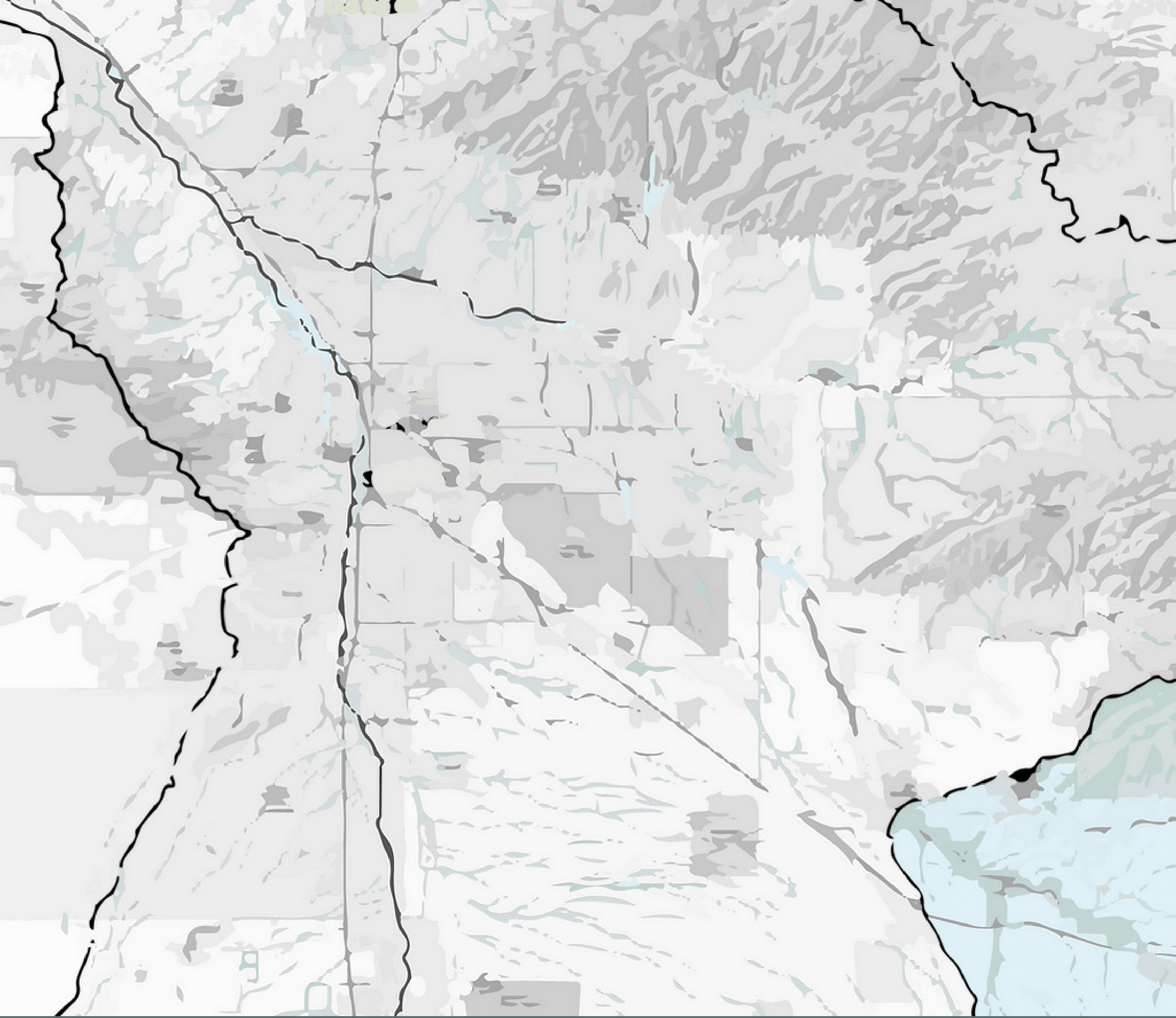

Advancing a Net Zero Urban Water Future in the US Southwest

Workshop Topic:
Alternative Water Sources and Retrofits

Rio Grande in Albuquerque | *Photo by Leo York Photos (Adobe Stock Images)*

Introduction

Researchers and practitioners from Albuquerque, Denver, Los Angeles, and Tucson convened virtually in November 2023 to discuss the development of NZUW model and integration of alternative water sources. The workshop was held in two sessions spanning two days, November 6th and November 17th, 2023. The first session aimed to identify the key questions that the NZUW model seeks to address and to prioritize scenarios for further investigation. It also focused on the challenges, adaptive solutions, and modeling needs for the 3 systems (natural, built and social) to be incorporated into the model. The second session delved into modeling methods used by previous studies to model urban water systems that integrate alternative water sources, to achieve objectives such as climate robustness, cost efficiency, and supply reliability (Porse et al., 2017; Newman et al., 2014; Bichai et al., 2015; Xu et al., 2020).

This brief first outlines the common scenarios across the four case study cities that need to be modeled to achieve net zero water targets. It then details the challenges, adaptive solutions, and modeling needs within the natural, built, and social systems to be incorporated for model development (See **Table 1**). It further discusses the unique perspectives of each city and how their situations diverge from the collective findings. Finally, we present a summary of modeling approaches used by sample past studies for modeling urban water systems with alternative water sources, to offer insights for NZUW model development (See **Table 2**).

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Scenarios Across the Four Cities

Various drivers of change, such as climate change, population growth, and economic development, are producing stresses on and within urban water systems. Innovation that integrates natural, social, and built systems through a lens of equity are required to adapt to these changes for a resilient, long-term urban water supply. Table 1 presents the scenarios with cross-cutting connections to natural, built, and social systems.

To engage with the NZUW framework, several terms must first be defined:

Governance refers to the framework of customs, regulations, and laws, as well as the engagement processes between the public and private sectors and civil society.

Water governance and policies are 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 (Zuniga, 2021). Ultimately, moving toward a net zero balance between urban water supply and demand will require an understanding of and updates to governance and policy across the Colorado River Basin, and within cities in the Southwest specifically.

Table 1 | Scenarios with cross-cutting connections to natural, built, and social systems

Scenario	System Challenge			System Solution		
	Natural	Built	Social	Natural	Built	Social
Suddenly being cut off from imported water (due to events such as earthquakes or forest fires)						
Impact from integrating alternative water supplies (centralized and decentralized supplies)						
Impact of decreases in water quality that cause a change in accessible quantity						
Unaccounted for water/wells that negatively impact total water balance						
Impacts of development and balancing needs for housing and water conservation						
Decreased supply to the natural system stemming from climate change and human activities						
Incremental transitions to a NZUW system due to cost constraints (such as infrastructure costs and investment, rate changes)						

Natural Systems: Challenges, Adaptive solutions and Modeling Needs

Natural systems within urban water systems encompass the integration of ecological processes and natural elements to enhance the sustainability and efficiency of water management in urban areas. These include watersheds, wetlands, green infrastructure, urban waterways (rivers and streams), aquifer recharge, etc.

Challenges

Natural systems face significant challenges, including the negative effects of climate change, the occurrence of natural disasters such as earthquakes, floods, and wildfires, and the critical need to meet ecosystem water requirements. Additionally, the threat of contamination from various sources poses a serious challenge to maintaining clean and safe water sources, while urban expansion and land development disrupt natural water cycles and ecosystems, complicating the achievement of net zero urban water goals.

Adaptive Solutions

To combat these challenges, several adaptive solutions have been proposed. Implementing new recharge projects of varying scales aims to address the hydro-climatic changes brought about by climate change. Urban greening campaigns and the re-naturalization of city centers promote the incorporation of green infrastructure and native plants, enhancing urban biodiversity and ecosystem services. In response to natural disasters, resilience measures are being integrated into water infrastructure design to increase durability against such events. Sustainable forest management and instream recharge serve as preventive measures against wildfires and water contamination, respectively. Moreover, promoting low-impact development (LID), green stormwater infrastructure (GSI), and sustainable land use practices ensures a balance between urban development and ecological preservation, safeguarding water sources and supporting ecosystem needs.

Modeling Needs

Addressing the challenges and implementing adaptive solutions within natural systems requires robust modeling efforts. The collection and analysis of historical, real-time, and geospatial hydro-climatic data are crucial for modeling the impacts of climate change on water systems. Integrated hydrologic models and Geographic Information Systems (GIS) are needed to plan for and mitigate the impacts of natural disasters. Scenario planning for climate change, risk assessment, and cost-benefit analyses help in evaluating the feasibility and effectiveness of management strategies. Additionally, monitoring and evaluation through modeling are essential for assessing the performance of adaptive solutions and making necessary adjustments. These modeling efforts are pivotal in guiding decision-making processes and ensuring the resilience and sustainability of urban water systems amidst changing environmental conditions.

Built Systems: Challenges, Adaptive Solutions and Modeling Needs

Built systems are a pivotal part of the NZUW framework, as they provide the essential infrastructure and technology for sustainable water management. These systems include water treatment facilities, distribution networks, water recycling and reuse infrastructure, and monitoring and control systems.

Challenges

Challenges within built systems encompass expanding distributed and centralized alternative water supplies, ensuring water quality amidst concerns like Per- and Polyfluoroalkyl substances (PFAS) concentration in direct potable reuse (DPR), and simulating water quality transitions across various scales—from household to block level. The broader obstacles involve managing energy use, costs, environmental flows, and balancing supply with demand. Furthermore, interfacing across different systems presents significant hurdles, alongside the daunting tasks of managing infrastructure failure, costs, investments, collecting detailed consumption and operation data, and addressing low spatial resolution issues that impact evaluations of distributional consequences and environmental justice.

Adaptive Solutions

Addressing the challenges in built systems involves a suite of adaptive solutions. These include leveraging wastewater, stormwater, and greywater for irrigation, enhancing GSI, and boosting aquifer storage and recharge capabilities. Smart metering and infrastructure upgrades emerge as critical tools for improving system efficiency and resilience. Demand-side management strategies, such as conservation measures, conservation rebate programs, and adjustments in water pricing and rate structures, play vital roles. Innovations in water code, dual plumbing systems, and metering are pivotal for optimizing water use. Additionally, adaptive treatment processes, including decentralized treatment options and treatment trains, offer flexibility in handling varying inflow quantities and qualities. Exploring the scales of implementation for alternative and decentralized solutions—from individual households to entire districts and cities—provides a comprehensive approach to addressing built system challenges.

Modeling Needs

Effective modeling of built systems requires close cooperation with water utilities to gather detailed consumption and operational data, including sub-monthly values. Models must be designed to accommodate spatial and temporal scales, ensuring adequate data for calibration and testing while aligning research questions with the appropriate time scales of modeling. Incorporating predictive capabilities is essential for anticipating the impacts of interventions and climate change on water availability and demand.

Social Systems: Challenges, Adaptive Solution and Modeling Needs

Social systems play a critical role in ensuring the successful implementation and acceptance of sustainable water management practices. These consist of public engagement and awareness about NZUW benefits, stakeholder collaboration, equitable access to safe and clean water, conservation programs, and regulatory framework that support sustainable water practices such as reuse, rainwater harvesting, and water-efficient building codes.

Challenges

The social system within the context of NZUW initiatives faces numerous challenges, crucial for modeling future scenarios. These challenges are listed below:

- Addressing equity in water pricing and differential rates based on location.
- Updating codes to support NZUW goals.
- Adapting to shifts in public preferences and attitudes towards water usage.
- Ensuring proper regulation and accounting of groundwater supplies.
- Balancing housing and population demand with water conservation.
- Considering implications of economic growth on water sustainability.
- Promoting a culture of water sustainability within organizations and agencies.
- Navigating local political dynamics that influence water policy.
- Managing social, economic, and regulatory contexts at various levels of operation.
- Implementing and enforcing conservation regulations and state policies.
- Accounting for public influence on policy, especially concerning conservation measures and DPR.
- Regulating both groundwater and recycled water resources effectively.
- Accounting for economic constraints affecting water resource management.
- Incorporating public preferences for DPR and equity into planning and modeling considerations.
- Addressing demographic shifts and the associated political challenges.
- Understanding and integrating the spatial dimension of water-related challenges in planning and policy-making.

Adaptive Solutions

The adaptive solutions associated with the variety of social system challenges as they relate to modeling come down to three solutions. The first is to designate a central point for the mixing and redistribution of recycled water to avoid social inequity stemming from spatial distribution. The second is to model types of regulations to try to curb usage. The third adaptive solution is to model rates to find cutoffs for basic water needs to be met, and to stage these rates to encourage water conservation while meeting basic needs.

Modeling Needs

The modeling needs for a just and equitable transition to NZUW are extensive. These needs are as follows:

- Integrate historical data on socioeconomic adaptations to periods of drought for predicting future behaviors under water stress.
- Model the frequency and severity of droughts to help plan for more extreme water scarcity scenarios.
- Account for the varying receptiveness of

communities to changing water use habits and address potential equity issues in the uptake of NZUW initiatives.
- Incorporate the effects of rates, regulations, and education on users' behavior, considering public willingness to accept changes.
- Address misconceptions in public perception, especially concerning water reuse, through public outreach.
- Account for diverse preferences regarding landscaping and residential outdoor spaces.
- Consider the psychological effects of "green" environments on public perception.
- Explore ways to quantify and model senses of well-being that relate to water sustainability.
- Identify the limits of what can realistically be modeled, as some aspects of human behavior and perception may be beyond the scope of quantitative models.

modelling challenges paragraph?

Sabino Creek in Tucson | *Photo by Billy McDonald (Adobe Stock Images)*

City Perspectives

Albuquerque

The scenarios relevant to Albuquerque to be modeled are as follows:

- Scenarios that are part of the 100 year water plan
- Quantity of non-potable reuse and increases in potable water reuse
- Decreased water quality due to forest fires and potential for the San Juan Chama water to be cut off
- Increasing GSI stored within the 72 hours window
- Climate change effects of decreased availability of San Juan Chama source water

Natural System

In regards to the natural system in Albuquerque, the city faces challenges such as climate change-related uncertainties in rainfall and heat, natural disasters, contamination, protecting ecosystem water needs, and land use changes. Albuquerque has a two-pronged modeling need related to natural systems. Modeling of traditional sources, including surface water, groundwater, and imported water, can likely be facilitated by the use of data from the San Juan Chama Diversion, which connects Albuquerque's water supply to the Colorado River Basin. To model alternative sources of rainwater, stormwater, and recycled water, data may be available from the local water utility.

Built System

Though the built system challenges do not differ from the general needs already outlined, Albuquerque encounters several distinct adaptive solutions. These include infrastructure upgrades, smart metering, GSI, reuse, conservation efforts in outdoor use, and multi-objective optimization for infrastructure investments.

Modeling potentially will be aided by the records of the drinking water plant, wastewater treatment plant, and flood control authority (AMAFCA) in Albuquerque.

Social System

Albuquerque faces several distinct challenges in its social system. These include population growth, economic growth, availability of upstream storage, code and policy changes, public preference, and concerns over the fluoride levels in recycled water.
Though the potential solutions are similar to the general list, there are some distinct modeling needs. These include domestic, industrial, commercial, and environmental considerations, as well as modeling water deliveries to meet obligations of the Colorado River Compact.

Denver

In regards to scenarios that need to be modeled for Denver, several models and other work already exist, so they need to determine how to tie this existing work into the NZUW project and framework. Additionally, there are some questions over whose needs are being reflected in the driving questions. For example, Denver Water is interested in modeling the differences between centralized and decentralized solutions.

Across all three systems, Denver's challenges, solutions, and modeling needs do not differ from the broader outline.

Los Angeles

Los Angeles outlines a specific set of scenarios to be modeled, listed below:

- Groundwater urban basin contamination (and PFAS) as a limiting factor to become NZUW compliant
- Cost and modeling of distributed small projects and the net effect of those projects on supply
- Energy cost of pumping and conveyance
- Per capita water consumption demand decreased to at least 80-90 GPCD
- Challenges in public perception related to the use of recycled water or costs
- Time scale of implementation
- Improved infrastructure and/or locations for recharge
- Long-term impacts of dry wells

Natural System

Relating to the natural systems, Los Angeles faces two specific challenges: groundwater urban basin contamination, and state policy affecting conservation codes at the local level. The corresponding modeling needed includes traditional water sources of surface water, groundwater, and imported water, all in terms of both quantity and quality. Additionally, alternative sources of rainwater, stormwater, and recycled water must be modeled.

Built System

Los Angeles also faces distinct challenges to the built system. These include the energy cost of pumping, the high cost of distributed small projects, and infrastructure space for recharge and storage. The adaptive solutions and modeling needs that correspond to these challenges are the same as what has been outlined across all four cities.

Social System

Regarding the social system, Los Angeles faces challenges of groundwater regulation and pumping rights in unadjudicated basins. They also experience high outdoor water use, public preference for DPR, and difficulties with recycled water access, cost, and public preference, given that recycled water is the most expensive water source in LA. Again, the adaptive challenges and modeling needs are similar to the general analysis.

Tucson

Tucson has a vision of specific scenarios to be modeled, which are as follows:

- New large-scale recharge projects, in which the aquifer serves as the city's storage
- A dry summer and wet winter would bound this scenario
- DPR and its various options, such as spectrum purple pipe, IPR, and DPR
- Climate change as a cross-cutting scenario
- Representing ecological sustainability and accounting for water quantities set aside for urban tree growth and existing ecology
- Representing decentralized water capture and how households manage it
- Earthquake causes CAP to suddenly become unavailable
- Price of water changes and how they differ when the price changes across the board versus for specific tiers or by location
- Sensitivity analysis on each modeling element to check influence on model output

Natural System

Tucson faces several challenges to the natural system. These include climate change, natural disasters, protection of ecosystem water needs, and land use changes. Potential adaptive solutions to these challenges are initiating new recharge projects at all scales, urban greening campaigns, incorporation of resilience measures while designing water infrastructures to help withstand disasters, re-naturalization of city centers, and promoting low-impact development (LID) and household solutions. The modeling needs for the natural system within Tucson focus on assessing the viability of traditional and alternative water sources, including surface, ground, imported, rainwater, stormwater, and recycled water. It involves evaluating groundwater permeability to identify recharge project locations and employing GIS-based analyses for optimal site selection,considering factors like soil properties, land use, and proximity to water sources. Additionally, assessing underground storage for treated water during peak demands and emergencies, alongside identifying areas suitable for stormwater recharge projects, are key components.

Built System

Tucson's challenges and adaptive solutions within the built system are the same as the overall outline. However, the modeling needs are distinct. Infrastructure upgrades or expansion are needed to improve water supply, distribution, and treatment systems. Smart metering is required to monitor and manage water use. The capacity of GSI to capture and manage stormwater while providing additional benefits also needs to be modeled. Lastly, multi-objective optimization is needed to prioritize and plan infrastructure investments based on multiple criteria, including cost-effectiveness and water supply security.

Social System

In Tucson's social system, several challenges complicate achieving NZUW goals. Key issues include ensuring water pricing equity, updating regulatory codes for sustainability, and balancing housing demands with conservation efforts. The city also aims to shift cultural attitudes within organizations towards water sustainability and navigate complex social, economic, and regulatory landscapes. Influential public opinions on policies, especially regarding conservation and DPR, alongside effective management of groundwater and recycled water, are critical. Incorporating public preferences for DPR and addressing equity in planning are essential modeling considerations. Moreover, Tucson is expected to experience population growth, adding pressure to water conservation and sustainability strategies.

The adaptive solutions are the same as what has been outlined across all four cities, but Tucson has several distinct modeling needs. Models will need to consider factors like population growth and economic trends while integrating domestic, industrial, commercial, and environmental demands. Tucson must also meet water compact obligations and ensure compliance on water deliveries. Water imported from CAP and its impact on local water demand must be evaluated, and the variations in imported water availability must be considered as well. Code and policy changes must be modeled, particularly regarding local water-related codes, regulations, and policies on water demand patterns. Lastly, public preferences and behaviors related to water conservation and usage must be incorporated.

Denver Skyline | *Photo by Brian Fox (Adobe Stock Images)*

Approaches for Modeling NZUW Systems with Alternative Water Sources

This section examines past studies on urban water systems that integrate alternative water sources, offering insights for developing a Net Zero Urban Water (NZUW) model. **Table 2** provides a summary, highlighting the region, alternative water sources, and modeling methods and tools used. These studies were driven by diverse objectives including cost efficiency, water supply reliability, climate resilience, and sustainability.

Systems analysis and optimization were employed in studies like Porse et al. (2017) and Bradshaw et al. (2019) to explore stormwater capture and wastewater recycling in Los Angeles, California. Specifically, Porse et al. assessed the viability of stormwater capture, while Bradshaw et al. examined the integration of recycled water with dynamic stormwater management for urban groundwater recharge. Newman et al. (2014) applied multi-objective optimization to balance system decentralization with the integration of various water sources. Hydrological and simulation models, including the WEAP system, have been pivotal in planning for enhanced supply security, as shown by Clark et al. (2015) and Ndeketeya & Dundu (2022). Analytical and model-based optimization methods, demonstrated by Bichai et al. (2015) and Khor et al. (2020), respectively, focus on the role of alternative water supplies and greywater reuse. Additionally, System Dynamics Modeling has been effectively used by Tian et al. (2020) and Xu et al. (2020) to enhance system efficiency and sustainability, particularly integrating desalinated water and treated wastewater. These sample studies and their methodologies for modeling urban water systems with alternative sources provide valuable insights for developing NZUW models.

Table 2 | Past studies on urban water systems that integrate alternative water sources for improving urban water security

Authors (Year)	Study Region	Alternative Water Sources	Modeling Approach	Key Findings
1. Porse et al. (2017)	Los Angeles CA	Stormwater, recycled water	Systems Analysis and Optimization	Analyzes and optimizes local water supply systems in Los Angeles for sustainability and self reliance.
2. Bichai et al. (2015)	Melbourne, Australia	Rainwater, stormwater, centralized and decentralized recycling	Analytical framework for decision-making using Alternative Water Atlas	Provides a framework to understand the role of alternative water supplies in urban water security.
3. Newman et al. (2014)	Streaky Bay, Australia	Rainwater, graywater, blackwater	Multi-objective optimization	Investigates the optimization of urban water systems with alternative sources and decentralization.
4. Khor et al. (2020)	US, UK household	Greywater	Model-based optimization	Focuses on the optimization of greywater reuse in urban areas for sustainable water consumption.
5. Ndeketeya & Dundu (2022)	Johannesburg, South Africa	Rainwater, recycled water	Conceptual analysis using Water Evaluation and Planning (WEAP) system	Discusses the importance of alternative water sources for enhancing water security.
6. Clark et al. (2015)	Salisbury, Australia	Stormwater	Hydrological modeling using WaterCress model	Evaluates the reliability of water supply from stormwater and aquifer recharge under various scenarios.
7. Bradshaw et al. (2019)	Los Angeles, California, US	Recycled water and stormwater	System modeling and optimization	Analyzes the integration of recycled and stormwater into urban groundwater recharge systems.
8. Xu et al. (2020)	Singapore	Desalinated water, NEWater (treated wastewater) for potable and non-potable reuse	Bi-objective optimization and system dynamics modeling	Optimizes urban water supply systems considering sustainability and system dynamics.
9. de Araujo et al. (2019)	Brazil	Recycled water, and inter-basin water	System Dynamics model	Aids in water management in semi-arid regions using a system dynamics approach.
10. Tian et al. (2020)	Tianjin City, China	Desalinated water, recycled water	System Dynamics model	Develops a sustainable water resource utilization model for urban areas, integrating water quality.

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The California Aqueduct moving water towards Los Angeles. | *Photo by trekandphoto (Adobe Stock Images)*

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