagement, and advocacy for change.

1.2.3 Public: citizens and customers

Public perception and trust influence the acceptance of large- and small-scale changes, such as DPR projects, in the urban water system (e.g., Ingram and Schneider, 2006; Hurlimann and Dolnicar 2010). "Public participation" is the process that involves the public in decision-making and considers their input (United States Environmental Protection Agency, n.d.). Despite shifts toward inclusivity over the past few decades (Varady et al., 2016a,b), public participation in infrastructure projects is often viewed as tokenistic due to top-down approaches (Boyle et al., 2022). Based on our research results, the main factors influencing public perception and trust include perceived issue severity, infrastructural inertia, cultural preference, and cost. In turn, the strategies the public uses to influence acceptance by any actor in the urban water system include advocacy for change, social contagion, and prioritizing community needs.

2 Methods

This paper synthesizes literature review, insights from an in-person workshop, and post-workshop interviews with water resource managers. The work was funded by a National Science Foundation Research Coordination Network grant under the Dynamic SocioEnvironmental Systems program specifically focused on addressing the challenges the US Southwest faces in a transition toward a NZUW future. The two-day workshop, held at the University of New Mexico in Albuquerque on February 29 and March 1, 2024, brought together academics, water managers, and government officials from Albuquerque, Denver, Los Angeles, and Tucson. As the third in a series of eight workshops in the research coordination network, this workshop focused on addressing the

TABLE 1 Rankings of influence of five identified factors (1 = most influential in the acceptance of the sociotechnical shift to NZUW in four cities, 5 = least influential factor) for each city and examples of successful strategies used under each factor.

Factor	City	Rank	Example of a strategy successfully used to address factor
Trust	**ABQ**	1	**Public communication and transparency:** The Water Authority efforts such as monthly Customer Conversations events, rebate programs, and public engagement in planning (e.g., water compliance reports).
	DEN	1	**Public communication and transparency:** Citizen Advisory Council to engage the public in decision-making. Another example is public messaging and stakeholder engagement efforts led by Denver Water to support DPR
	LA	1	**Public communication and transparency:** Measure W Campaign engaged the community and stakeholders, highlighting the benefits of stormwater capture and reuse projects (Safe Clean Water Program, 2018).
	TUS	1	**Public communication and transparency:** Tucson Water utility efforts to build public trust through effective outreach via media, messaging boards, newsletters, and direct communication from the Mayor and City Council.
Perceived issue severity	**ABQ**	2	**Public messaging:** The Water Authority includes information in billing inserts about recommended watering schedules and public water-related meetings and also uses social media apps like NextDoor to communicate important information.
	DEN	3	**Public messaging:** Utility uses a Drought Response Plan with watershed-based metrics to communicate drought responses, focusing on water efficiency and conservation.
	LA	3	**Public messaging:** Consistent Messaging on Climate Change by LADWP to educate the public.
	TUS	2	**Advocacy for change:** Watershed Management Group campaigns
Cultural Preference	**ABQ**	3	**Public education for behavior change:** The Water Authority's drought management plans educate the community. It also advocates for regulations that support the reduction of turf areas and promotes drought-resistant landscaping. The Office of the State Engineer (OSE) has modified water policy to allow use of rain barrels (within specified limits).
	DEN	4	**Public education for behavior change:** ColoradoScape Program to encourage adoption of water-efficient landscaping suitable for local climate, to reduce water use.
	LA	4	**Social contagion:** Neighborhood transformations through drought-resistant landscapes in areas like Long Beach. **Regulations and code:** Mandatory water assessments for new developments to ensure that developers adopt water-saving practices (Villaraigosa, 2008).
	TUS	3	**Public education for behavior change:** The University of Arizona's Project WET and Citizen Water Academy programs for increasing awareness about water conservation.
Infrastructural Inertia	**ABQ**	4	**Collaboration and breaking silos:** The Water Authority collaborates with UNM, NM Bureau of Geology, and others to advance stewardship of scarce water resources.
	DEN	2	**Collaboration and Breaking Silos:** Diverse actors, including Denver Water, NGOs, and government entities, working together to address water management challenges.
	LA	2	**Collaboration and breaking silos:** Collaboration on Measure W involved LADWP, LA Sanitation & Environment, NGOs and community organizations.
	TUS	5	**Collaboration and breaking silos:** Collaboration across multiple actors, including Tucson Water, for Santa Cruz River Heritage Project which includes water credit accounting.
Cost	**ABQ**	5	**Incentives and innovation:** The Water Authority offers rebates on low-flow appliances, planting drought tolerant trees, and xeriscaping (Albuquerque Bernalillo County Water Authority, n.d1.,n)
	DEN	5	**Rate structures:** Denver Water limits rate increases to 5% to consider equity and communicates to the public about rate increases using an in-house journalism team.
	LA	5	**Incentives and innovation:** Turf Replacement Financial Incentives by LADWP, and subsidized Flume device to detect leaks and monitor water usage.
	TUS	4	**Incentives and innovation:** "Storm to Shade" program funds new GSI initiatives through a water use tax.

Rankings were produced from interviews with water managers in each city.

pressing challenges around acceptance of the sociotechnical shift needed to move toward NZUW in the US Southwest.

The workshop was structured around a series of breakout group discussions designed to explore public preference challenges from different disciplinary and geographic perspectives. On the first day, participants were divided into expert working groups aligned with natural, social, and built systems to identify key research gaps. Subsequent breakout sessions mixed participants across disciplines and cities to explore the role of public preference and behavior in the innovation-adoption-diffusion process for water reuse and conservation. On the second day of the workshop, participants were organized into city-specific working groups to examine the role of collective action, environmental stewardship, and city-tailored strategies for increasing acceptance of NZUW pathways. The final breakout session focused on identifying next steps and action items specific to each case study city.

To gain deeper insights into the challenges associated with transitioning to NZUW in each of the four case study cities, we conducted one-hour interviews via the videoconferencing platform Zoom with a fixed interview script with utility managers from all four cities after the workshop. There were eight interviews total, with two interviews (one water utility manager and one stormwater utility manager) from each of the four cities. The interview questions were structured based on the major issues

identified during the prior two-day workshop in Albuquerque. From these eight interviews, the research team then created detailed notes and coded these notes by major topics introduced by each of these eight utility managers. These consistently expressed topics across the four cities created our coding scheme and formed the basis for the five main factors presented in this paper (i.e. public trust, perceived issue severity, infrastructural inertia, cultural preference, and cost). Then, strategies (successful or unsuccessful) mentioned by the utility managers in the interviews were identified and coded by the five main factors to form the sub-topics. Finally, city specific issues were identified, which formed the basis for the case study sections of this paper. After this analysis was complete, tables were completed with the factors and strategies. The utility managers were asked to verify these factors and strategies, and then rank their importance (from 1 to 15 with 1 being the most important and no factor occupying more than one rank) to their city's urban water system and its transition to NZUW, which resulted in Tables 1, 2. The analysis of key themes from the workshop and interviews provided a foundation for this paper, specifically in identifying the primary categories of actors important to acceptance of a sociotechnical shift; the factors at play in influencing that shift; example strategies used to influence these factors in each city; and the relative ranking of the importance of the actors, factors, and strategies for each city.

TABLE 2 Ranking of different strategies to influence acceptance of the sociotechnical shift to NZUW-aligned initiatives in four cities, as reported by water managers.

Ranked strategies under the five identified factors	ABQ	DEN	LA	TUS
Public trust				
Public communication and messaging	1	2	1	1
Public engagement and participation	2	13	3	2
Perceived Issue and Issue Severity				
Leading by example	6	1	7	11
Public communication and messaging	3	8	3	8
Advocacy for change	15	9	13	3
Infrastructure Inertia				
Collaboration and breaking silos	10	11	3	14
Public engagement and participation	7	7	7	7
Advocacy for innovation	14	14	12	4
Public/Cultural Preference				
Public education	4	6	5	13
Social contagion	11	15	11	10
Regulations and code	12	3	3	5
Prioritizing community needs	8	10	13	12
Cost				
Rate structures	9	5	8	9
Institutional incentives	5	4	5	6
Public communication and messaging	13	12	12	15

1 = most effective/successful and 15 = least effective/successful. More precisely, dark red = 13 or most effective, light red = 46 or next effective, orange = 79 or effective, yellow = 1012 or less effective, white = 1315 or least effective.

3 Results: factors: drivers of change and corresponding strategies to influence acceptance and change in the sociotechnical shift toward a NZUW future in the Southwest

The three actors described in Section 3 are influenced by factors within the urban water system. Our workshop and interviews identified five key factors influencing urban water system changes: (1) public trust, (2) perceived issue severity, (3) infrastructural inertia, (4) cultural preference, and (5) cost. This section examines these factors and the strategies actors use to promote acceptance of sociotechnical changes for a NZUW future. Figure 2 highlights how the three actor types interact across these factors and their respective strategies.

3.1 Trust

Public trust in water authorities is a key factor in driving the sociotechnical shift toward a NZUW future in the Southwest, particularly impacting the acceptance around reclaimed water use (Hurlimann and Dolnicar, 2018; Garcia-Cuerva et al., 2016). Trust is defined as the public's confidence in the actions of the water system operators to act in the public's best interest (Roberts et al., 2013). The factors influencing social acceptability include technical feasibility, local impacts, ethics, health, and economics (Boyle et al., 2022), alongside contextual, psychological, and personal influences (Devine-Wright, 2011).

Key strategies used to influence trust and acceptance of change (and direction of influence) include:

- *Public Communication and Messaging (Institution and Civil Society to the Public):* Transparency and clear communication are keys to building trust, particularly for potable water reuse and GSI projects. Effective messaging is critical for public acceptance of sustainable water initiatives, such as DPR projects (Sedlak, 2014; National Research Council (NRC), 2012; Ormerod and Scott, 2013). Civil society also plays a role in shaping public trust through similar efforts.
- *Public Engagement and Participation (Institution and Civil Society to the Public):* Engagement can vary from information sharing to decision-making (Sterling et al., 2017). Engagement efforts must have clear goals, outline feasible results, and acknowledge tradeoffs (Bobbio, 2019). Equity in public engagement is essential as marginalized communities often lack opportunity to engage (Viswanath et al., 2022; Zuniga-Teran et al., 2021). Thus, engagement efforts must prioritize inclusivity, offering diverse participation options, using multiple languages, and working with trusted community organizations (Zuniga-Teran et al., in review).

3.2 Perception of the issue and issue severity

Perception of urban water challenges, especially climate change's impacts like water scarcity and extreme heat, drives acceptance of change in water systems. Institutional recognition of issue severity influences actions as well as public and civil society's understanding of localized impacts.

Key strategies used to influence perception of the issue and acceptance of chang (and direction of influence) include:

- *Leading by Example (Institution to the Public):* Local utilities and governments inspire conservation efforts by integrating alternative local water sources in operation of government buildings and infrastructure and adopting sustainability goals of city climate action plans.
- *Public Communication and Messaging (Institution to the Public):* Public communication and messaging is also critical for influencing perception of issue severity, as discussed in section 4.1.
- *Advocacy for Change (Civil Society and Public to Institutions):* The public and civil society can influence institutional perception of issue severity by raising concerns through advisory councils and public meetings and emphasizing water quantity and quality issues.

3.3 Infrastructural inertia

The large and siloed traditional urban water infrastructure put in place over the last century has resulted in what is referred to as infrastructural inertia, or a difficulty to make changes in the urban water system. Infrastructural inertia involves challenges in upgrading or replacing aging systems due to technical, financial, institutional, and societal constraints (Sedlak, 2014), which hinders the NZUW transition. Traditional urban water systems with linear and compartmentalized designs are no longer suitable for addressing climate change and population growth (United States Water Alliance, 2012, 2016; Marlow et al., 2013).

Key strategies used to influence infrastructural inertia and acceptance of change (and direction of influence) include:

- *Collaboration and Breaking Silos (Institution to Institution and Civil Society):* Cities across the US are adopting the One Water approach, which promotes integrated, equitable management of water resources (Arabi et al., 2024), and requires transitioning to decentralized systems (Daigger et al., 2019). For NZUW, this means encouraging inter-agency collaboration to manage all water sources effectively.
- *Public Engagement and Participation (Institution and Civil Society to the Public):* Public engagement and participation can contribute to social acceptability by gaining public support and behavior change for overcoming inertia. Engagement fosters inclusivity and capacity building (Boyle et al., 2022; Zuniga-Teran et al., 2021), as discussed in section 4.1.
- *Advocacy for Innovation (Civil Society and Public to Institution):* Civil society and the public can advocate for innovative solutions like neighborhood sub-metering and decentralized GSI to promote water conservation and reuse. Advocacy can promote diverse perspectives and accelerate change.

3.4 Cultural preference

Cultural preferences, like the demand for water intensive urban landscapes, can hinder NZUW progress. Shifting to native, low water use species is essential, but public resistance may persist. Similarly, public preferences related to reuse of wastewater can play a key role in NZUW adoption. As Stenekes et al. (2006) noted, values, rather than facts, shape acceptance of reuse, emphasizing the need for early, two-way dialogues in planning.

Key strategies use to influence cultural preference and acceptance of change (and direction of influence) include:

- *Public Education (Institution and Civil Society to the Public):* Convincing people to reduce water use in their landscapes can be achieved through education. Landscape choices not only depend on pro-environmental factors (the need to use less water) but also on contextual and internal factors (e.g., values, attitudes, education, aesthetic preferences) (Kollmuss and Agyeman, 2002). Public communication and messaging (see section 4.1) complement public education, which denotes a deeper, long-term engagement effort.
- *Social Contagion (the Public to the Public):* Social contagion, or mimicry, strongly influences human behavior. Nassauer et al. (2009) has shown social contagion to influence landscape choices among residents.
- *Regulation and Code (Institution to the Public):* Regulation and code are key to driving public acceptance of native vegetation in developments. Resistance persists in some areas, such as homeowners' associations or neighborhoods with restrictions on native planting or limited plant options. Targeted regulations can address these barriers and drive broader cultural acceptance.
- *Prioritizing Community Needs (the Public to Institution and Civil Society):* Conveying to the public that no single project can fix all environmental problems is the key to addressing challenges in low-income Southwest communities facing heat and flooding issues. For example, an equity-centered approach is needed to expand GSI's benefits to these communities (Zuniga-Teran et al., in review).

3.5 Cost: water utility finance considerations for net zero urban water

NZUW transitions demand new investments and innovative financial models to change existing urban water systems. Many cities in the Southwest have long invested in supply augmentation and conservation through water pricing structures informed by long-term adaptation studies (Hughes, 2012; MacDonald, 2010; Richter et al., 2020). However, these changes to the existing water system for a NZUW future will likely impact the costs for water

services raising affordability concerns. Hence, this section outlines three strategies to influence acceptance of changes in cost.

- *Rate Structures (Institution to the Public):* Water utilities in the US set rates to cover fixed and variable costs, balancing fiscal needs with affordability (Alliance for Water Efficiency, 2014). Many utilities adopt tiered or budget-based rate structures to promote conservation (Woodcock et al., 2017). These rate structures can influence water demand and household behavior (Moncur, 1987), with price-based strategies being explored to encourage conservation, especially during droughts (Nieswiadomy, 1992; Pint, 1999), and marginal cost pricing encouraging reduced outdoor use (Olmstead and Stavins, 2009; Nieswiadomy, 1992). Low-income households are more responsive to price increases (Mini et al., 2014), and block rates have been effective in reducing use (Wichman, 2014; Wichman et al., 2016; Baerenklau et al., 2014; Baerenklau and Pérez-Urdiales, 2019; Pint, 1999; Lee et al., 2021). However, affordability assessments are necessary for marginalized communities (United States Environmental Protection Agency, 1997; Teodoro, 2018).
- *Institutional Incentives (Institution to the Public):* The public may not often change their water use habits until offered incentives. Rebates for efficient fixtures, turf conversion, and onsite water conservation encourage sustainable behaviors. An integrated approach that combines financial incentives, public education, and community leadership is crucial to drive changes for a sustainable water future.
- *Public Communication and Messaging (Institution to the Public):* Clear messaging can address public resistance to increased costs for climate adaptation and mitigation efforts. Examples like Los Angeles' Measure W, a special parcel tax enacted through voter approval that now funds the Safe, Clean Water Program, show how public perceptions shift over time with information and engagement.

3.6 Case study cities

To further examine and illustrate the dynamics between actors, factors, and strategies in the acceptance of a sociotechnical shift in the NZUW transition, case studies were conducted in Albuquerque, Denver, Los Angeles, and Tucson, all connected to the Colorado River with diverse water sources. Table 1 summarizes the critical factors in order of their importance to each city, and successful strategies used by each city to influence acceptance. Table 2 presents a heat map of how water managers prioritize strategies.

Across these four cities, public trust is identified as the most important factor influencing acceptance toward a NZUW future. Albuquerque, Los Angeles, and Tucson also share public preference as a critical factor. Key differences exist around the stated importance of infrastructural inertia. The large cities of Los Angeles and Denver cite infrastructural inertia as a dominant factor, while the relatively smaller cities of Albuquerque and Tucson did not emphasize infrastructure inertia. Another clear difference between the cities was the historic role and relative success of civil society in impacting acceptance of past water system transitions. Tucson and Albuquerque reported a history where civil society has and continues to play the dominant role in influencing acceptance, whereas Los Angeles and Denver characterize a history where institutions dominated influence over water system adaptations.

3.6.1 Albuquerque

The Albuquerque Bernalillo County Water Utility Authority (ABCWUA or Water Authority) serves 650,000 people in the City of Albuquerque and parts of Bernalillo County, New Mexico. The Water Authority has active education and conservation programs that reduced total system (i.e., not just residential) per capita water demand from 250 to 128 gallons per capita per day (GPCD) between 1994 and 2022, with further reductions planned to 110 GPCD by 2037. The city's current residential use is 80 GPCD (Crosson et al., 2024).

Albuquerque's water planning has historically been driven by the Water Authority, but increasingly a mix of state-level planning, regional planning, public engagement, and local advocacy is also playing a significant role. Key features of each of these actors is outlined below:

- **Institutions (water utility and supporting agencies):** The Water Authority advocates for and leads planning for potable water reuse, with entities like the Bernalillo County Natural Resources Department and the Albuquerque Metropolitan Arroyo Flood Control Authority leading efforts on GSI. The Middle Rio Grande Conservancy District handles water conservation and management related to agricultural water, and the New Mexico Bureau of Geology and Mineral Resources promotes public engagement through meetings and collaboration with regulators and advocacy groups (Middle Rio Grande Conservancy District, n.d.; New Mexico Bureau of Geology and Mineral Resources, n.d.).
- **Civil Society (NGOS, CBOs, and similar organizations):** The efforts of the Ciudad Soil and Water Conservation District and the Arid LID Coalition provide education on Low Impact Development practicesto improve environmental health (CIUDAD Soil and Water Conservation District, n.d.; Arid LID Coalition, n.d.). The Universityof New Mexico promotes water conservation through education and engagement University of New Mexico, n.d.). CBOs, such as New Mexico WaterAdvocates and New Mexico Water Dialogue, use multi-stakeholdercollaboration and community engagement to promote conservation of water resources (New Mexico Water Advocates, n.d.; New Mexico Water Dialogue, n.d.).
- **The Public:** Public trust in the Water Authority is generally high, reinforced by the utility's transparency and public engagement in planning processes. Monthly Customer Conversations events, rebate programs, and public engagement in planning have helped strengthen public trust.

The main factors thatinfluence acceptance of a sociotechnical shift across the water system in Albuquerque are public trust, perceived issue severity, and public preference. Table 1 outlines

effective strategies water managers have employed to address these acceptance factors in advancing NZUW-aligned initiatives.

Albuquerque would face significant challenges in a transition toward a NZUW future.While public engagement initiatives by the Water Authority have improved public trust, challenges remain in communicating the interconnected nature of groundwater and surface water. Many residents rely on multiple water sources, including private wells and water from the Middle Rio Grande Conservancy District, making the urgency of reducing use from all sources difficult to convey. Improved communication and messaging along with public education are critical for building understanding about local water resources.

Examples of dynamics around perceived issue severity and public preference include urban agriculture's high water demand and private well usage for non-functional turf (NFT) irrigation, which significantly increase water consumption. Effective strategies must address agricultural water management, well usage, and water-efficient landscaping. Policies like NFT irrigation restrictions, surcharges for excessive water use, monitoring well water usage, and revised development codes could incentivize conservation. Programs promoting turf reduction and drought-resistant landscaping, supported by policy changes (e.g., allowing rain barrel use), provide a strong foundation for cultural change (Albuquerque Bernalillo County Water Authority, n.d1.). However, further efforts are needed to implement stricter Home Owner's Association (HOA) regulations, introduce surcharges for NFT irrigation, and mandate net-zero water requirements for new developments.

Albuquerque's reliance on centralized systems and imported water, such as the San Juan-Chama Project, reflects infrastructural inertia. High costs and limited federal assistance have stalled large-scale reuse projects, necessitating new financial strategies to support such needed infrastructure. Continued collaboration with regional agencies and academic institutions can advance innovation.

Transitioning Albuquerque to a NZUW future would require reducing groundwater pumping and consumptive use while enhancing water use efficiency. A stepwise strategy that balances resource optimization, public engagement, and financial feasibility is essential.

3.6.2 Denver

Denver Water serves 1.5 million people in the City and County of Denver and surrounding communities. The average residential per capita demand for the past 5 years (2017–2022) is 96 GPCD. For single-family residential customers, who currently are the majority of Denver Water's customer base, goals are set for indoor water consumption (40 GPCD) and outdoor water consumption (12 gallons per square foot of pervious area annually) (Crosson et al., 2024).

The changes in water management practices in Denver have historically been led by Denver Water, with the current landscape including government entities like the Colorado Water Conservation Board, NGOs, and regulatory bodies. Key features of each of these actors is outlined below:

- **Institutions (water utility and supporting agencies):** In the city, the DPR efforts are primarily driven by Denver Water staff and supported by NGOs, while GSI is advocated by the City and County of Denver, Mile High Flood District, and NGOs.
- **Civil Society (NGOS and CBOs, and similar organizations):** Groups like Western Resource Advocates, and Colorado Watershed Assembly bring diverse stakeholders together to address water issues (Western Resource Advocates, n.d.; Colorado Watershed Assembly, n.d.). NGOs such as the Greenway Foundation advocate for GSI (Greenway Foundation, 1974), while the Water for Colorado Coalition protects water resources by supporting initiatives like the "Colorado Water Plan" (Water for Colorado Coalition, n.d.; Colorado Water Conservation Board, 2023). Organizations like Colorado WaterWise, Roaring Fork Conservancy, and Water Education Colorado each educate and engage with the public on water conservation topics (Colorado WaterWise, n.d.; Roaring Fork Conservancy, n.d.; Water Education Colorado, n.d.).
- **The Public:** Public trust in the water authority is robust, supported by effective outreach, a citizen advisory council, and dedicated customer service support. Denver Water engages with the public through initiatives like landscape transformation programs and Colorado Scaping camps (Denver Water, n.d1,n).

The key factors for Denver in driving the acceptance of the sociotechnical shift toward a NZUW future are public trust, infrastructure inertia, perceived issue severity, and cultural preferences. Table 1 outlines effective strategies the city has employed to address these acceptance factors in advancing NZUW-aligned initiatives.

Denver faces several challenges in advancing toward a NZUW future, driven by critical factors such as public trust, perceived issue severity and infrastructural inertia.

Public trust and perceived issue severity are central to Denver's efforts to transition toward NZUW. To build trust, Denver prioritizes public communication and transparency through efforts like the Citizen Advisory Council, with additional public messaging to communicate and address the perceived issue severity regarding droughts.

Denver's reliance on large, aging water infrastructure and imported water creates significant infrastructural inertia for transitions to NZUW. The long-standing practice of identifying and creating projects to import water and the high reliability of those imported water sources creates a context that limits consideration of alternative approaches. These limited resources hinder the shift to decentralized systems leading to a focus on optimizing existing infrastructure, which includes assessing the potential for effluent supply for DPR with neighboring areas like Aurora. A regional approach to DPR and continued public education efforts can help mitigate the regulatory barriers and water rights constraints.

Cultural preferences for traditional landscaping pose hurdles for transitioning to sustainable landscapes. Initiatives like the ColoradoScape Program have helped, yet significant challenges remain in training the public, providing resources, and ensuring

the availability of suitable plants in nurseries (Denver Water, n.d.). Financial constraints, labor shortages, and inflation further complicate landscape transformation. Addressing these challenges will require increased financial support for landscape conversion initiatives, targeted public education, and training programs.

Transitioning toward a NZUW future in Denver will require a multifaceted approach that builds public trust, addresses infrastructural inertia including institutional changes to divert from reliance on imported water, and promotes cultural acceptance of sustainable landscaping. Strategies such as public education, financial incentives, and regional collaboration will play a pivotal role in overcoming these challenges.

3.6.3 Los Angeles

The City of Los Angeles is the largest of the 88 cities in metropolitan Los Angeles County. Over 3.8 million people comprise the city's population. Water consumption per capita in 2022 hovered around 112 GPCD, down from about 146 GPCD in 2016, with a modest future goal of reaching 105 GPCD (Crosson et al., 2024).

For LA, a mix of actors have driven the water management changes, including organizations like Los Angeles Department of Water and Power (LADWP), Los Angeles County Flood Control District, Metropolitan Water District, LA Sanitation and Environment (LASAN), as well as the public, and NGOs. Key features of each of these actors is outlined below:

- **Institutions (water utility and supporting agencies):** In the city, potable reuse is primarily led by LADWP and LASAN. GSI initiatives are bolstered by LASAN, Measure W (also known as the Safe Clean Water Program, a voter-approved parcel tax to fund stormwater capture and reuse projects) and NGO advocacy.
- **Civil Society (NGOs and CBOs and supporting agencies):** In LA, NGOs like Heal the Bay, Los Angeles Waterkeeper and the Upper Los Angeles River Watershed Management Group lead the GSI related initiatives (Heal the Bay, n.d.; Los Angeles WaterKeeper, n.d.; Upper Los Angeles River Watershed Management Group, 2015), while the Mono Lake Committee focuses on conserving Mono Lake and promoting water education (Mono Lake Committee, 1978). Several community-based organizations address environmental justice, including Pacoima Beautiful, and groups like the Environmental Justice Coalition for Water advocates for clean and affordable water access for underserved communities statewide (Pacoima Beautiful, 1996; Environmental Justice Coalition for Water, 1999).
- **The Public:** Public awareness of water scarcity in the region has led to reduced water usage. Further, the public trust in the water authority varies significantly across demographics. For example, first-generation immigrants often distrust public water (Pierce and Gonzalez, 2017), and historical distrust of LADWP exists, even in affluent communities.

In Los Angeles, the main factors that influence the acceptance of this sociotechnical shift are public trust, perceived issue severity, infrastructure inertia, and public preference. Table 1 outlines effective strategies the city has employed to address these acceptance factors in advancing NZUW-aligned initiatives.

Los Angeles faces significant challenges in transitioning toward a NZUW future, driven by factors such as public trust, infrastructural inertia, and cultural preferences.

Public trust is critical for advancing a sociotechnical shift in LA's water system. While public engagement has improved, legacy policies and institutional resistance persist. Public acceptance of potable water reuse remains mixed, with broad support for water rate increases but hesitancy around DPR, despite four new projects in development (California Water Boards, 2023). Managing water demands from new developments while maintaining trust in water quality is crucial.

Infrastructure inertia also remains a challenge, particularly in repurposing systems within the existing built environment and urban scale. The Hyperion Wastewater Treatment Plant's reliance on gravity-based operations exemplifies the difficulty of modernizing centralized systems. Climate change impacts, such as the 2023 storm damage to the LA Aqueduct, highlight the need for resilient infrastructure and cost analyses for imported water. Water rights, jurisdiction over reclaimed water, and limited land availability further complicate the transition. Collaborative approaches, as seen with Measure W, are essential to overcome institutional silos and drive system-wide change (Safe Clean Water Program, 2018).

Cultural preferences for turf and high outdoor water use hinder the shift to sustainable landscaping. Programs like LADWP's turf replacement incentives have made progress, but large-scale behavior change remains challenging (Pincetl et al., 2019). Reforming commercial landscaping practices and enforcing turf removal require statewide legislation and better enforcement mechanisms.

To achieve NZUW, LA can expand local water sources, including recycled water, improved groundwater management, and enhanced stormwater infiltration. Public education campaigns are vital to build trust and encourage behavioral changes like reducing outdoor water use and adopting sustainable landscapes.

3.6.4 Tucson

The Metropolitan Statistical Area of Tucson, Arizona, includes over one million people with over half that population living within the city limits. In 2021, Tucson's total potable water use was 120 GPCD, with a residential GPCD of 76 (Tucson Water, 2023). Tucson Water's current master plan, One Water 2100, aims to increase water conservation and expand the use of all available water sources, including purified wastewater (Crosson et al., 2024).

Historically, pivotal water management changes in the Tucson water system have been driven largely by advocacy from citizens and NGOs. Currently, drivers of change are more mixed and include policymakers and the water utility. Key features of each of these actors is outlined below:

- **Institutions (the water utility and supporting agencies):** Tucson Water has historically engaged with the public and civil society to expand potable water reuse. Programs like

"Storm to Shade" enhance urban resilience by implementing GSI to capture stormwater, and support native vegetation (City of Tucson, 2021), while the Pima County Regional Flood Control District helps reduce flood risks and supports GSI to enhance flood resilience and promote groundwater recharge (Pima County Regional Flood Control District, 2023).

- **Civil Society (NGOs, CBOs and similar organizations):** Tucson has a strong network of CBOs including Tucson Clean and Beautiful, Watershed Management Group, and Dunbar Spring Neighborhood Foresters, which mobilize volunteers for clean ups, tree planting, and water-efficient landscaping, while promoting water conservation education (Tucson Clean and Beautiful, n.d.; Watershed Management Group, n.d.; Dunbar/Spring Neighbourhood Foresters, n.d.). Sonora Environmental Research Institute helps expand the rainwater harvesting rebates to low-income communities (Sonora Environmental Research Institute, n.d.). The Santa Cruz Watershed Collaborative highlights Indigenous voices in water conservation (Santa Cruz Watershed Collaborative, n.d.), while the Southern Arizona Water Users Association seeks to improve water quality and quantity through collaboration and policy advocacy (Southern Arizona Water Users Association, n.d.). The University of Arizona provides educational programs, such as Arizona Project WET and Citizen Water Academy (University of Arizona, n.d., 2019).
- **The Public:** The public has high trust in the water utility for water quantity, but relatively lower confidence in water quality due to past water quality issues, injustices and subsequent cultural perceptions (Superfund site). There is strong public interest in the One Water 2100 master plan of Tucson Water that supports an increased use of recycled water, DPR, and stormwater reuse (City of Tucson, 2023).

In Tucson, the key factors influencing acceptance of this sociotechnical shift are public trust, perceived severity of water issues, and public preferences. Table 1 outlines effective strategies the city has employed to address these acceptance factors in advancing NZUW-aligned initiatives.

Tucson's shift toward a NZUW future faces several challenges, driven by factors such as public trust, perceived issue severity, and cultural preferences.

Public trust is hindered by resistance to rising water costs, which can be addressed through transparent communication, paired with tiered water pricing and education on DPR safety and Per- and polyfluoroalkyl substances (PFAS) treatment. The perceived urgency of water issues remains low among some residents. Advocacy campaigns, like those by the Watershed Management Group, can build a stronger sense of urgency.

Public preference for non-native, water-intensive landscapes in certain communities pose a barrier, despite xeriscape ordinances and incentives and programs like "Storm to Shade". More targeted incentives, banning non-functional turf, and implementing excessive water use charges are needed to drive widespread behavior change.

High costs for DPR and stormwater reuse systems remain a significant challenge. Aligning DPR costs with other water sources and balancing water offsets with development costs, particularly for housing, are essential to address affordability concerns and gaining public support. Infrastructure inertia is also a barrier, given the city's extensive and dispersed infrastructure, with substantial investments in importing water and centralized wastewater treatment. Limited space for stormwater capture and recharge in the existing built environment also complicate NZUW efforts.

To advance its NZUW goals, Tucson's future actions must prioritize DPR initiatives led by the water utility, further investments in decentralized infrastructure and conservation programs, and expanding recharge efforts.

3.6.5 Strategies influencing NZUW acceptance across cities

Table 2 presents a heat map of how water managers prioritize strategies influencing acceptance of NZUW-aligned activities across the four cities. First, the table was created based on the detailed coded notes from the interviews that set the categories (see Section 2.0 Methods). The research team then asked the utility managers to rank the importance of each of the factors (from 1 to 15 with 1 being the most important and no factor occupying more than one rank) within the context of their city making the sociotechnical shift toward NZUW. Public communication and messaging emerge as the most effective strategy for building public trust in water utilities. For cultural preferences, regulations and code, followed by public education, are most impactful in shaping attitudes toward water use. Addressing perceived issue severity relies heavily on clear communication and messaging, though leading by example in Denver and advocacy for change in Tucson are notably effective.

To overcome infrastructural inertia, public engagement and participation ensure public buy-in for infrastructure projects in most cities. However, collaboration in Los Angeles (e.g. Measure W) and advocacy for innovation in Tucson are more effective strategies to overcome inertia. In Denver, water managers identified inertia as a significant barrier, but the lower ranking of current strategies suggests gaps in addressing this challenge. For cost-related factors, institutional incentives like rebates and subsidies are the most effective in driving acceptance of NZUW transitions.

4 Discussion

Our findings align with and extend existing research on water system transitions and sociotechnical change. A central theme in our study is the importance of public trust and effective communication, consistent with studies on potable reuse and drinking water safety (Ormerod and Scott, 2013; Hurlimann and Dolnicar, 2018; Pierce and Gonzalez, 2017). The emphasis that our workshop participants placed on transparency, outreach, and community engagement as strategies to build trust is consistent with best practices mentioned in the literature (National Research Council (NRC), 2012; Sedlak, 2014; Viswanath et al., 2022).

Infrastructural inertia emerged as another key barrier, particularly in larger cities, consistent with the literature that highlights that traditional urban water systems often face an

"innovation deficit" due to rigid infrastructure and siloed institutions (Marlow et al., 2013; Kiparsky et al., 2013). Our study confirms that breaking down silos and adopting a One Water approach through strategies like regional partnerships for reuse and multi-agency stormwater programs is critical for such transformations (Daigger et al., 2019; Arabi et al., 2024). Infrastructural inertia also varies by city size: larger cities with extensive systems show more resistance, reflecting the inertia of established water systems (Fuenfschilling and Truffer, 2014). Overcoming this requires both policy innovation, such as enabling decentralized solutions, and financial strategies to offset sunk costs.

Our study emphasizes that cultural preferences, and social norms also shape acceptance, a fact that is strongly supported by existing research in environmental psychology and urban planning (Kennedy and Zube, 1991; Kendal et al., 2012). Residents' choices, such as maintaining water-intensive landscapes, often reflect identity and values rather than environmental knowledge, demonstrating a "value-action gap" (Kollmuss and Agyeman, 2002). Our results demonstrate that strategies like demonstration gardens, community champions, incentives, and policy measures gradually shift norms and support sustainable water use behaviors (Nassauer et al., 2009; Stenekes et al., 2006).

In our study, the factor of perceived issue severity, or risk perception, was found to influence acceptance, consistent with risk communication theory that people support proactive changes when problems are seen as urgent and personally relevant (Devine-Wright, 2011). Our findings show that water managers use strategies such as leading by example and targeted public messaging to heighten urgency, aligning with evidence from other sustainability areas. Variations in risk perception across residents highlight the need for tailored communication (Pierce and Gonzalez, 2017).

Similarly, our finding that financial incentives also support acceptance align with prior studies on price elasticity of water demand (Moncur, 1987; Wichman, 2014; Wichman et al., 2016). Cities like Los Angeles (with Measure W's success) and Tucson (extending rebates to low-income participants) demonstrate that coupling financial tools with inclusive outreach can lead to broader acceptance.

A key insight from our research is the varying actor dominance between cities- larger cities relying more on institutional leadership and smaller ones on civil society. These findings complement Reames and Wright (2021), who reviewed the role of community-based organizations in pursuing sustainability and driving substantial changes as demonstrated by the cases of Tucson and Albuquerque. Varady et al. (2016a) also discusses water governance across scales, demonstrating that context matters. For practitioners, this suggests that strategies to enhance acceptance should consider local context, engaging community networks and ensuring transparency and advisory mechanisms where appropriate.

4.1 Limitations

While Albuquerque, Denver, Los Angeles, and Tucson offer valuable insight, these cases are all situated within the relatively similar political, climatic, and regulatory context of the US Southwest. Although similar climatic factors and technological strategies exist throughout the world affecting urban water systems, the geographic focus of this study may limit the generalizability of findings to other global regions with different water governance structures or cultural norms. Additionally, to understand the complex dynamics associated within acceptance of change and how acceptance is influenced by different actors within the US Southwest, this study pulls apart five main factors and outlines strategies that three key actors use to influence one another toward or away from acceptance of the sociotechnical shift in urban water systems. However, acceptance is often non-linear, context-dependent, and politically contested, involving resistance, negotiation, and backsliding that can vary across geopolitical regions. While the four case study cities offer variations within the framework to address these complexities within the US Southwest, limitations within any clearly defined framework will certainly exist to address all complexities within a given system.

5 Conclusion

NZUW is not a new concept. The barriers are significant but given the immediacy of climate impacts on water resources in the Southwest, the time is now to engage in the changes needed. This requires a deep engagement with the complex sociotechnical systems that have risen over the past century to ensure the populations of the Southwest of reliable and ample water supplies. We outline three categories of actors that influence and are influenced by one another in acceptance of the sociotechnical transition needed for urban water systems: institutions, civil society, and the public. Within the dynamics of acceptance influencing these actors, we identify that five factors dominate: (1) public trust, (2) perceived issue severity, (3) infrastructural inertia, (4) cultural preference, and (5) cost. Related to each of these factors, numerous strategies have been documented to influence acceptance of the sociotechnical shift of urban water systems across four case study cities, including Albuquerque, Denver, Los Angeles, and Tucson.

Across the case study cities, the most important factor influencing acceptance is public trust. The larger cities of Los Angeles and Denver place importance on infrastructural inertia while the relatively smaller cities of Albuquerque and Tucson more highly prioritize public preference in transitioning toward sustainable water futures. Additionally, in the relatively larger cities, institutional actors appear to dominate shifts in the urban water system, while Albuquerque and Tucson cite civil society as playing the most important role in acceptance of water system changes. In terms of strategies, public communication, engagement, and advocacy remain central across all factors, while financial incentives, regulations, and collaboration effectively target specific challenges.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://drive.google.com/

drive/folders/1_HFaUq36JQNohnerrzTs6RRQPxfGZ4UE?usp=share_links.

Author contributions

CC: Funding acquisition, Writing – original draft, Visualization, Conceptualization, Project administration, Supervision, Methodology, Writing – review & editing, Investigation. SP: Writing – original draft, Funding acquisition, Conceptualization, Writing – review & editing. RB: Methodology, Data curation, Formal analysis, Writing – original draft, Investigation, Conceptualization, Writing – review & editing. CS: Methodology, Conceptualization, Writing – review & editing, Writing – original draft. AZ-T: Writing – review & editing, Writing – original draft, Conceptualization. NG: Writing – original draft, Conceptualization, Writing – review & editing. EP: Writing – review & editing, Writing – original draft, Conceptualization. SS: Writing – review & editing, Writing – original draft, Conceptualization. DB: Conceptualization, Writing – original draft, Writing – review & editing. GP: Writing – review & editing, Conceptualization. AS: Writing – review & editing, Writing – original draft, Conceptualization. JM: Writing – review & editing, Investigation, Conceptualization. HP: Conceptualization, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This work was supported by the National Science Foundation's Dynamic and Integrated Socioenvironmental Systems program under award number 2206132.

Acknowledgments

We are grateful to collaborations with our utility and community partners throughout the US Southwest. We thank Katie Spahr of Denver Water, Steve Baule from the City of Los Angeles, Diane Agnew of Albuquerque Bernalillo County Water Authority, Patrick Chavez from Albuquerque Metropolitan Arroyo Flood Control Authority, and Kali Bronson from Bernalillo County for their significant input and time. We are grateful to support from our utility and non-governmental organizational partners: Albuquerque Bernalillo County Water Authority, Denver Water, Los Angeles Department of Water and Power, Mile High Flood District, Pima County Regional Flood Control District, and Tucson Water.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2025.1637215/full#supplementary-material

References

Albuquerque Bernalillo County Water Authority (n.d1.). *Conservation Rebates*. Available online at: https://www.abcwua.org/conservation-rebates-rebates/ (Accessed November 5, 2025).

Albuquerque Bernalillo County Water Authority (n.d2.). *Xeriscaping Rebates*. Available online at: https://www.abcwua.org/conservation-rebates-xeriscape/ (Accessed November 5, 2025).

Alliance for Water Efficiency (2014). *Building Better Water Rates for an Uncertain World: Balancing Revenue Management, Resource Efficiency, and Fiscal Sustainability*. Chicago, IL: Alliance for Water Efficiency.

Arabi, M., Millonig, S., Dezfooli, D., Wiersema, I., Mutter, J., Wamsta, K., et al. (2024). One *Water Cities: Development of Guidance Documents and Assessment Metrics*. Denver, Colorado: Water Research Foundation.

Arid LID Coalition (n.d.). Available online at: https://aridlidcoalition.org/ (Accessed November 5, 2025).

Baerenklau, K.enneth A., and Pérez-Urdiales, M. (2019). Can allocation-based water rates promote conservation and increase welfare? A California case study. *Water Econ. Policy* 5:1850014. doi: 10.1142/S2382624X18500145

Baerenklau, K.enneth A., Schwabe, K., and Dinar, A. (2014). *Do Increasing Block Rate Water Budgets Reduce Residential Water Demand? A Case Study in Southern California. Water Policy.*

Bobbio, L. (2019). Designing effective public participation. *Policy Soc.* 38, 41?57. doi: 10.1080/14494035.2018.1511193

Boyle, E., Galvin, M., Revez, A., Deane, A., ., Ó., et al. (2022). Flexibility & structure: community engagement on climate action & large infrastructure delivery. *Energy Policy* 167:113050. doi: 10.1016/j.enpol.2022.113050

California Water Boards (2023). *Water Supply Strategy Implementation- Planned Recycled Water*. Available online at: https://www.waterboards.ca.gov/water_issues/programs/recycled_water/docs/2024/planned-rw-projects.pdf (Accessed November 5, 2025).

Carlsson, B., Jacobsson, S., and Bergek, A. (2004). *Dynamics of Innovation Systems: Policy-Making in a Complex and Non-deterministic World*. London; New York, NY: Pinter Publishers.

City of Tucson (2021). *Storm to Shade Green Stormwater Infrastructure Program*. Available online at: https://climateaction.tucsonaz.gov/pages/gsi (Accessed November 5, 2025).

City of Tucson (2023). *One Water 2100 Plan*. Available online at: https://tucsononewater.com/wp-content/uploads/2023/10/Tucson-Water-One-Water-2100-Plan_Spreads_Web-Version.pdf (Accessed November 5, 2025).

CIUDAD Soil and Water Conservation District (n.d.). Available online at: https://www.ciudadswcd.org/ (Accessed November 5, 2025).

Colorado Water Conservation Board (2023). *Colorado Water Plan*. Available online at: https://cwcb.colorado.gov/colorado-water-plan (Accessed November 5, 2025).

Colorado Watershed Assembly (n.d.). Available online at: https://www.coloradowater.org/ (Accessed November 5, 2025).

Colorado WaterWise (n.d.). Available online at: https://coloradowaterwise.org/ (Accessed November 5, 2025).

Crosson, C., Achilli, A., Zuniga-Teran, A. A., Mack, E. A., Albrecht, T., Shrestha, P., et al. (2020). Net zero urban water from concept to applications: integrating natural, built, and social systems for responsive and adaptive solutions. *ACS ES&T Water* 1, 518–529. doi: 10.1021/acsestwater.0c00180

Crosson, C., Pincetl, S., Scruggs, C., Gupta, N., Bhushan, R., Sharvelle, S., et al. (2024). Advancing a net zero urban water future in the United States southwest: governance and policy challenges and future needs. *ACS ES&T Water*. 4, 1966–1977. doi: 10.1021/acsestwater.4c00031

Daigger, G. T., Sharvelle, S., Arabi, M., and Love, N. G. (2019). Progress and promise transitioning to the one water/resource recovery integrated urban water management systems. *J. Environm. Eng.* 145:04019061. doi: 10.1061/(ASCE)EE.1943-7870.0001552

Denver Water (n.d.). *Residential Rebates*. Available online at: https://www.denverwater.org/residential/rebates-and-conservation-tips/residential-rebates (Accessed January 14, 2025).

Denver Water (n.d1). *Residential Rebates*. Available online at: https://www.denverwater.org/residential/rebates-and-conservation-tips/residential-rebates (Accessed November 5, 2025).

Denver Water (n.d2). *ColoradoScaping*. Available online at: https://www.denverwater.org/residential/rebates-and-conservation-tips/remodel-your-yard (Accessed November 5, 2025).

Devine-Wright, P. (2011). Place attachment and public acceptance of renewable energy: a tidal energy case study. *J. Environ. Psychol.* 31, 336–343. doi: 10.1016/j.jenvp.2011.07.001

Dunbar/Spring Neighbourhood Foresters (n.d.). Available online at: https://dunbarspringneighborhoodforesters.org/ (Accessed November 5, 2025).

Environmental Justice Coalition for Water (1999). Available online at: https://ejcw.org/ (Accessed November 5, 2025).

Espeland, W. N. (1998). *The Struggle for Water: Politics, Rationality, and Identity in the American Southwest*. Chicago, IL: University of Chicago Press.

Fuenfschilling, L., and Truffer, B. (2014). The structuration of socio-technical regimes—conceptual foundations from institutional theory. *Res. Policy* 43, 772–791. doi: 10.1016/j.respol.2013.10.010

Garcia-Cuerva, L., Berglund, E. Z., and Binder, A. R. (2016). Public perceptions of water shortages, conservation behaviors, and support for water reuse in the U.S. *Resour. Conservat. Recycl.* 113, 106–115. doi: 10.1016/j.resconrec.2016.06.006

Greenway Foundation (1974). Available online at: https://thegreenwayfoundation.org/ (Accessed November 5, 2025).

Heal the Bay (n.d.). *Making Waves of Change*. Available online at: https://healthebay.org/ (Accessed November 5, 2025).

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., and Smits, R. (2007). Functions of innovation systems: a new approach for analysing technological change. *Technol. Forecast. Soc. Change* 74, 413–432. doi: 10.1016/j.techfore.2006.03.002

Hughes, S. (2012). Voluntary environmental programs in the public sector: evaluating an urban water conservation program in California. *Policy Stud. J.* 40, 650–673. doi: 10.1111/j.1541-0072.2012.00468.x

Hurlimann, A., and Dolnicar, S. (2018). "Public acceptance and perceptions of alternative water sources: a comparative study in nine locations," in *Water Reuse Policies for Potable* Use (London: Routledge), 151–74.

Ingram, H., and Schneider, A. L. (2006). "Policy analysis for democracy," in *The Oxford Handbook of Public Policy*, eds. M. Moran, M. Rein, and R. E. Goodin (Oxford: Oxford University Press), 169–189.

Kendal, D., Williams, K. J. H., and Williams, N. S. G. (2012). Plant traits link people's plant preferences to the composition of their gardens. *Landscape Urban Plan.* 105, 34–42. doi: 10.1016/j.landurbplan.2011.11.023

Kennedy, C. B., and Zube, E. H. (1991). Attitudes towards vegetation in a desert urban forest: creating a sense of place. *Arboricult. Urban Forestry* 17, 159–166. doi: 10.48044/jauf.1991.042

Kiparsky, M., Sedlak, D. L., Thompson, B. H., and Truffer, B. (2013). The innovation deficit in urban water: the need for an integrated perspective on institutions, organizations, and technology. *Environ. Eng. Sci.* 30, 395–408. doi: 10.1089/ees.2012.0427

Kollmuss, A., and Agyeman, J. (2002). Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environm. Educ. Res.* 8, 239–260. doi: 10.1080/13504620220145401

Lee, J., Nemati, M., Allaire, M., and Dinar, A. (2021). *Asymmetric Effects of Rate Structure Change on Residential Water Conservation in California*. Available online at: https://ageconsearch.umn.edu/record/312919/files/Abstracts_21_06_29_23_51_51_55__129_130_18_60_0.pdf (Accessed November 5, 2025).

Los Angeles WaterKeeper (n.d.). Available online at: https://www.lawaterkeeper.org/ (Accessed November 5, 2025).

MacDonald, G. M. (2010). Water, climate change, and sustainability in the southwest. *Proc. Nat. Acad. Sci.* 107, 21256–21262. doi: 10.1073/pnas.0909651107

Marlow, D.avid R., Moglia, M., Cook, S., and Beale, D. J. (2013). Towards sustainable urban water management: a critical reassessment. *Water Res.* 47, 7150–7161. doi: 10.1016/j.watres.2013.07.046

Middle Rio Grande Conservancy District (n.d.). Available online at: https://www.mrgcd.com/ (Accessed November 5, 2025).

Mini, C., Hogue, T. H., and Pincetl, S. (2014). Patterns and controlling factors of residential water use in Los Angeles, California. *Water Policy* 16 (6):1054–1069. doi: 10.2166/wp.2014.029

Moncur, J. E. T. (1987). Urban water pricing and drought management. *Water Resour. Res.* 23, 393–398. doi: 10.1029/WR023i003p00393

Mono Lake Committee (1978). *What We Do*. Available online at: https://www.monolake.org/ (Accessed November 5, 2025).

Nassauer, J. I., Wang, Z., and Dayrell, E. (2009). What will the neighbors think? Cultural norms and ecological design. *Landsc. Urban Plan.* 92, 282–92. doi: 10.1016/j.landurbplan.2009.05.010

National Research Council (NRC). (2012). *Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater*. Washington, DC: The National Academies Press.

New Mexico Bureau of Geology and Mineral Resources (n.d.). Available online at: https://geoinfo.nmt.edu/ (Accessed November 5, 2025).

New Mexico Water Advocates (n.d.). Available online at: https://nmwateradvocates.org/ (Accessed November 5, 2025).

New Mexico Water Dialogue (n.d.). Available online at: https://nmwaterdialogue.org/ (Accessed November 5, 2025).

Nieswiadomy, M. L. (1992). Estimating urban residential water demand: effects of price structure, conservation, and education. *Water Resour. Res.* 28, 609–615. doi: 10.1029/91WR02852

Olmstead, S. M., and Stavins, R. N. (2009). Comparing price and nonprice approaches to urban water conservation. *Water Resour. Res.* 45:4. doi: 10.1029/2008WR007227

Ormerod, K. J., and Scott, C. A. (2013). Drinking wastewater: public trust in potable reuse. *Sci.Technol. Human Values* 38, 351–373. doi: 10.1177/0162243912444736

Pacoima Beautiful (1996). Available online at: https://www.pacoimabeautiful.org/ (Accessed November 5, 2025).

Pierce, G., and Gonzalez, S. (2017). Mistrust at the tap? Factors contributing to public drinking water (mis) perception across US households. *Water Policy* 19, 1–12. doi: 10.2166/wp.2016.143

Pima County Regional Flood Control District (2023). *Dashboard, StormwaterNet Increase (Delta) from Developed Areas*. Available online at: https://www.arcgis.com/home/item.html?id=e431d23fbbf040a58627c933c8e5a220 (Accessed November 5, 2025).

Pincetl, S., Gillespie, T. W., Pataki, D. E., Porse, E., Jia, S., Kidera, E., et al. (2019). Evaluating the effects of turf-replacement programs in Los Angeles. *Landsc. Urban Plan.* 185, 210–221. doi: 10.1016/j.landurbplan.2019.01.011

Pint, E. M. (1999). Household responses to increased water rates during the California drought. *Land Econ.* (1999) 1999, 246–266. doi: 10.2307/3147009

Reames, T. G., and Wright, N. S. (2021). The three E's revisited: How do community-based organizations define sustainable communities and their role in pursuit of? *Sustainability* 13:8825. doi: 10.3390/su13168825

Richter, B.rian D., Benoit, K., Dugan, J., Getacho, G., LaRoe, N., Moro, B., et al. (2020). Decoupling urban water use and growth in response to water scarcity. *Water* 12:2868. doi: 10.3390/w12102868

Roaring Fork Conservancy (n.d.). Available online at: https://roaringfork.org/ (Accessed November 5, 2025).

Roberts, M. R., Reid, G., Schroeder, M., and Norris, S. P. (2013). Causal or spurious? The relationship of knowledge and attitudes to trust in science and technology. *Public Understand. Sci.* 22, 624–641. doi: 10.1177/0963662511420511

Safe Clean Water Program (2018). Available online at: https://safecleanwaterla.org/

Santa Cruz Watershed Collaborative (n.d.). Available online at: https://sites.google.com/site/santacruzcollaborative/scwc-home (Accessed November 5, 2025).

Scott, W. R. (2013). *Institutions and organizations: Ideas, Interests, and Identities*. New York City: Sage Publications.

Sedlak, D. (2014). Water 4.0: *The Past, Present, and Future of the World? S Most Vital Resource*. New Haven, CT: Yale University Press.

Sonora Environmental Research Institute (n.d.). *Rainwater Harvesting Program*. Available online at: https://seriaz.org/water-conservation/rainwater-harvesting-program/ (Accessed November 5, 2025).

Southern Arizona Water Users Association (n.d.). Available online at: https://sawua.org/ (Accessed November 5, 2025).

Stenekes, N., Colebatch, H., and Ashbolt, N. (2006). Risk and governance in water recycling: public acceptance revisited. *Sci. Technol. Human Values* 31, 107–134. doi: 10.1177/0162243905283636

Sterling, E. J., Betley, E., Sigouin, A., Gomez, A., Toomey, A., Cullman, G., et al. (2017). Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biol. Conserv.* 209, 159–171. doi: 10.1016/j.biocon.2017.02.008

Teodoro, M. P. (2018). Measuring household affordability for water and sewer utilities. *J.-Am. Water Works Assoc.* 110, 13–24. doi: 10.5942/jawwa.2018.110.0002

Tucson Clean and Beautiful (n.d.). Available online at: https://tucsoncleanandbeautiful.org/ (Accessed November 5, 2025).

Tucson Water (2023). *Water Conservation Program 2022. Annual Report*. Available online at: https://www.tucsonaz.gov/files/sharedassets/public/v/1/water/documents/conservation/2022-conservation-report.pdf (Accessed November 5, 2025).

United States Environmental Protection Agency (1997). *Combined Sewer Overflows–Guidance for Financial Capability Assessment and Schedule Development*.

United States Environmental Protection Agency. (n.d.). *The Environmental Justice Collaboration Program*. Available online at: https://www.epa.gov/environmentaljustice/environmentaljustice-collaborative-problem-solving-cooperative-agreement-5 (Accessed January 14, 2025).

United States Water Alliance (2012). *Weatherizing Water*. Washington, DC: U.S. Water Alliance, Federal Way.

United States Water Alliance (2016). *One Water Roadmap: The Sustainable Management of Life's Most Essential Resource*. Washington, DC: United States Water Alliance.

University of Arizona (2019). *Water and Energy Sustainable Technology Center, Citizen Water Academy*. Available online at: https://west.arizona.edu/industry-community/citizen-water-academy (Accessed November 5, 2025).

University of Arizona (n.d.). *Arizona Project WET*. Available online at: https://projectwet.arizona.edu/ (Accessed November 5, 2025).

University of New Mexico (n.d.). *Center for Water and The Environment. Outreach and Education. Outreach and Education*. Albuquerque: Center for Water and the Environment | The University of New Mexico.

Upper Los Angeles River Watershed Management Group (2015). Available online at: https://www.waterboards.ca.gov/rwqcb4/water_issues/programs/stormwater/municipal/watershed_management/los_angeles/upper_losangeles/index.html (Accessed November 5, 2025).

Varady, R. G., Zuniga-Teran, A. A., Garfin, G. M., Martin, F., and Vicuña, S. (2016b). Adaptive management and water security in a global context: Definitions, concepts, and examples. *Curr. Opin. Environm. Sustainab.* 21, 70–77. doi: 10.1016/j.cosust.2016.11.001

Varady, R. G., Zuniga-Teran, A. A., Gerlak, A. K., and Megdal, S. (2016a). Modes and approaches of groundwater governance: a survey of lessons learned from selected cases across the globe. *Water* 8:417. doi: 10.3390/w8100417

Villaraigosa, A. (2008). "Securing LA's water supply," in *Department of Water and Power*. Available online at: https://planning.lacity.gov/eir/8150Sunset/References/4.K.1.%20Water%20Supply/WS.13_Securing%20LAs%20Water%20Supply_2008.pdf (Accessed November 5, 2025).

Viswanath, K., McCloud, R. F., Lee, E., and Bekalu, M. (2022). Measuring water matters: data, absenteeism, science communication and the perpetuation of inequities. *Ann. Am. Acad.* 700, 208–9. doi: 10.1177/00027162221093268

Water Education Colorado (n.d.). Available online at: https://www.watereducationcolorado.org/ (Accessed November 5, 2025).

Water for Colorado Coalition (n.d.). Available online at: https://waterforcolorado.org/ (Accessed November 5, 2025).

Watershed Management Group (n.d.). Available online at: https://watershedmg.org/ (Accessed November 5, 2025).

Western Resource Advocates (n.d.). Available online at: https://westernresourceadvocates.org/ (Accessed November 5, 2025).

Wichman, C. J. (2014). Perceived price in residential water demand: evidence from a natural experiment. *J. Econ. Behav. Organiza.* 107, 308–323. doi: 10.1016/j.jebo.2014.02.017

Wichman, C. J., Taylor, L. O., and von Haefen, R. H. (2016). Conservation policies: who responds to price and who responds to prescription?" *J. Environm. Econ. Managem.* 79, 114–134. doi: 10.1016/j.jeem.2016.07.001

Woodcock, C., Giardina, R., and Cristiano, T. (2017). *M1: Principles of Water Rates, Fees, and Charges* (Seventh edition). Denver: American Water Works Association.

Zuniga-Teran, A. A., Brown, A. R., Gerlak, A. K. (in review). Advancing justice: The evolution of public engagement in environmental and natural resource governance in the US. *Soc. Nat. Resourc.* 38, 494–515. doi: 10.1080/08941920.2025.2463064

Zuniga-Teran, A. A., Gerlak, A. K., Elder, A., and Tam, A. (2021). The unjust distribution of urban green infrastructure is just the tip of the iceberg: a systematic review of place-based studies. *Environm. Sci. Policy* 126, 234–245. doi: 10.1016/j.envsci.2021.10.001