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Authors
Crosson, Courtney
Pincetl, Stephanie
Scruggs, Caroline
et al.

Publication Date
2024

DOI
10.1021/acsestwater.4c00031

ACS ES&T Water

pubs.acs.org/estwater

Perspective

Advancing a Net Zero Urban Water Future in the United States Southwest: Governance and Policy Challenges and Future Needs

Courtney Crosson,* Stephanie Pincetl, Caroline Scruggs, Neha Gupta, Rashi Bhushan, Sybil Sharvelle, Erik Porse, Andrea Achilli, Adriana Zuniga-Teran, Gregory Pierce, Dominic L. Boccelli, Charles P. Gerba, Melinda Morgan, Tzahi Y. Cath, Bruce Thomson, Steve Baule, Steve Glass, Mark Gold, James MacAdam, Luke Cole, Mead Mier, Catlow Shipek, and Thomas Meixner

Cite This: https://doi.org/10.1021/acsestwater.4c00031

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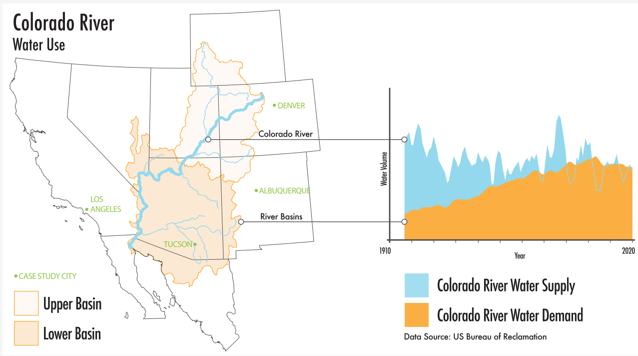
ABSTRACT: The Colorado River supplies >40 million people in the United States Southwest with their daily water supply and is unable to meet the current demands. New approaches are needed to enhance sustainability and resilience. A net zero urban water (NZUW) approach meets the needs of a given community with a locally available and sustainable water supply, without detriment to interconnected systems and the long-term water supply. Transitioning to a NZUW future will require considerable modifications to governance and policy across the Southwest and its cities specifically. We identify five areas of governance and policy challenges: diversified water sources and sinks; planning, design, and operation; monitoring and enforcement; coordination; and addressing equity and justice. Four case study cities are investigated: Albuquerque, Denver, Los Angeles, and Tucson. Across these cities, the policy priorities include supporting potable water reuse, coordinating policies across jurisdictions for alternative water sources, addressing equity and justice, developing and incentivizing water conservation plans, and making aquifer storage and recovery projects easier and more economical to pursue. We conclude that a NZUW transition in the Southwest faces considerable governance and policy challenges, but moving cities toward this goal is crucial.



1. INTRODUCTION

1.1. Challenge of Water Self-Sufficiency in Southwestern U.S. Cities. More than 40 million people in the U.S. Southwest depend on the Colorado River for their daily water supply. The Colorado River serves residents of seven U.S. states, Native nations, and Mexico through a series of massive canals, aqueducts, dams, and energy-intensive water lifts over mountains, all managed by a complex set of interstate compacts, laws, and policies. The Colorado River is facing its worst megadrought in a millennium, highlighting inadequacies in the century-old Colorado River Compact that has regulated this system.[1] As a result, cities throughout the Southwest are reconsidering their dependence on imported water and thus also the reliability and management of their existing 20th century water systems.[2] Under the pressure of climate change, population growth, and aging infrastructure and in light of the techno-economic and social advances of the past century, one possible strategy presents itself: can community water management be reinvented to thrive using only local water sources? Furthermore, within the large, interconnected water systems of the Southwest, what is the appropriate geographic scale that can be considered "local"?

These are not easy questions to answer. A net zero urban water (NZUW) approach meets the needs of a given community through a locally available and sustainable water supply, without detriment to interconnected systems or the long-term water supply.[3] This paper investigates governance and policy challenges to reaching a NZUW balance in cities in the Southwest.

The paper first describes the NZUW approach and provides a baseline definition for water governance and policy. Next, the methods employed for data collection are discussed along with the description of the Colorado River system as the study area.

Received: January 12, 2024
Revised: March 30, 2024
Accepted: April 1, 2024

Table 1. Summary of the Characteristics of the Case Study Cities[a]

	Albuquerque[b]	Denver	Los Angeles	Tucson
population	0.56 million	0.72 million	3.9 million	0.54 million
area	188.95 square miles	154.7 square miles	502 square miles	241.33 square miles
main local source	groundwater and surface water	surface water	groundwater and surface water	groundwater
imported water source(s)	Colorado River via the San Juan-Chama Project	Colorado River (infrastructure used to divert river to Denver)	Los Angeles Aqueduct, California State Water Project, and Colorado River water (via Metropolitan Water District)	Central Arizona Project (Colorado River) via the Central Arizona Project canal and lift stations
annual rainfall[c]	8.84 in.	15.85 in.	14.3 in.	10.76 in.
total annual water use (city boundary)	27 billion gal (Water Authority)	30 billion gal* (Denver Water)	160 billion gal (LADWP)	28 billion gal (Tucson Water)
total annual water use (utility boundary)	29 billion gal (Water Authority)	60 billion gal (Denver Water)	160 billion gal (LADWP)	28 billion gal (Tucson Water)
percent imported water (volume)	80% (31 billion gal)	46% (13.8 billion gal)	89% (142 billion gal)	84% (23.8 billion gal)
percent dependence on Colorado River water	80%	46%	6%	84%
per capita water use (residential)	80 GPCD (Water Authority)	96 GPCD (Denver Water)	112 GPCD (LADWP)	76 GPCD (Tucson Water)
city location within the Colorado River Basin	adjacent	inline	terminus	terminus with water rights junior to California

[a]Water use numbers were calculated by the different utilities and not as a part of this study; therefore, there may be differences in how the numbers were calculated. Information was obtained for Albuquerque from the Water Authority based on the 2023 Annual Operating Plan for the period from April 1, 2023, through March 31, 2024; for Denver from https://www.denverwater.org/your-water/water-supply-and-planning/water-use; for Los Angeles from https://ladwp-jtti.s3.us-west-2.amazonaws.com/wp-content/uploads/sites/3/2021/10/04152431/2020-2021_Facts_and_Figures_Digital_final.pdf; and for Tucson from https://www.ewra.net/wuj/pdf/WUJ_2021_28_01.pdf. [b]Albuquerque's dependence on Colorado River water changes from year to year and is dependent on conditions in the Rio Grande River; the numbers in this table represent 2023 conditions. [c]The numbers represent the average annual precipitation derived from the 30-year Climate Normal (1991−2020), sourced from National Oceanic and Atmospheric Administration (NOAA).

The Results section outlines the five main areas of governance and policy challenges to a NZUW future in the Southwest. This is followed by a discussion that delves into these challenges using case studies of four cities (Albuquerque, Denver, Los Angeles, and Tucson) of varying sizes, water usage portfolios, and locations within the Colorado River Basin to understand the implications of these challenges and how to address them. The review concludes with recommendations for future policies to support a NZUW transition in the four case study cities and across the urban Southwest.

1.2. NZUW Concept. NZUW is an integrative approach that uses progressive targets and a quantitative assessment framework to adapt to challenges created by multiple drivers of change in the urban water system. Upon implementation of a quantitative framework, a suite of alternative future strategies can be evaluated to assess the trade-offs involved in mitigating the human impact on natural water systems; these strategies can be at building, district, and city scales and over short- to long-term horizons. At the same time, the framework includes a sociocultural shift in attitudes about water and its scarcity, as substantive changes will require public understanding and buy-in. Thus, a diverse urban water supply portfolio is a precursor to the NZUW transition and must include a fundamental understanding by and support from the public. Additionally, interconnected environmental systems and long-term water supply should not be harmed in the NZUW transition.[3]

1.3. Defining Governance and Policy. Water governance is defined as "the range of political, organizational, and administrative processes through which community interests are articulated, their input is incorporated, decisions are made and implemented, and decision-makers are held accountable".[4] Governance refers to the framework of customs, regulations, laws, and the engagement processes between the public and private sectors and civil society,[5] or the collaborative process for making laws, regulations, and policies. Governance includes both formal policy (laws, statutes, and regulations) and "informal policy" (e.g., time-bound programs) but also incorporates stakeholder processes (organizing to influence policy and programs) and citizen action (social movements). Policies are the "mechanisms that support different levels of water management".[6] Ultimately, moving toward a net zero balance between urban water supply and demand would require an understanding and reforming of governance and policy across the Colorado River Basin and specifically within cities in the Southwest.

2. METHODS

2.1. Data Collection. The study focused on identifying key governance and policy challenges for achieving a NZUW future in the Southwest. Findings were drawn from a three-day workshop focused on NZUW governance and policy that included water managers, nongovernmental organizations, and academics from across the Southwest. This workshop is part of a four-year National Science Foundation Research Coordination Network grant under the Dynamic and Integrated Socio-Environmental Systems Program that focuses on identifying the cross-cutting challenges to a NZUW future in the Southwest. Prior to the workshop, preworkshop interviews and surveys were conducted with utilities and academics in the four case study cities. This initial data collection aimed to understand the specific challenges each city faced in working toward a NZUW future. Subsequently, the three-day in-person workshop was held at the University of Arizona in Tucson. Following the workshop, postworkshop virtual meetings and collaborations with attendees were conducted to gather additional information to codify the challenges and how they relate to each of the four cities. Finally, future policy needs were prioritized for each city and across the urban Southwest to shift toward a NZUW future.

2.2. Study Area: Colorado River System, Water Allocation, and Urban Areas. The last 23 years of drought have demonstrated the vulnerability of the Colorado River and the 40 million people in the basin to a rapidly changing climate. Increasing temperatures have dramatically decreased flows in the Colorado River Basin over the past few decades, and the climate crisis has greatly increased the probability of major drought events.[7] Currently, water allocations to the seven basin states exceed annual river flows by an average of 2−4 million acres per year (MAFY). The longer-term future of the Colorado River Basin management will be determined through the post-2026 Colorado River Operations Planning process that was recently initiated. The impacts of this process on water allocations to states (and therefore cities) and senior water rights holders could be enormous. The post-2026 agreements should finally provide clear water rights to the dozens of tribes within the basin, an allocation estimated to be as high as 1.5 MAFY (≲30%), which will make balancing the remaining Colorado River water even more difficult. It is a critical moment in the history of urban water management in the Southwest to consider policies and regulations that can be coordinated to move toward a more sustainable water future. The four case study cities represent a cross section of the urban water future.

Albuquerque, Denver, Los Angeles, and Tucson were selected as case study cities from the broader set of urban areas across the Colorado River system (Table 1). These four cities provide a spectrum of population sizes, states, complexities of urban water systems, and positions within the Colorado River system. The case study cities also sit within larger intrastate and interstate water governance and policy dynamics. In addition to the Colorado River Compact, each state is governed by additional agreements. For example, New Mexico is party to eight interstate compacts, including the Colorado River Compact and the Rio Grande Compact.[8] Each of these compacts identifies the distribution of water resources among the signatory states.[8,9] An overarching, unique, and complex system of laws and policies governs water management for each state and city.

3. RESULTS: GOVERNANCE AND POLICY CHALLENGES FOR A FUTURE NZUW BALANCE ACROSS THE COLORADO RIVER BASIN

There are myriad challenges to achieving NZUW for cities in the Southwest. Here five areas of challenges related to policy and governance are discussed: (1) accounting for diversified water sources and sinks; (2) planning, design, and operation; (3) monitoring and enforcement; (4) coordinating between multiple agencies and sectors; and (5) addressing equity and justice in the NZUW transition.

3.1. Incorporating and Accounting for Diversified Water Sources and Sinks. *3.1.1. Introducing and Regulating New Water Sources and Treatment.* Multiple urban water sources can be important contributors to NZUW approaches, including stormwater, rainwater, graywater, and recycled treated wastewater. Stormwater serves as a valuable, local source of water, and studies have shown potential to meet substantial water demand in arid regions, specifically in Denver, Los Angeles, and Tucson.[10−13] The practices of stormwater and rainwater harvesting are attracting more attention and offer hydrologic benefits while also expanding local water supplies.[14,15] However, governance and policy challenges must be addressed[16,17] that can be characterized as (1) regulatory (e.g., timing of release following collection, legally appropriate uses, and water rights issues accounting for groundwater and surface water return flow), (2) technological, (3) siting complications, (4) development of integrated water management benefits (e.g., support of urban agriculture efforts), (5) inherent variability in availability, (6) energy intensity,[18] and (7) water quality concerns (e.g., *Escherichia coli*, pathogens, or heavy metals, required treatment levels).

Wastewater reclamation and reuse also provide opportunities to meet demands, particularly in arid regions, such as the Southwest. These practices can provide benefits to urban regions via landscape and agricultural irrigation, industrial and environmental uses, aquifer recharge, nonpotable urban uses, and indirect potable reuse (IPR) or direct potable reuse (DPR).[19,20] While nonpotable use of treated wastewater has become common, it still has policy challenges.[21] In addition, widespread adoption of potable water reuse, particularly DPR, faces several governance and policy challenges, including (1) providing reliable treatment of reclaimed water to meet stringent water quality requirements for potable water reuse, (2) gaining public acceptance, (3) evolving state regulations and a growing list of emerging contaminants, and (4) project costs.[22] Colorado is the first U.S. state to have regulations for DPR, and California has recently followed. Other states, such as Arizona and New Mexico, are in the process of developing regulations for DPR.[23,24] To encourage and facilitate adoption of DPR and other forms of water reuse, the EPA's Water Reuse Action Plan aims to align federal, state, local, and tribal policies and programs.[20]

Graywater technologies at the building scale are not consistently allowed in states across the Colorado River Basin, as some states require that graywater be treated and returned to the river for delivery to downstream users. Use of graywater is therefore complicated as its use may violate the return requirements in interstate regulations.[21,25] Graywater reuse at the individual household scale presents public health concerns, is expensive to implement when replumbing is required,[26] and can result in decreased sewer flow velocities.[27] The "best" scale of reuse depends on the context of myriad factors.[28,29]

3.1.2. Role of Green Infrastructure in NZUW. Green infrastructure (GI) is defined as "a network of natural and seminatural or engineered systems designed and managed to deliver a wide range of ecosystem services" that includes support of water needs for vegetation in arid regions.[30−32] Implementation of GI has the potential to provide water supply benefits such as groundwater recharge in specific settings where site conditions such as groundwater depths and soil conditions are favorable.[33,34] However, GI implementation is not necessarily essential to achieving a NZUW balance in the Southwest, and in some cases, the water demand to establish and maintain vegetation within GI could potentially be perceived as being in conflict with NZUW.[35,36] However, if a city is to achieve a NZUW balance without detriment to interconnected natural systems while also meeting stormwater runoff regulations and maintaining livable cities, the nGI is an essential component of a water management plan. Despite strong interest in GI, many regulatory and policy challenges were identified by workshop participants specific to the Southwest region that serve as

https://doi.org/10.1021/acsestwater.4c00031
ACS EST Water XXXX, XXX, XXX−XXX

barriers to implementation, including those noted below related to water rights, timing of release, and acknowledgment of groundwater−surface water connectivity. Additionally, stormwater management in many cities lacks dedicated revenue and/or dedicated utilities to fund, plan, implement, and maintain GI projects.[37,38]

3.1.3. Complex and Fragmented Water Rights. In 1922, the Colorado River Compact (the "Law of the River") allocated water rights that exceed the annual availability of recent decades. Many cities rely on these diversions to fulfill a significant portion of the supply. The water supply for cities relying on water from the Colorado River is dictated by a set of complex and fragmented water rights, which present a host of challenges to NZUW accounting and the transition to a NZUW goal in the Southwest.

River compacts across the Southwest have historically attempted to ensure that the water from the Colorado River is not captured by upstream users to the detriment of downstream water rights holders. Furthermore, approaches to policy development and strategy implementation are strongly fragmented across cities in the Colorado River Basin. Factors such as water rights, return flow credits, and compact obligations for discharges should be considered holistically across the Colorado River Basin to design a more systematic and quantifiable approach that allows cities to meet their municipal and basin-wide water demands. For example, entities may prioritize retaining the relatively small portion of water rights they currently have by continuing to use their full water rights allocation, hindering advancement toward conservation and NZUW because they do not want to lose rights to the Colorado River. Without high-level reform of these interstate, intrastate, and basin management rules, it is unlikely that NZUW can be fully implemented.

3.1.4. Characterizing Groundwater and Surface Water Interactions. The lack of clear accounting for surface and groundwater interactions along the Colorado River system complicates the development of policies for holistic water management, which recognize connections between water sources. This is particularly important for achieving NZUW because accounting for water is core to incentivizing implementation. An important example that was identified by workshop participants is the ability to account for stormwater returned to groundwater via GI for deep infiltration (where occurring) to obtain credits for returned water. This would require a context-sensitive scientific understanding and an accounting for only the water in GI that does infiltrate to depths sufficient to replenish local groundwater sources (not water that is evapotranspired or remains as shallow soil moisture) and could enable more efficient and flexible use of different water sources via trading mechanisms to achieve NZUW, particularly in areas where accounting for return flows or infiltration is necessary to get credit (e.g., Albuquerque).

3.2. Planning, Design, and Operations. *3.2.1. Understanding the Current and Future Impacts of Climate Change.* Reliable models can support policymakers and water managers in decision making. A better understanding of the impacts of climate change, including more regionally specific models, can improve current and future policies and governance of urban water resources. This is particularly relevant in cities of the Southwest with predicted significant changes in temperature and precipitation and both spatial and temporal climatic variability.[39,40]

3.2.2. Iterative Evaluation of Water Demand Forecasting and Local Water Supply Potential. Reaching a NZUW goal requires the planning of future operations and capital improvements. Thus, NZUW requires modeling that simultaneously evaluates both future water demand and the local water supply potential. On the demand side, continued investments in water use efficiency that reduce consumption and overall demand are critical. On the local supply side, the potential for stormwater capture and use, groundwater recharge, water reuse, graywater management, and local diversions should be evaluated to understand the fiscal and managerial implications of these potential investments.

3.2.3. Multibenefit Evaluation and Investment. Advocating for governmental investment in new urban water sources can be challenging when only traditional metrics are considered.[41] For example, the inability to measure and value multiple benefits associated with alternative water sources, such as GI practices, has traditionally led to less investment in these approaches in the Southwest.[42,43] Additionally, accounting procedures within water agencies need to be updated to support continued investments beyond the status quo; this means including future upgrade and maintenance costs of existing infrastructure so that investments in new alternatives do not appear to be less attractive.

3.3. Monitoring and Enforcement. Beyond the political will to enforce policy, there is a monetary cost associated with monitoring efforts, including personnel time to support the integration of new water sources. The process of monitoring indicators to assess, much less ensure, progress toward a desired target in resource management is very challenging to sustain over the long term without clear lines of regulatory responsibility and long-term funding for monitoring and enforcement of policies. The three main challenges for the long-term monitoring of indicators in a Southwestern watershed with multiple jurisdictions include data compatibility and integration, data availability and consistency, and challenges with scale.[44] New monitoring technologies, such as automated meter infrastructure (AMI), real time monitoring of water quality, and remote sensing for monitoring urban land cover, would be needed to optimize efficiencies to achieve NZUW in the Southwest.[45]

3.4. Coordinating among Multiple Agencies and Sectors. The regulatory landscape that provides guidance on the implementation and operation of alternative water sources is slowly changing though national, state, and local efforts[46] yet remains largely uncoordinated across the country and in the Southwest in particular.[45] Specifically, coordination among local, state, and national agencies can assist in technology rollout and implementation through efficient approvals and regulations. Also needed is better integration of water, wastewater, and stormwater management so that water resources can be considered holistically and used efficiently.

3.5. Addressing Equity and Justice in the NZUW Transition. *3.5.1. Ensuring Consistent Quality of Water across the Urban Water System.* From an equity perspective, one of the most important aspects of NZUW in the Southwest is to ensure that all customers receive the same quality and affordability of water at the tap.[47] Water quality is a contentious issue as some contaminants can be difficult and/or costly to remove, regardless of source. In some water utility service areas, recycled water, which is a critical contributor to NZUW, is processed and available in only limited parts of a service area due to limited infrastructure, and its delivery through the

https://doi.org/10.1021/acsestwater.4c00031
ACS EST Water XXXX, XXX, XXX−XXX

Table 2. Five Areas of Governance and Policy Challenges toward a NZUW Future across the Four Case Study Cities[a]

Policy Needs Toward a NZUW Future	Priority Need for the City			
	ABQ	DEN	LA	TUS
a. Accounting for Diversified Water Sources and Sinks				
1. Expanded system of water accounting for new sources and diversified and sustainable uses for urban water	2	1	1	1
2. Metering of private wells to understand its actual water balance	4	1	1	1
3. Make aquifer storage and recovery projects easier and economical to pursue	5	3	5	2
4. Allow use of graywater at household scale	1	1	2	1
5. Legal changes to limitations on holding stormwater	1	2	2	4
6. Increase funding to build more alternative water projects (rainwater capture projects, reclaimed water and brackish water systems, SCU, and GI projects)	4	4	4	4
7. Design systematic approaches to quantify water recharged through GI measures	1	2	1	1
8. Create clear policies that incorporate surface-groundwater interactions	2	1	3	4
9. Develop and incentivize water conservation plans to reduce indoor and outdoor water consumption with climate-appropriate landscapes, including shading from built structures and a vibrant urban tree canopy to promote cooling	5	5	5	5
b. Planning, Design, and Operations				
10. Improve planning, designing and implementation of GI with considerations for climate variability, water quality, water accounting, and water rights	1	3	2	2
11. Secure improved forecasts of urban water supply and demands for accurate urban water planning	4	4	3	2
12. Support DPR and IPR (through development of advanced treatment technologies, public engagement, and establishing state regulations)	5	5	4	5
13. Develop funding sources to adequately pay for new alternative water supplies	5	4	5	5
14. Ensure full-cost accounting of water supply sources to ensure relatable comparisons of the annualized unit costs of supply for existing and new sources given likely future contributors of inflation, regulations, and energy prices	2	2	1	2
c. Monitoring and Enforcement				
15. Increase capacity to measure and manage how water is used	3	4	4	4
16. Enable comprehensive metering of urban water inputs and outputs for alternative water sources	2	3	3	2
17. Develop efficient monitoring and accounting practices for GI and groundwater-surface water interactions across the Basin	2	1	1	3
18. Invest in hiring and training of staff to allocate and distribute water to users in accordance with the law	3	2	2	3
19. Train staff and stakeholders in alternative water projects to safeguard public health	3	3	3	3
d. Coordination between Multiple Agencies and Sectors				
20. Increase coordination between different water management sectors to enable a quantitative approach to urban water management	4	5	5	2
21. Increase coordination across cities in the river basin for a more coordinated, robust and regulated GI implementation	1	2	3	3
22. Create coordination among national, state and local agencies on implementation and operation of alternative local water sources	5	5	5	5
23. Develop a clear vision of NZUW goals, including timeline, coordinated across the Colorado River Basin	1	3	1	3
e. Addressing Equity and Justice in the NZUW Transition				
24. Ensure representation, participation and accountability of all stakeholders for urban water planning	5	5	5	5
25. Ensure all users have access to same quality and affordability of basic water need	5	4	4	5
26. Build equity while planning access and distribution of GI and other centralized and decentralized water project benefits	3	3	3	4
27. Establish more progressive water pricing	2	2	2	3
28. Increase funding capacity to help lower-income communities have equitable access to water	4	4	4	4

[a]Members from water utilities for the four case study cities were asked to select five policy priorities to transition to a NZUW future: 1, very low or no priority (white); 2, low or minor priority (yellow); 3, moderate priority (orange); 4, high priority (red); and 5, very high priority (dark red).

distribution system may coincide with the geography of underserved communities.[48] While the recycled water may be treated to the same standards as those in the rest of the service area, perceptions may be that people in such communities are receiving inferior water. In less wealthy communities, affordability becomes an important barrier to equity, because the burden of water purification infrastructure makes water utility bills more expensive, and water could be underutilized to meet basic health and welfare needs.[49] Without proactive planning, the NZUW transition may exacerbate existing water inequities in communities in the Southwest with fewer resources.

3.5.2. Access to Trees and Heat-Mitigating Vegetation. Another issue with moving toward NZUW in the water scarce Southwest involves outdoor irrigation and landscaping, which often accounts for half of municipal urban water use.[50−52] The trees and vegetation growing in many areas of the Southwest are largely non-native species and have higher water requirements, especially when not adapted to hot dry summers and needing irrigation.[53] Because outdoor water use is a consumptive water use, for urban areas to maintain outdoor vegetation under NZUW, landscaping in the urban Southwest will need to survive with little to no supplemental irrigation, implying a major transformation in some cities toward native and/or drought-tolerant plants and landscapes and streets designed to optimize passive stormwater harvesting. Still, vegetation may use water that could possibly serve as indoor water demand. Tree canopy is a key component of heat mitigation efforts,[54,55] requiring

https://doi.org/10.1021/acsestwater.4c00031
ACS EST Water XXXX, XXX, XXX−XXX

adequate water to conserve and maintain trees in urban areas in the Southwest.

3.5.3. Investment in New Systems and Equity. There are both centralized and decentralized solutions to move toward NZUW. Net zero is an approach geared toward societal benefit, but there may be an unintended unequal distribution of infrastructure impacts (particularly in the case of decentralized systems) and/or costs, especially in the timing of the transition (for instance, see ref 56). Thus, it is, and will be, important to consider the impacts across scales (city, neighborhood, and resident) as the urban water systems in the Southwest are updated and to ensure that already underserved communities are prioritized. This may require the use of equity-centered tools not generally applied to water systems, such as the examination of socio-demographic characteristics of neighborhoods, the distribution of existing environmental harms, water and sewer rates, and the creation of special programs for communities to ensure affordability that go beyond traditional first-come, first-serve rebate approaches.[57,58] Attention should be paid to public outreach about the new systems and the reasons they are being built to encourage public support.

4. DISCUSSION: CITY SPECIFIC CASE STUDY APPLICATIONS

To understand the concrete implications of these five areas of challenges in governance and policy for the NZUW transition in the Southwest, four case study cities were investigated: Albuquerque, Denver, Los Angeles, and Tucson. Each of these four cities is connected to the Colorado River system yet represents a different population size, water system complexity, position within the Colorado River system, and mix of local and imported water sources included in its supply portfolio. Table 1 provides the general characteristics of these cities and outlines their current water sources to understand the implications of a NZUW goal. Table 2 summarizes how the challenges from the proceeding section cut across these four case study cities. Shared future policy priorities for moving toward a NZUW future include supporting potable water reuse through development of advanced treatment technologies, public engagement efforts, and establishing regulations for DPR and IPR; coordination among national, state, and local agencies for the implementation and operation of alternative local water sources; addressing equity and justice of all stakeholders in urban water planning; developing and incentivizing water conservation plans to reduce indoor and outdoor water consumption; and making aquifer storage and recovery projects easier and more economical to pursue.

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

4.1.1. Policy and Governance Challenges to Net Zero Urban Water. The eight compact agreements to which New Mexico is a party outline specific water quantity allocations for compact signatories and often require minimum deliveries to downstream users. Policies and permits with return flow requirements are intended to "keep the river whole" and minimize impacts on the Rio Grande system. Laws to protect threatened and endangered species in and around the Rio Grande are also a major driver for river management dynamics.[8]

Albuquerque's current approach to additional water sources includes the following:

- Wastewater recycling. The New Mexico Environment Department (NMED) currently approves potable water reuse projects on a case-by-case basis, although it aims to enact regulations in the near term.[59] The Water Authority included potable water reuse as an element of its 100-year water plan but likely will not implement it for several decades. High implementation and operations costs and a low density of development dictate that future potable water reuse systems be centralized. In cases in which the Water Authority owns the water rights and has an interested user, it has implemented nonpotable water reuse systems for golf course and park irrigation. However, when considered from a basin-wide perspective, these systems are not considered water conservation in situations in which return flow credits are required to meet streamflow requirements or downstream delivery obligations.[60]
- Aquifer storage and recovery (ASR). Water can be stored in the aquifer after completing permitting processes with the NMED for water quality and the New Mexico Office of the State Engineer (OSE) for water quantity. The Water Authority has two full-scale ASR projects that store San Juan-Chama surface water. Additional ASR projects are key elements in the 100-year water management strategy.
- Graywater harvesting. The NMED does not have regulations for nonpotable water reuse but has published a guidance document that is used when approving such projects.[61] Graywater harvesting is not currently a component of the Water Authority's water management strategy.
- Rainwater harvesting. Residential and commercial roof surfaces in Albuquerque can be used to harvest rainwater for on-site landscape irrigation or domestic use in a manner that does "... not reduce the amount of runoff that would have occurred from the site in its natural, pre-development state".[62] While harvested rainwater can help reduce dependency on potable water supplies, in New Mexico precipitation is unreliable and predicted to decrease in the coming years.[63,64]
- Stormwater harvesting. To use stormwater in Albuquerque, one would need a water right to use Rio Grande water, and these rights are expensive and difficult to obtain. However, the OSE allows stormwater detention without a right for ≤96 h. Within that time frame, the water must infiltrate into the ground or be released.[65]

4.1.2. Future Policies Needed for a NZUW Future. The elements of NZUW plans described above are being practiced to an increasing extent in Albuquerque. Of the compiled future policy needs to move the Southwest toward a NZUW future (Table 2), priorities for Albuquerque include the following:

- Making ASR projects easier and more economical to pursue. Currently, the process is onerous and expensive.
- Continued water conservation planning to reduce indoor and outdoor water use with climate-appropriate landscapes. This includes shading from built structures and a vibrant urban tree canopy to promote cooling.

https://doi.org/10.1021/acsestwater.4c00031
ACS EST Water XXXX, XXX, XXX−XXX

- Supporting IPR and DPR through development of advanced treatment and monitoring technologies, public engagement, and establishing regulations. Support and funding for potable water reuse must also account for workforce development. Needed are trained personnel who are highly skilled and qualified to operate advanced treatment processes and conduct performance and reliability monitoring.[66]
- Developing funding sources to pay for ASR, DPR, and other new supply.
- Increased coordination and collaboration between different water management entities (e.g., water and wastewater treatment and flood control) to enable a quantitative approach to urban water management. Also, many private/domestic wells in New Mexico are not metered; requiring metering of wells within the service area would provide an understanding of the impact that these wells have on water resources in the Middle Rio Grande watershed and better enable a quantitative approach to management.

4.2. Denver. Denver Water serves 1.5 million people in the City and County of Denver and the surrounding communities. The average residential per capita demand for the past five years (2017−2022) is 96 GPCD; this consumption is 20% lower that than before the 2002−2003 drought that spurred widespread conservation and efficiency initiatives. 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 gal per square foot of pervious area annually).

4.2.1. Policy and Governance Challenges. The Colorado Water Plan has identified future gaps in water supply and the need to implement practices toward NZUW to address those gaps in water supply and demand (Colorado Water Conservation Board 2015). The plan specifically calls out the need for the use of alternative water sources and to promote land use planning that is sensitive to water use to meet future water demand. Water in Colorado is governed by very strict water rights laws and enforcement to ensure downstream water uses and interstate water compacts are met.[67] This has served as a barrier for development and implementation of policies to allow for the use of alternative water sources. This is exemplified in the policy and implementation for the use of wastewater, graywater, and stormwater.

Denver's current approach to additional water sources includes the following:

- Wastewater recycling. Only water that is allowed to be used to extinction, typically water sourced from interbasin transfers, can be recycled after treatment.[68] In Denver, ∼30% of the total supply can be reused.
- Graywater harvesting. While Colorado Regulation 86[69] allows for the use of graywater for irrigation and toilet flushing, each city is responsible for developing an ordinance for allowance of graywater use in their city that demonstrates no impact to downstream water users. Denver has successfully developed ordinances for graywater use,[70] but very few other cities have ordinances.
- Rainwater harvesting. To minimize potential impacts to the water rights of downstream users, the allowance of rainwater capture from roofs is quite limited. Only single-family residences or multifamily residences with fewer than four units can use rainwater captured from roofs; only two 55 gal barrels can be used for collection of rainwater at each home.[71]
- Stormwater harvesting. Water rights even further complicate stormwater capture and use as well as use of stormwater to recharge natural areas. Regulations that enable stormwater capture and use do not exist in Colorado, and the practice has been restricted due to water rights law. In addition, stormwater management policy requires that water be discharged to surface water bodies within 72 h of collection.[72]

4.2.2. Future Policies Needed toward a NZUW Future. Like the case in other cities in the Southwest, NZUW systems cannot be achieved in Denver without addressing complex and long-standing water rights laws. A robust Colorado Water Court provides the opportunity to address complex water rights issues. The water rights laws create barriers for the use of local water sources, including treated wastewater, graywater, and stormwater. In addition, requirements to discharge stormwater after a 72 h period create challenges for beneficial use of stormwater, including recharge of natural water systems, e.g., wetlands or local groundwater. Of the compiled future policy needs to move the Southwest toward a NZUW future (Table 2), priorities for Denver include coordination among national, state, and local agencies on implementation and operation of alternative water sources; ensuring representation, participation, and accountability of all stakeholders for urban water planning; developing and incentivizing water conservation plans to reduce indoor and outdoor water consumption (while maintaining an appropriate level of tree canopy for the urban cooling effect); increasing coordination among different water management sectors (water supply, wastewater, stormwater, and groundwater) to enable a quantitative approach to urban water management; and supporting IDP and DPR (through development of advanced treatment, monitoring technologies, and public engagement). Colorado has passed regulations that enable DPR, but implementation remains a challenge due to requirements to meet water rights and garnering public support.

4.3. Los Angeles. The City of Los Angeles is by far the largest of the 88 cities in the metropolitan Los Angeles County. More than 3.8 million people comprise the city's population. Water consumption per capita in 2022 hovered around 112 GPCD, down from ∼146 GPCD in 2016, with a modest future goal of reaching 105 GPCD. However, there is still a long way to go to reduce water consumption sufficiently, such that NZUW can be achieved.

4.3.1. Policy and Governance Challenges. The City of Los Angeles receives imported water from three main sources, presenting complexities compared to other cities reliant on a single source. Of these sources, the Los Angeles Aqueduct comprises the majority of imports for the city, followed by the State Water Project and the Colorado River, which are shared with other agencies. Los Angeles also has significant local sources; it shares groundwater resources with neighboring water agencies for up to 70 000 acre-feet of annual pumping in five separate basins.

Los Angeles has also invested in alternative water sources for a decade or more, including the following:

- Wastewater recycling. In the past decade, the City of Los Angeles has embarked on an aggressive set of policies to reclaim water and to infiltrate stormwater. The city has committed to recycling 100% of the 260 million gal of wastewater currently being discharged to the ocean[73]

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ACS EST Water XXXX, XXX, XXX−XXX

through the Hyperion Wastewater Treatment Plant (HWTP) by 2035. This adds to established recycling programs in different parts of the city that make up ∼2% of the current water supply.[74] DPR, which received approval in California in December 2023, is being discussed for advanced treated wastewater from HWTP.[75,76]

- Graywater harvesting. Graywater harvesting is allowed for residential and commercial applications.[77]
- Rainwater harvesting. Rainwater harvesting is permitted for residential, commercial, and institutional applications and required for new single-family residences. However, the public health approval process for institutional projects has impeded growth in harvesting projects.[78]
- Stormwater harvesting. Today, on average, the city's stormwater capture basins collect >27 000 acre-feet (>8.8 billion gal) of stormwater each year, where it recharges the San Fernando Groundwater Basin. The city has spent more than \$500 million on bond funds to enhance stormwater harvesting. Los Angeles County operates additional capture basins that recharge groundwater for sources used by the City of Los Angeles and its neighbors and has a designated Safe Clean Water Program aimed at capturing stormwater for multiple benefits.

Porse and co-authors[12] estimated that Los Angeles County could get closer to achieving NZUW through investments in stormwater capture to recharge groundwater basins in wet years, increased use of recycled water, and significant water use efficiency, especially through dramatic landscape transformation with native and drought-tolerant vegetation. Achieving NZUW would likely ultimately require a total urban water use of 80 GPCD, with residences using 40−45 GPCD indoors. While ambitious, modeling indicates that, by 2030, the average indoor per capita use in California's cities would likely be 44−45 GPCD through passive efficiency alone.[79]

4.3.2. Future Policies Needed toward a NZUW Future. NZUW in Los Angeles is feasible but would require substantial changes. Several of the identified future policy needs to move the Southwest toward a NZUW future (Table 2) take priority in the City of Los Angeles: increasing regional coordination and better understanding surface and groundwater interactions to make aquifer storage and recovery projects easier and economical to pursue; increasing agencies' investments in alternative water projects, including rainwater capture projects, reclaimed water and brackish water systems, stormwater capture and use, and green infrastructure; increasing regional cooperation for IPR and DPR through development of advanced treatment and monitoring technologies, public engagement, and implementation of newly adopted potable water reuse regulations; and increasing programs, outreach, and funding capacity to support equitable access to water in low-income and marginalized communities. Such programs include rebates on rainwater harvesting and graywater systems, direct retrofit and installation programs to improve water use efficiency and replace turf, and programs that support water quality in households, such as service line and fixture replacement.

4.4. Tucson.

The Metropolitan Statistical Area of Tucson, AZ, includes >1 million people with just more than half of that population living within the City of Tucson limits. In 2021, total potable water use was 120 GPCD, with a residential GPCD of 76.[80] Tucson Water's current master plan, One Water 2100, aims to increase water conservation and expand the use of all available water sources.

4.4.1. Governance and Policy Challenges. Tucson has a long history of progressive water policies and a culture of sensitive water practices related to its location in the Sonoran Desert.[81] Tucson sits at the end of the 336-mile Central Arizona Project, which brings water from the Colorado River.[82] Active management areas (AMAs) were created in 1980 under the Arizona Groundwater Code for the state to have oversight over groundwater levels, including the Tucson AMA covering the basin of the greater metropolitan area.[83,84] The governance approach adopted by Tucson consists of a combination of hard path and soft path approaches, including (1) changes in water uses, from agriculture to municipal use through the purchase of the neighboring farms, (2) diversification of the water portfolio (e.g., Colorado River water, reclaimed water, graywater, rainwater, stormwater, and remediated groundwater), (3) protection of the hydrological cycle (e.g., protection of riparian ecosystems and xeriscaping), (4) water conservation, and (5) education and communication.[52,85,86]

Tucson's current approach to additional water sources includes the following:

- Wastewater recycling. Tucson has an extensive reclaimed water network initiated in the early 1980s.[85] It delivers ∼25 MGD of reclaimed wastewater to schools, parks, cemeteries, golf courses, and high-landscape water users, including more than 700 single-family homes. Overall, approximately half of the effluent municipal wastewater of Tucson is utilized as reclaimed water while the other half is discharged to the Santa Cruz River for wildlife habitat preservation, recreation, and a defacto indirect water reuse for the downstream communities and groundwater recharge.[87,88]
- Graywater harvesting. Graywater use is allowed by the state and city for residential and commercial applications.[89]
- Rainwater. Rainwater harvesting is permitted by the state and in some cases required or incentivized by the City of Tucson for residential and commercial applications.[57,58] However, rainwater supplies have been highly variable in recent years, increasing the need for active storage during dryer, hotter times.
- Stormwater harvesting. Since 2019, Tucson has had a "Green Stormwater Infrastructure" fee attached to water bills that funds the expansion and maintenance of public GI projects to mitigate stormwater and address flooding.[90] Incentives, rebates, grants, low-interest loans, and some requirements for rainwater and stormwater projects are offered by the city and county.[52]

4.4.2. Future Tucson Governance and Policy Needs toward a NZUW Future. A NZUW balance for Tucson would mean a reliance on only local water sources, thus removing itself from the Colorado River. Even with partial or intermittent shortages of the imported Colorado River, there is no clear, current, or immediate incentive to be net zero as another subscriber to the Colorado River would simply use this water instead (see section 2.1). Of the compiled future policy needs to move the Southwest toward a NZUW future (Table 2), priorities for Tucson include the following:

- Evaluating comparative costs and developing funding sources to adequately pay for new alternative water supplies.

https://doi.org/10.1021/acsestwater.4c00031
ACS EST Water XXXX, XXX, XXX−XXX

- Creating clear policies that incorporate surface and groundwater interactions. Data-driven policies that recognize surface and groundwater interactions are needed to support a more complete and holistic water management and accounting.
- Developing and incentivizing water conservation plans to reduce indoor and outdoor water consumption with climate-appropriate landscapes (including shading from built structures and a vibrant urban tree canopy to promote cooling).
- Supporting IDP and DPR (through development of advanced treatment and monitoring technologies, public engagement, and establishing uniform regulations).
- Addressing equity and justice concerns in a NZUW transition. Representation, participation, and accountability of all stakeholders for urban water planning will need to be ensured. It will be critical to ensure that all users have access to the same quality and affordability of basic water needs.
- Coordination will need to be further increased among different water management sectors (potable water supply, wastewater, stormwater, groundwater, and flood control) to enable a quantitative approach to urban water management.

5. CONCLUSION

The Colorado River supplies >40 million people in the Southwest with their daily water supply and is unable to meet the current demands or fulfill past agreements. As cities in the Southwest reconsider their dependence on imported water, NZUW is an important framework for comprehensively understanding the urban water supply and demand balances across natural, built, and social systems. Transitioning to a NZUW future in which cities thrive within local water supplies will require considerable modifications to governance and policy across the Southwest and its cities specifically. This paper outlines the governance and policy challenges across five key areas: accounting for diversified water sources and sinks; planning, design, and operation; monitoring and enforcement; coordinating among multiple agencies and sectors; and addressing equity and justice in the NZUW transition. These challenges are reflected in four case study cities: Albuquerque, Denver, Los Angeles, and Tucson. Across these cities, the policies needed to move toward a NZUW future in the Southwest are related to supporting DPR and IPR; creating coordination among national, state, and local agencies on implementation and operation of alternative local water sources; addressing equity and justice of all stakeholders in urban water planning; developing and incentivizing water conservation plans to reduce indoor and outdoor water consumption; and making aquifer storage and recovery projects easier and economical to pursue.

A NZUW transition in the Southwest has considerable challenges but is possible. As NZUW is meant to be a progressive target, the transition toward this future will be gradual and dependent on comprehensive urban water system modeling (encompassing natural, built, and social systems) and accurate data for the decision and support to move toward a net zero balance. Governance and policy will provide a critical framework and process for guiding this transition and will need to address equity and justice concerns. Although these changes are heavy lifts, they must be made to prevent further inequalities within cities and across cities in the Southwest built upon a foundation of water rights from an over-allocated Colorado River.

AUTHOR INFORMATION

Corresponding Author

Courtney Crosson − *College of Architecture, Planning, and Landscape Architecture, University of Arizona, Tucson, Arizona 85721, United States;* orcid.org/0000-0003-1757-8741; Email: ccrosson@arizona.edu

Authors

Stephanie Pincetl − *Institute of the Environment and Sustainability, University of California Los Angeles, Los Angeles, California 90024, United States*

Caroline Scruggs − *School of Architecture and Planning, University of New Mexico, Albuquerque, New Mexico 87131, United States;* orcid.org/0000-0003-2840-0068

Neha Gupta − *Arizona Institute for Resilience, University of Arizona, Tucson, Arizona 85721, United States*

Rashi Bhushan − *College of Architecture, Planning, and Landscape Architecture, University of Arizona, Tucson, Arizona 85721, United States*

Sybil Sharvelle − *Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, Colorado 80523, United States*

Erik Porse − *California Institute for Water Resources, University of California Agriculture and Natural Resources, Davis, California 95618, United States*

Andrea Achilli − *Department of Chemical and Environmental Engineering, University of Arizona, Tucson, Arizona 85721, United States*

Adriana Zuniga-Teran − *School of Geography, Development, and Environment, University of Arizona, Tucson, Arizona 85721, United States*

Gregory Pierce − *Luskin Center for Innovation, University of California Los Angeles, Los Angeles, California 90024, United States*

Dominic L. Boccelli − *Department of Civil and Architectural Engineering and Mechanics, University of Arizona, Tucson, Arizona 85721, United States*

Charles P. Gerba − *College of Public Health, University of Arizona, Tucson, Arizona 85721, United States*

Melinda Morgan − *Department of Geography and Environmental Studies, University of New Mexico, Albuquerque, New Mexico 87131, United States*

Tzahi Y. Cath − *Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, Colorado 80523, United States;* orcid.org/0000-0002-0669-4117

Bruce Thomson − *Department of Civil Engineering, University of New Mexico, Albuquerque, New Mexico 87131, United States*

Steve Baule − *Los Angeles Department of Water and Power, Los Angeles, California 90024, United States*

Steve Glass − *Ciudad Soil and Water Conservation District, Albuquerque, New Mexico 87131, United States*

Mark Gold − *Natural Resources Defense Council, Los Angeles, California 90024, United States*

James MacAdam − *Tucson Water, City of Tucson, Tucson, Arizona 85701, United States*

Luke Cole − *Sonoran Institute, Tucson, Arizona 85711, United States*

https://doi.org/10.1021/acsestwater.4c00031
ACS EST Water XXXX, XXX, XXX−XXX

Mead Mier − *Pima Association of Governments, Tucson, Arizona 85701, United States*
Catlow Shipek − *Watershed Management Group, Tucson, Arizona 85716, United States*
Thomas Meixner − *Department of Hydrology and Atmospheric Sciences, University of Arizona, Tucson, Arizona 85721, United States*

Complete contact information is available at:
https://pubs.acs.org/10.1021/acsestwater.4c00031

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors dedicate this paper to their brilliant colleague and co-principal investigator, Dr. Thomas Meixner. Tom (as he preferred to be called) shaped and supported the Net Zero Urban Water project, providing insights broadly and specifically in watershed biochemistry. Tom was a generous mentor to countless faculty and students and selfless contributor and connector to the many communities of which he was a part. His passionate and energetic influence as an educator, researcher, and human example will have ripple effects across a multidisciplinary audience for decades to come. The authors also thank Katie Spahr of Denver Water and Diane Agnew of Albuquerque Bernalillo County Water Authority for their significant input and time. The authors are grateful for the support from our utility and nongovernmental organizational partners: Albuquerque Bernalillo County Water Authority, Denver Water, Los Angeles Department of Water and Power, Mile High Flood District, Pima County Wastewater and Reclamation, Pima County Regional Flood Control District, Tucson Water, Pima Association of Governments, Sonoran Institute, and Watershed Management Group. This work is supported by the National Science Foundation's Dynamic and Integrated Socioenvironmental Systems program under Grant 2206132.

■ DEDICATION

This paper is dedicated to the memory of Thomas Meixner, who passed away on October 5, 2022.

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