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Innovating the Urban Water System: Achieving a Net Zero Water Future Beyond Current Regulation

Recent extreme climatic events and failing infrastructure have increased awareness of the need for expanded resilience within urban water systems. Architects and engineers are more seriously considering integrating water capture and reuse technologies into projects; yet, the systems necessary to meet net zero water resilience are not currently legal for commercial use. This paper investigates the regulatory changes necessary to accommodate net zero water projects in Arizona. Institutional innovation in three critical systems—making rainwater potable, reusing water on-site, and decentralizing wastewater treatment—is needed to implement existing technology. Extrapolating from the removal of the identified barriers, this article sets forth a regulatory pathway for regenerative water design. For urban water reinvention to occur, institutional innovation will be as important as technological innovation.

Introduction

> It is not that the body of knowledge of technoscience failed to keep up . . . but that . . . the sum of governmental and civil institutions collectively failed to exercise the sound judgment to serve human purpose through it.[1]

Recent prolonged and severe drought conditions and increasing incidents of the associated, harmful effects of climate change, particularly in the Southwest of the United States, have amplified awareness of the need for expanded resiliency within urban water systems. National reports of failing, aged infrastructure and municipal water systems unable to meet acceptable drinking water standards further underscore a "looming urban water crisis."[2] Over the next 25 years, the American Water Works Association (AWWA) and the American Society of Civil Engineers (ASCE) estimate a required investment of $1 trillion for drinking water and $271 billion for wastewater infrastructure to meet current and future water demands.[3] An institutional innovation deficit currently exists within urban water systems.[4]

Large, municipal-scale management systems have been the dominant lens through which water system resilience has been discussed while, in relative order, less progress has been made on district- or building-scale system improvements.[5] In recent decades, the architecture and engineering community has increasingly recognized the necessity to embrace newly available water technologies.[6] Many of the newly available water technologies that offer solutions to urban water management are decentralized, or systems that function independently from the municipal utility. David Sedlak, civil engineer and author, asserts that "to wean cities from centralized systems and all their associated problems, we might simply have to find a way to make decentralized water supply and treatment practical at higher population densities."[7] Net Zero Water (NZW), or water independence, is the ability of a water system to meet one hundred percent of water needs with the project site's resources. NZW buildings and districts are decentralized systems that support urban water system resilience at density with current technologies, but these practices remain largely illegal. Persistent and pervasive regulatory barriers exist at the federal, state, and municipal levels for building professionals attempting NZW permitting (Table 1). We need fundamental changes in regulations that reconstruct the boundaries of urban water systems. For urban water reinvention to occur, institutional innovation will be as important as technological innovation.[8] Emerging water management technologies capable of finely monitoring compliance in real time are beginning to enable new performance-centered code to replace the old regulatory systems that were suited for traditional monitoring constraints. Performance-based codes may support further innovation by incentivizing the discovery of increasingly efficient methods for meeting standards.

This paper investigates the current regulation of the NZW systems of district- and building-scale commercial projects in Arizona and pinpoints existing barriers. Arizona has both an arid climate and a large, growing population concentrated in urban areas, making it a worthy case study for urban water reinvention. Additionally, the state has been a leader in water policy, thus barriers that exist within the state are likely barriers in many other places. Institutional innovation in three critical systems—making rainwater potable, reusing water on-site, and decentralizing wastewater treatment—is needed to implement existing technology. Extrapolating from the barriers identified, this paper recommends regulation changes and sets forth a permitting pathway for regenerative water systems.

Net Zero Water

Net Zero Water (NZW), or water independence, on the district or building scale is defined as meeting one hundred percent of a project's water needs through on-site capture, reuse, or other closed-loop systems and managing one hundred percent of a project's storm water. Any water discharged to ground or surface must be managed for ecological benefit.[9] Although NZW literature is scarce, nongovernmental organizations (NGOs) in Washington and Oregon have documented the obstacles to permitting NZW projects within their communities and have also concentrated their critique on decentralized potable supply, on-site water reuse, and on-site black water treatment.[10]

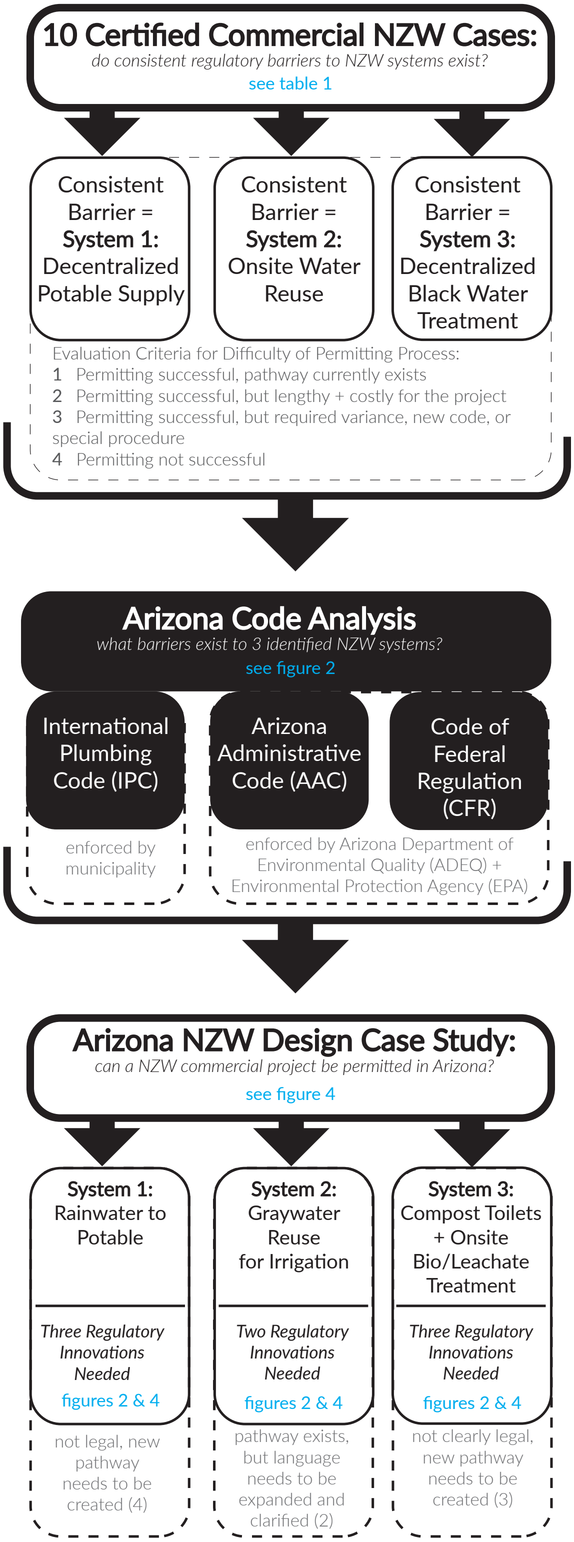
A notable distinction in the reliance on centralized infrastructure exists between commonly accepted definitions of NZW and Net Zero Energy (NZE). In the definition of NZE set out by the US Department of Energy (DOE), a building or district's system can be tied to the centralized energy grid.[11] In NZW, the system's operation is limited to site boundaries and the project cannot be connected to municipal water supply inputs or sewer outflows. An emergency connection to municipal supply for fire suppression is permitted. In contrast to common NZE definitions, NZW is independent from and provides resiliency outside of the functioning of the larger municipal system.

Currently, the only third-party certification for NZW is the Living Building Challenge (LBC), administered by the International Living Futures Institute (ILFI). Table 1 catalogs ten current commercial NZW projects and the decentralized water systems used to achieve certification. From the study of these ten projects three necessary systems were identified to structure this paper's investigation: decentralized potable supply (system 1), on-site water reuse (system 2), and decentralized sewage treatment (system 3).

The Bullitt Center in King County, Washington—the largest certified NZW project—contains these three systems. In system 1, rainwater is collected on the roof, stored, and treated to meet the project's potable water demands. In system 2, gray water from bathroom sinks, kitchen sinks, and showers is channeled to a rooftop-constructed wetland. Finally in system 3, compost toilets are used to address human waste. The leachate and biosolid byproducts from the compost toilets are taken off-site for constructed wetlands treatment or used for agricultural purposes, respectively. Currently, the Washington State Department of Health has not permitted the Bullitt Center's rainwater to potable system as a public water supply and the building relies on municipal water. System 2 was permitted through an existing regulation. System 3 required the provision of new codes for "sewer ready" connection and biosolid and leachate removal. It was ultimately permitted.[12]

◁ Opening Figure (Previous Page): Central Arizona Project (CAP) canal transports water across Arizona to serve Phoenix and Tucson.

▽ Figure 1. Method of inquiry undertaken in study.



The Pressure For Water Independence In Arizona

The water-stressed state of Arizona is the platform for the code analysis undertaken by this paper. Arizona's water supply is comprised of twenty-three percent imported water from the Colorado River, transferred over 330 miles by the Central Arizona Project (CAP).[13] According to the United States Bureau of Reclamation (USBR), Colorado River supply shortages for Arizona may be declared as early as 2018.[14] While water resources become scarce, population in the state has grown considerably in the past decades and the growth is expected to continue, with a population increase of forty-four percent projected from 2015 to 2040.[15] The Arizona Department of Water Resources (ADWR) determined that in twenty-five years Arizona will need to come up with an additional 900,000 acre-feet of water to meet projected shortages. In 100 years, Arizona's water demand will outweigh supply by about 3.2 million acre-feet.[16] The imbalance between future available water resources and projected water demands presents tremendous challenges for water resource management, necessitating the development of novel strategies and tools to meet the growing demand.[17] NZW systems and associated systems technologies are a component of the future solution for the state's water stress. Although Arizona has made progressive changes to water regulation in the last decade, codes guiding decentralized NZW systems remain limited and inhibitory, uncoordinated between building and public health scales. This paper proposes a pathway for institutional innovation to support available NZW technology as an important solution to the prototypical water stress in Southwestern states.

The Water Innovation Deficit and Institutions

Two concepts essential to understanding the way in which change can occur with our urban water systems are innovation and institutions. Innovation can be defined as the development, application, diffusion, and utilization of new knowledge.[18] Specific to water systems, innovation encompasses new technologies (such as desalination, membrane bioreactor, in-pipe water quality monitoring), new efficiency techniques (like submetering, leak detection), and new management techniques (such as tiered water-rate pricing, water tax, and new regulation as proposed here). Institutions can be defined as the rules, practices, and norms that govern decision-making.[19] Institutions can be formal, such as laws and regulations, but also include behavioral and cultural factors.[20] Although the laws and regulation that govern water use act as a major barrier to achieving innovation within the urban water system, behavioral and cultural factors likewise play a significant role. In the case of Direct Potable Reuse (DPR), sometimes referred to as "toilet to tap," implementation of centralized technology has been stalled for decades in the United States, despite the achieved regulatory innovation, due to public psychological barriers.[21]

Water institutions worldwide are generally characterized as highly stable organizations, which have proved to be very resistant to change.[22] Science Technology Studies (STS) is an area of inquiry that looks at the enmeshed relationship between social, political, and cultural values and technological progress. STS has heavily studied the sociotechnical conditions under which innovation occurs. In recent years, literature on innovation transitions

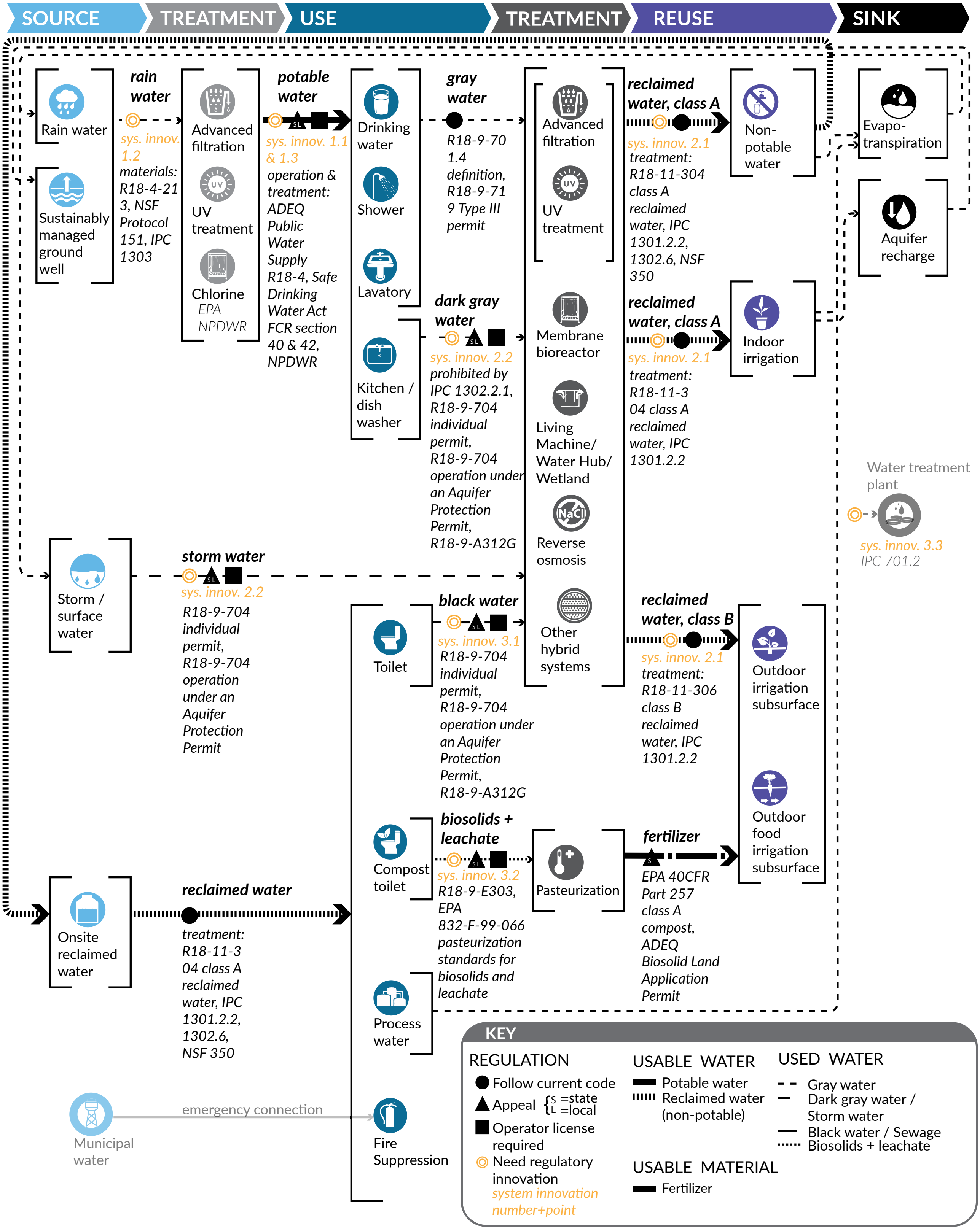
Table 1. NZW commercial projects in the United States currently in operation certified under the LBC, compiled by author. Sources: International Living Futures Institute, "Water Petal Case Study: Bertschi Science Wing and Bullitt Center," ILFI, September 2016; and Jeff Michael, "The Bullitt Center Rainwater Case Study," EcoBuilding Northwest Guild, 2014.

Net Zero Water System Commerical Project Case Study	Location	Program	Size (GSF)	Date	System 1: Decentralized Potable Supply	System 1: Permitting Success
1. Omega Center for Sustainability	Rhineback, NY (suburban)	Education	6,200	2009	Sustainably managed well	1
2. Bullitt Center	Seattle, WA (urban center)	Office	52,000	2010	Rainwater to potable, but not permitted to use, thus rely on municipal water	4
3. Hawaii Preparatory Academy	Kamuela, HI (suburban)	Education	6,100	2010	Rainwater to potable as a back up supply if no bottled water	3
4. Bertschi Living Building	Seattle, WA (urban)	Education	1,425	2013	Rainwater to potable, but not permitted to use, thus rely on municipal water	4
5. Bechtel Environmental Center	Whately, MA (natural)	Education	2,300	2014	Rainwater to potable and sustainably managed well	3
6. Phipps Center for Sustainable Landscapes	Pittsburgh, PA (suburban)	Office and education	24,350	2015	Rainwater to potable, but not permitted to use, thus rely on municipal water	4
7. The Healthy, Wellness, and Nutrition Center at the Willow School	Gladstone, NJ (suburban)	Education	19,991	2015	Rainwater to potable, but not permitted to use, thus rely on municipal water	4
8. Morris & Gwendolyn Cafrits Foundation	Accokeek, MD (rural)	Assembly	4,000	2015	Sustainably managed well, will switch to rainwater to potable when feasible permitting option	1
9. Dixon Water Foundation	Leo, TX (rural)	Visitor center	5,381	2016	Sustainably managed well	1
10. Brock Environmental Center	Virgnia Beach, VA (natural)	Office	10,518	2016	Rainwater to potable (to meet all building water demands)	3

Legend

1. Permitting was successful and a pathway for permitting currently exists
2. Permitting was successful, but was lengthy and costly to the project
3. Permitting was successful, but required granting of variance, formulation of a new code, or special procedure
4. Permitting was not successful

	System 2: Onsite Water Reuse	System 2: Permitting Success	System 3: Onsite Black Water Treatment	System 3: Permitting Success	Note
	Rainwater to non-potable uses	1	Constructed and reciprocating wetlands (EcoMachine)	3	
	Graywater to constructed wetland (on roof)	3	Composting toilets with off-site leachate and biosolids treatment	3	Rainwater to potable system not currently allowed by State of Washington Public Health
	Graywater to irrigation	1	Septic tank and leach field	1	Hawaii State Department of Health granted rainwater to potable appeal for back up supply system
	Graywater for indoor green wall irrigation	2	Compost toilets with on-site leachate and biosolid treatment	3	Rainwater to potable system not currently allowed by State of Washington Public Health
	Graywater for irrigation	1	Compost toilets with off-site leachate and on-site biosolid treatment	3	On-site leachate application not allowed by local regulators
	Rainwater for non-potable use	1	Graywater and black water treated in constructed wetlands	3	Local health regulation does not allow rainwater to potable, thus municipal water is used
	Graywater to non-potable uses not permitted, thus use rainwater	4	Constructed wetland wastewater treatment system	2	New Jersey Board of Public Health did not grant rainwater to potable system nor graywater to non-potable system
	Graywater for irrigation	1	Compost toilets with on-site leachate and biosolid treatment	2	
	Rainwater and graywater for irrigation	1	Constructed wetlands	3	
	Graywater to rain garden	1	Compost toilets with off-site leachate and on-site biosolid treatment	3	Possibly first in US to receive commercial permit for rainwater to potable in accordance with federal requirements



△ Figure 2. Water systems pathways that support achievement of NZW and current Arizona regulation of these pathways, labeled with places for needed innovation.

has focused on the rigidity and inertia of sociotechnical systems that result from the historically grown coalignment of technologies and institutions.[23] Another line of transitions literature has examined extreme events, like those of scarcity, that cause breakthroughs in alternative technology paradigms (for example, expansion of accepted water technologies during the 2000s Australian drought).[24] However, criticism of this literature suggests that these type of shocks are limited to a few cases and that the investigation of gradual processes within technosocial systems plays the dominant role in innovation transitions and thus deserve more attention.[25]

This paper specifically inspects the *institutional* regulatory barriers to existing technology to realize innovation within the urban water system. The paper recognizes that laws and regulation are only one component needed for institutional innovation within our urban water system and that this view of endogenous change is only one way transitions in innovation can occur. Change in regulation does not necessarily equate to innovation if other practices, norms, or cultural perceptions are not aligned. This paper inspects NZW projects where technology exists and owners and occupants are pushing for change, but regulation presents barriers to realizing a full innovation transition.

Methodology

Four methodological stages were completed in this study of NZW regulation in Arizona (Figure 1). First, ten LBC certified NZW projects in the United States were studied to locate categories of consistent regulatory barriers to the technological systems necessary to achieve NZW (Table 1). The three areas of technological progress identified as facing consistent institutional obstacles were (1) decentralized potable water, (2) on-site water reuse, and (3) on-site black water management.

Second, a code analysis for the state of Arizona was conducted for the three systems identified in stage 1 to locate what, if any, barriers existed to NZW (Figure 2). During stage 2, the sections of the Arizona health, environmental, and building codes that pertain to NZW system permitting were analyzed for barriers defined as regulatory language gaps, incongruities between regulatory settings, or restrictions to permitting NZW systems. The International Plumbing Code (IPC) was investigated as the adopted law that governs water system construction and operation in the state.[26] The Arizona Administrative Code (AAC) and Federal Code of Regulation (FCR) were examined as the public and environmental health law. IPC is enforced at the local level by the municipality, AAC at the state level by the Arizona Department of Environmental Quality (ADEQ), and FCR at the state level by ADEQ and the national level by the Environmental Protection Agency (EPA). Figure 2 outlines the systems necessary to achieve NZW overlaid with a roadmap to the current Arizona code requirements. Existing barriers are noted along the circulation lines connecting source, use, treatment, reuse, and sink elements.

Third, a NZW system for a speculative commercial project in Arizona, designed by the author, was used as a case study to validate the identified barriers in a complete NZW system application (Figure 4).[27] The commercial project was a four-story office building for 240 full-time employees in an urban site in Tucson, Arizona. As midsize commercial office buildings are one of the fastest growing sectors in Arizona, this building type could disproportionately benefit from regulatory changes.[28]

This case study used rainwater to potable for system 1, on-site gray water reuse (including kitchen water) for system 2, and compost toilets with on-site application of leachate and biosolids byproducts for system 3. The system selections were defined by constraints provided by the urban site in Tucson, namely infrastructure and ecological constraints (rainwater was selected to supply potable water, as drilling a new well was not possible for the site's hydrogeology), climate constraints (gray water reuse and compost toilets allowed the project to align water demand with the site's available rainwater supply), and land area constraints (composting toilets were selected as a solution to black water treatment as sufficient site area did not exist for other systems such as constructed wetlands). A water budget was then constructed to size the three systems in relation to project water demand (Figures 5, 6). Occupancy loads, water uses, and fixture specifications dictated demand. Supply was determined by the historic rainfall averages from a site-proximate weather station and the catchment surface areas of the project's roof and site design. Finally, the catchment, storage, and infiltration elements of the rainwater to potable system were calibrated using a system simulation model constructed with the last 25 years of daily precipitation data, projected potable water demand, and site infiltration capacity. The required storage volume was sized to achieve NZW systems resilience.

To complete stage 3, the three systems of the NZW case study were checked against the code analysis from stage 2. Currently, no complete pathway exists in Arizona for any of the systems used in the NZW case study.

Finally, in stage 4, a proposal of new regulatory pathways was created based on the three identified areas of technological progress and hurdles faced by the case study. The next section, Recommendations, lays out the necessary innovations within the three NZW systems identified in stage 1 and used during the analysis in stages 2 and 3. For NZW projects to be permitted in Arizona, three regulatory changes are needed for decentralized potable systems, two changes for on-site water reuse, and three changes for decentralized black water treatment. Overall, a regulatory pathway for NZW was constructed based on the need for expanded regulatory language and performance specification for decentralized water supply, treatment, and dispersal.

Recommendations

Recommended changes to current Arizona water regulation are given for each of the three NZW systems. Together these suggested changes create a pathway for permitting NZW commercial projects in Arizona. To identify and explain needed regulatory changes, NZW projects (Table 1) and the in-depth case study of a NZW Arizona commercial project (Figure 4) are used.

System 1: Decentralized Potable Water Supply

In the United States, potable water or drinking water is legally defined by chemical and microbial contaminant limits set by the Safe Drinking Water Act (SDWA) in the Code of Federal Regulation (CFR) Titles 40 and 42 passed in 1974 and amended in 1986 and 1996. Over 90 chemical and biological contaminants are addressed in the law.[29] NZW projects have predominantly used rainwater as the source for potable water given its cleanliness (it requires much less treatment compared to other available water sources such as surface water) and renewability (Table 1, specifically projects 2, 4–7, 10).

Regulatory Barrier

The Arizona case study (Figures 4, 5, and 6) uses a rainwater to potable system as the first system in its NWZ design. Based on code analysis of the ability for such a system to be permitted, three areas of impediment exist:

1. Decentralized systems must operate and be regulated as an individual utility-scale public water supplier (Figure 3).
2. ADEQ and IPC offer no clear guidance on materials and products acceptable for the catchment component of rainwater to potable systems.
3. There is no clear method of proving that performance criteria are met by custom-designed treatment systems for potable water provision.

Institutional Innovation Opportunities

A Pathway to Become a Satellite of an Existing Public Water Utility: Arizona Administrative Codes (AAC) R-18-4-101 and R18-4-107

Public water suppliers are defined by the Arizona Administrative Code (AAC, R18-4-101 [1998]) as any water system "that serves more than 25 people or has 15 or more service connections" (Figure 3).[30.] All commercial-scale projects (the focus of this paper) fall into the public water supplier definition and thus carry the risk and liability of their public water provision.[31] Strict regulation from local, state, and federal code in the areas of public health, environmental protection, and engineered plumbing systems creates a multilayered and multisector regulatory compliance pathway. Rainwater to potable public water systems at building or district scale face two possible choices: carry the cost and liability of operating as a public water utility, or align with the existing potable water provider where the project is located. In the latter, no current pathway exists to be permitted as a satellite operator. For public rainwater to potable systems to become a realistic pursuit of NZW projects, regulatory innovation requires the creation of a satellite operator status.

Guidance on Materials for Rainwater Catchment: IPC 1303 and AAC, R-18-4-213

The second barrier is lack of clarity on acceptable materials for rainwater catchment for potable use. In the Arizona case study (Figure 4 and projects 2–7 and 10 in Table 1) the complete potable system encompasses rainwater collection materials (for example, roof membrane and roof equipment like photovoltaics), conveyance (pipes and gutters), storage (cistern and day tank), and point of use (shower and faucet). Under IPC 1303 and AAC, R-18-4-213, materials and products certified under the National Science Foundation's (NSF) Protocol 151 are permissible for use in potable water supply systems.[32] However, as rainwater to potable systems are rare, NSFp151 options do not exist for most components of such systems.[33] Standard materials that do not degrade over time are arguably safe to serve as the catchment component of a rainwater to potable system. Regulatory language needs to state parameters of the desired performance of system materials.

Performance Code for Custom Systems Using Multiple Technologies: IPC 1303 and AAC, R18-4-218

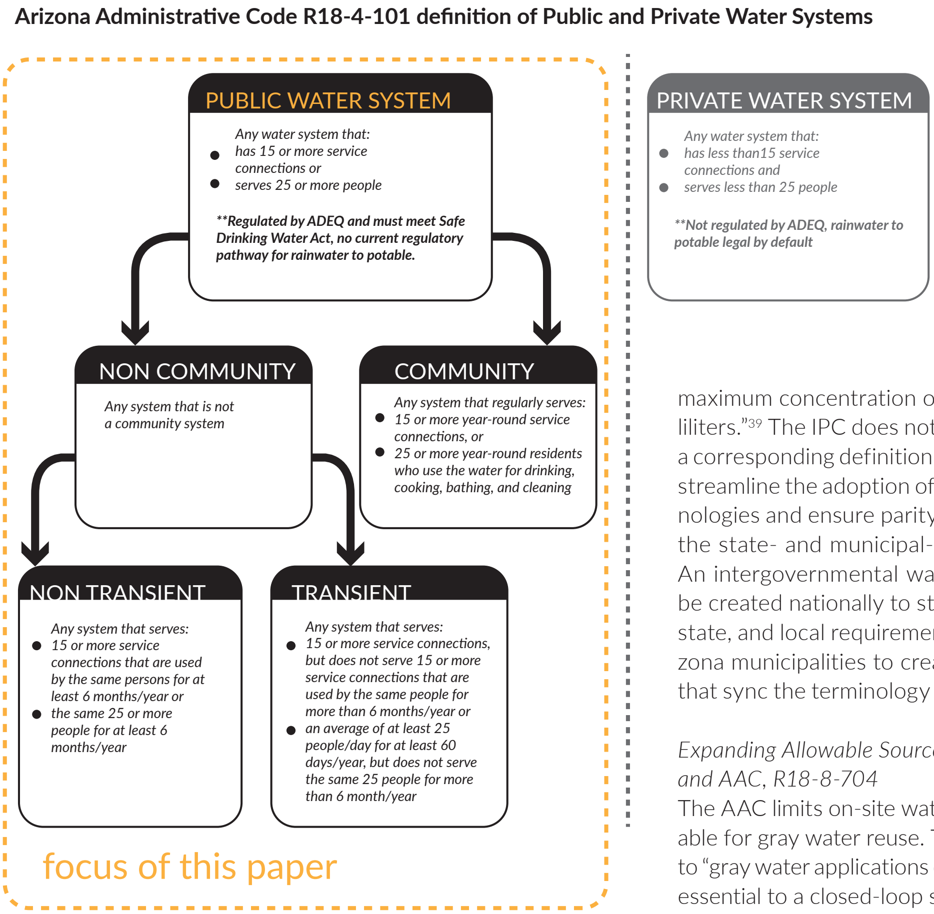
Finally, a clear performance pathway for custom-designed treatment systems for the public potable water provision is needed. All decentralized potable water systems in the projects in Table 1 were custom designed. Rainwater is relatively clean compared to SDWA standards, meaning it does not contain many of the chemical and microbial contaminants found in other sources. Therefore simple, low-energy, custom systems are capable of treating water to a SDWA performance standard, but the AAC does not provide explicit guidance on such systems and leaves permitting to the Authority Having Jurisdiction (AHJ). This lack of a clear pathway presents a steeper obstacle than may be apparent. The AHJ is not incentivized to permit or grant variance to public water systems that present any potential risk. For example, if the custom treatment system does not perform as expected and the public gets ill from substandard water quality, the staff members of the AHJ face losing their jobs, and they and the AHJ may be subject to litigation. Duncan Thomas and Roger Ford attribute the remarkably slow innovation in this area to a set of regulatory institutions that "have been pathologically risk averse" coupled with a market that has not created incentives to commit to possible new technological solutions.[34]

System 2: On-site Water Reuse

In the last several decades, the greatest advancements in federal, state, and municipal water regulation have been in the area of water reuse—going from prohibited to permissible at varying levels for on-site and off-site sources and applications. Gray water and black water are the two possible sources for water reuse. The AAC defines gray water as "wastewater collected separately from sewage flow that originates from a clothes washer, bathtub, shower, and sink, but does not include wastewater from a kitchen sink, dishwasher, or toilet."[35] Black water, or wastewater or sewage, is defined as water that has come into contact with fecal material. Once treated to an acceptable standard, gray water and black water can be put to new purposes and are then referred to as reclaimed or recycled water. Unlike potable water, which is defined in the SDWA by a set of limited chemical and microbial contaminants, gray water and black water are defined simply by their previous use. When reclaimed, the water does have minimum quality standards set and enforced by the state board of health (in Arizona, the ADEQ).

Regulatory Barriers

In the Arizona case study, gray water and dark gray water are reused for on-site irrigation (Figures 4 and 6). Two central barriers continue to exist for on-site water reuse in Arizona: the lack of unification between the AAC public health and environmental quality laws and the IPC locally enforced plumbing codes, and a narrow definition of water sources available for reuse (that is, dark gray water, black water, and storm water are excluded).



◁ Figure 3. Public versus private water systems, AAC R18-4-101.

Institutional Innovation Opportunities

Coordinating Vocabulary on Water Reuse between Health and Building Codes: IPC 1301.2.2 and AAC, R18-11-301 to 306

The ADEQ currently uses the term *reclaimed water* to guide all water reuse and defines it as "the direct reuse of treated effluent for beneficial use."[36] Arizona is one of a handful of states with a progressive tiered system for water reuse permitting. AAC provides five classes of water quality (A+, A, B+, B, C) within three types of permits (Type 1, 2, and 3).[37] The only decentralized on-site water reuse currently allowed by the AAC is gray water, granted through a Type 1 permit. Centralized reclaimed water systems (or purple pipe) in Tucson, Phoenix, Flagstaff, and the Grand Canyon treat black water in wastewater treatment plants and operate under a Type 3 permit for water agencies.

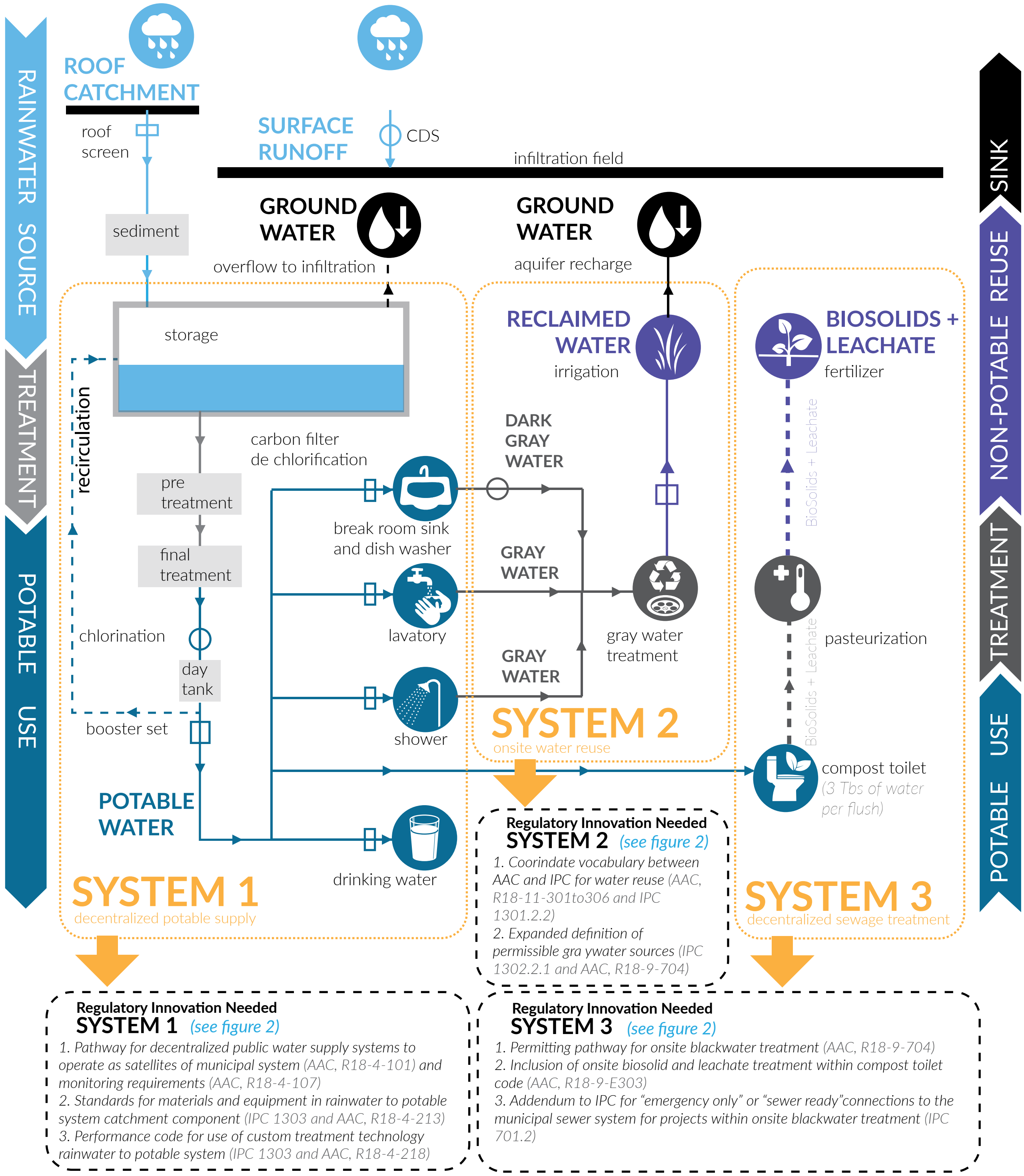
Although the greatest progress in water regulation has been in water reuse, the multiple codes that form its permitting pathway in Arizona, like most other states, is uncoordinated with building and plumbing codes. Under the AAC, the case study must treat on-site water reuse to class A for "applications where access to the reclaimed water by the general public is uncontrolled."[38] The chemical and microbial standard for class A are stipulated in R-18-11-304 (2016) as "(1) the 24-hour average turbidity of filtered effluent is two Nephelometric Turbidity Unit (NTU) or less, (2) no detectable fecal coliform organisms in four of the last seven days of reclaimed water samples, and (3) any single sample has a maximum concentration of fecal coliform less than 23/100 milliliters."[39] The IPC does not have a tiered vocabulary for reuse or a corresponding definition of necessary water quality. In order to streamline the adoption of new water treatment and reuse technologies and ensure parity in permitting, incongruities between the state- and municipal-adopted codes need to be resolved. An intergovernmental water reuse permitting authority could be created nationally to streamline permitting between federal, state, and local requirements. A state solution would be for Arizona municipalities to create and adopt addendums to the IPC that sync the terminology of the AAC to the IPC.

Expanding Allowable Sources of Gray Water: IPC 1302.2.1 and AAC, R18-8-704

The AAC limits on-site water reuse to a Type 1 permit only available for gray water reuse. The IPC also limits on-site water reuse to "gray water applications only."[40] In NZW projects, water reuse is essential to a closed-loop system. Explicit reuse permitting pathways for black water, dark gray water (the gray water definition expanded to include kitchen and dishwasher water, Figure 4), and storm water is needed. Current technologies already exist to convert these other non-gray-water forms of reusable water to the performance standards of all five AAC classes. The greater potential for hazardous material contamination (for example, heavy metals in storm water from streets) or microbial agents (such as food waste from kitchen sinks) can be addressed through a stipulated performance code for the reclaimed water produced.[41]

System 3: Decentralized Black Water Treatment

A NZW system must dispose of all water outputs while protecting historic ecological conditions of the site. Water-independence projects function separate from municipal resources in order to ensure that their water resources are kept within the site; thus using a sewer system for off-site treatment is not an option. Instead, water outflows must be treated and put to use on-site or infiltrated into the ground. The NZW projects in Table 1 address on-site sewage with either biological treatment (such as constructed wetlands), hybrid biological treatment aided by mechanical systems (for example, Living Machine systems), mechanical treatment (such as membrane bio-reactors), or minimization of wastewater through use of compost toilets. A permitting pathway for compost toilets was adopted in the AAC in 2005.[42] Otherwise, these options do not have defined permitting processes in either AAC or IPC.



Regulatory Innovation Needed
SYSTEM 2 *(see figure 2)*

1. *Coorindate vocabulary between AAC and IPC for water reuse* (AAC, R18-11-301to306 and IPC 1301.2.2)
2. *Expanded definition of permissible gra ywater sources* (IPC 1302.2.1 and AAC, R18-9-704)

Regulatory Innovation Needed
SYSTEM 1 *(see figure 2)*

1. *Pathway for decentralized public water supply systems to operate as satellites of municipal system* (AAC, R18-4-101) *and monitoring requirements* (AAC, R18-4-107)
2. *Standards for materials and equipment in rainwater to potable system catchment component* (IPC 1303 and AAC, R18-4-213)
3. *Performance code for use of custom treatment technology rainwater to potable system* (IPC 1303 and AAC, R18-4-218)

Regulatory Innovation Needed
SYSTEM 3 *(see figure 2)*

1. *Permitting pathway for onsite blackwater treatment* (AAC, R18-9-704)
2. *Inclusion of onsite biosolid and leachate treatment within compost toilet code* (AAC, R18-9-E303)
3. *Addendum to IPC for "emergency only" or "sewer ready"connections to the municipal sewer system for projects within onsite blackwater treatment* (IPC 701.2)

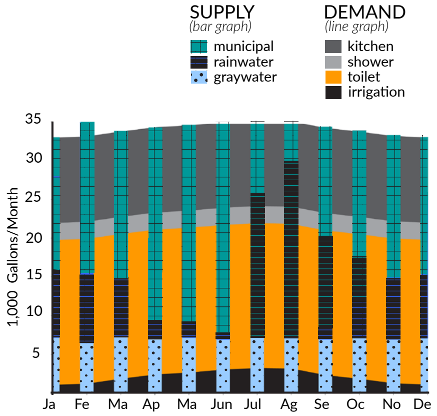
NZW CASE STUDY PROJECT

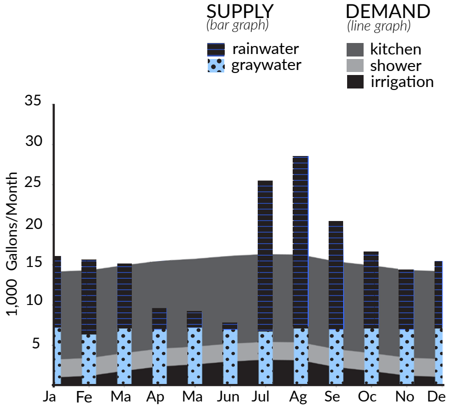
Location: **Tucson, Arizona (urban)**
Program: **Office**
Full Time Occupancy: **240 people**
Visitor Occupancy: **10 people**
Construction: **Speculative, UnBuilt**

Floors: **3 floors with a basement**
Gross Building Area: **40,000 GSF**
Roof (catchment) Area: **11,000 SF**
Landscape (infiltration) Area: **20,000 SF**
Parking Lot + Sidewalk: **10,000 SF**

System 1: **Rainwater to Potable**
Cistern (for NZW): **100,000 gallons**
System 2: **Gray + Dark Gray Water Reuse**
System 3: **Compost Toilets**
BioSolid+Leachate Disposal: **Onsite**

△ Figure 4. NZW system case study for commercial building in Arizona.





◁ Figure 5 (Left). Baseline case: Water budget for a commercial building in Arizona that is not NZW.

◁ Figure 6 (Right). Design case: Water budget for a commercial building in Arizona designed to accomplish NZW. (By author.)

Regulatory Barriers

The Arizona case study uses compost toilets with on-site treatment and use of biosolids and leachate byproducts (Figures 4 and 6). Three current barriers exist for on-site black water treatment: (1) the lack of a permitting pathway for black water treatment using existing technology, (2) an ambiguous pathway for the on-site pasteurization and application of biosolids and leachate, and 3) a requirement for connection to the municipal sewer for all urban buildings. Although this paper focuses on regulatory transitions, it is important to note that strong social and cultural barriers to black water reuse inhibit current, proven technologies from being adopted.

Institutional Innovation Opportunities

Pathway to Permitting Existing Black Water Treatment Technology: AAC, R18-9-704

Building on the discussion and proposed solutions in the last section, on-site black water treatment technologies exist, but their use currently requires gaining an Aquifer Protection Permit, granted to certified water agents. A permitting pathway for existing biological and mechanical black water treatment technology is needed in the AAC and IPC.

On-site Treatment and Use of Biosolids and Leachate: AAC, R18-9-E303

Currently, the AAC compost toilet code (AAC, R18-9-E303) only allows for the byproducts to remain in the ground or be carried off-site by a licensed septic professional. A new option of heat pasteurization (via existing EPA pasteurization standards for biosolids and leachate, EPA 832-F-99-066) and then on-site application (via existing EPA standards for "class A" biosolids, EPA 40 CFR Part 257) has yet to be incorporated into the existing compost toilet code and Biosolid Land Application Permit.[43]

Emergency Only or Sewer Ready Connections: IPC 701.2

Finally, the IPC poses a significant barrier to requisite sewer connection to NZW projects. In locations that are proximate to available sewer infrastructure, sewer connection is required and disconnection is illegal.[44] When wastewater is managed on-site for NZW, no sewer (and the associated high fees) is necessary. A pathway for permitting the sewer connection requirements in projects with compost toilet or on-site black water reuse as "emergency only" or "sewer ready" is necessary.

For example, in the case of the Bullitt Center, a code waiver was established for an urban project with an on-site sewer system (OSS) to install sewer connections for emergency backup use only. Sewer fees only had to be paid if and when the sewer system was used.[45]

Through code analysis and case study, this paper identifies the current regulatory changes required to achieve NZW technological progress and expand water system resilience (Figure 2). Three systems structure the recommendations (Table 1 and Figure 4). For system 1, modifications include: (1) adding a permitting pathway to allow for decentralized public potable systems to operate as a satellite of the municipal system, (2) creating standards for materials and equipment for rainwater to potable systems, and (3) adding rainwater to potable systems performance code for custom treatment technology. Fast track certification of existing, proven technologies is one immediate way to make this change. For system 2, recommendations include: (1) coordinating vocabulary between state health codes and local building codes, and (2) expanding the definition of gray water to include dark gray water. Establishment of an intergovernmental water reuse regulatory authority to streamline permitting between federal, state, and local requirements would also support expanded water innovation. For system 3, changes include: (1) creating a permitting pathway for on-site black water treatment, (2) providing a permitting pathway for on-site biosolid and leachate treatment and dispersal, and (3) adding an "emergency only" sewer connection option. Although this paper focuses on regulatory change, the future water system innovation transition will only be sustained if social factors are aligned. Where there is a documented negative public perception in areas of innovation, such as in black water treatment, a cultural shift will be required.

Conclusion

> Without unity of conception and execution, no technology will be socially sustained.[46]

Climate change and deteriorating, aged infrastructure portend an urban water crisis in the coming decades. The future of water resources will become increasingly dependent on architects and engineers to add resiliency to urban water infrastructure systems through buildings and community plans that integrate water-system technological advancements. Beyond conservation and water management, meeting the projected demand–supply deficit in Arizona will rely on a broadening of solutions, including decentralized systems integrated by building professionals. To date, decentraslized water-innovation technology has been underutilized due to high regulatory barriers for construction and operation. Arizona's water-resource future calls for the dissection, evaluation, and fundamental reconstruction of current inhibitory regulation to create pathways for new water-system innovation to occur. New advances in water-management technology, such as sensors and in-line water-quality testing, will aid in the integration of decentralized systems and the monitoring of the new infrastructural configurations of the urban water system.

In essence, this paper argues not simply to design a better, more efficient code, but to reconstruct the boundaries of the systems to be coded to include decentralized water technology.[47] Building, health, and environmental regulations need to be integrated at the federal, state, and local levels to support water innovation. The coming urban water crisis calls for novel solutions. NZW decentralized systems offer a critical solution only if institutional innovation aligns with the current technological progress.

Notes

1. Steven Moore and Barbara Wilson, *Questioning Architectural Judgment* (New York: Routledge, 2014), 2.
2. Jan-Olof Drangert, "Addressing Urban Water Scarcity: Reduce, Treat and Reuse: The Third Generation of Management to Avoid Local Resources Boundaries," *Water Policy* 19, no. 6 (2017), http://wp.iwaponline.com/content/early/2017/07/05/wp.2017.152.
3. American Water Works Association, *State of the Water Industry* (Washington, DC: AWWA, 2016); and American Society of Civil Engineers, "2017 Infrastructure Report Card," ASCE, accessed July 25, 2017, www.infrastructurereportcard.org.
4. Duncan Thomas and Roger Ford, *The Crisis of Innovation in Water and Wastewater* (Clarington: Edward Elgar, 2005); Jason Potts, "The Innovation Deficit in Public Services: The Curious Problem of Too Much Efficiency and Not Enough Waste and Failure," *Innovation* 11, no. 1 (2009): 34–43; and Michael Kiparsky et al., "The Innovation Deficit in Urban Water: The Need for an Integrated Perspective on Institutions, Organizations, and Technology," *Environmental Engineering Science* 30, no. 8 (2013): 395–408.
5. Glen T. Daigger and George V. Crawford, "Enhancing Water System Security and Sustainability by Incorporating Centralized and Decentralized Water Reclamation and Reuse into Urban Water Management Systems," *Journal of Environmental Engineering and Management* 17, no. 1 (2007): 1.
6. Glen T. Daigger, "Evolving Urban Water and Residuals Management Paradigms: Water Reclamation and Reuse, Decentralization, and Resource Recovery," *Water Environment Research* 81, no. 8 (2009): 809–23; and Glen T. Daigger, "Sustainable Urban Water and Resource Management," *Bridge* 41, no. 1 (2011): 13–18.
7. David Sedlak, *Water 4.0* (New Haven: Yale University Press, 2014), 244.
8. Kiparsky et al., "The Innovation Deficit in Urban Water," 405.
9. International Living Futures Institute, "Living Building Challenge 3.0," ILFI, 2014, accessed January 10, 2016, https://living-future.org/wp-content/uploads/2016/12/Living-Building-Challenge-3.0-Standard.pdf.
10. James D. Englehardt et al., "Net Zero Water Management: Achieving Energy-Positive Municipal Water Supply," *Environmental Science: Water Research & Technology* 2, no. 2 (2016): 250–60; Cascadia Green Building Council, *Toward Net Zero Water: Best Management Practices for Decentralized Sourcing and Treatment* (Seattle, OR: Cascadia Green Building Council, March 2011), https://living-future.org/wp-content/uploads/2016/11/Toward_Net-Zero_Water.pdf; Central City Concern, *Achieving Water Independence in Buildings: Navigating the Challenges of Water Reuse in Oregon* (Portland, OR: Central City Concern, 2009); and City of Seattle and Cascadia Green Building Council, *Regulatory Pathways to Net Zero Water: Guidance for Innovative Water Projects in Seattle* (Seattle, WA: City of Seattle and Cascadia Green Building Council, 2011).
11. U.S. Department of Energy, *A Common Definition for Zero Energy Buildings* (Washington, DC: U.S. DOE, September 2015).
12. International Living Futures Institute, "Living Building Challenge Certified Case Studies," ILFI, 2017, accessed November 10, 2017, https://living-future.org/lbc/case-studies/.
13. U.S. Bureau of Reclamation, *Colorado River Basin Stakeholders Moving Forward to Address Challenges Identified in the Colorado River Basin Water Supply and Demand Study*, (Washington, DC: U.S. Bureau of Reclamation, 2015).
14. Ibid., 3.
15. Arizona Office of Economic Opportunity, "Medium State Population Projects," Arizona Department of Economic Opportunity, 2017, accessed July 30, 2017, https://population.az.gov/population-projections.
16. Arizona Department of Water Resources, *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability* (Phoenix. AZ: Arizona Department of Water Resources, 2014).
17. These projections are developed from the twentieth-century mindset that water demands will continue to grow at the pace of population growth and that new sources for water must be located to meet those demands. In cases in Australia and Israel, significant water reduction has been achieved in times of scarcity, despite population growth. Future water systems in the American West are more likely to be about water management and incorporation of new technology than about discovering new sources of water.
18. Bo Carlsson, Staffan Jacobsson, and A. Bergek, "Dynamics of Innovation Systems–Policy-Making in a Complex and Non-Deterministic World," in *International Workshop of Functions in Innovation Systems* (Utrecht, the Netherlands: University of Utrecht, June 2004); and Marko P. Hekkert et al., "Functions of Innovation Systems: A New Approach for Analysing Technological Change," *Technological Forecasting and Social Change* 74, no. 4 (2007): 413–32.

19. Kiparsky et al., "The Innovation Deficit in Urban Water," 405 (see n. 4).

20. W. Richard Scott, *Institutions and Organizations: Ideas, Interests, and Identities* (Los Angeles: Sage Publications, 2013).

21. Lea Fuenfschilling and Bernhard Truffer, "The Interplay of Institutions, Actors and Technologies in Socio-Technical Systems: An Analysis of Transformations in the Australian Urban Water Sector," *Technological Forecasting and Social Change* 103 (2016): 298–312.

22. Wendy Nelson Espeland, *The Struggle for Water: Politics, Rationality, and Identity in the American Southwest* (Chicago, IL: University of Chicago Press, 1998); Lea Fuenfschilling and Bernhard Truffer, "The Structuration of Socio-Technical Regimes: Conceptual Foundations from Institutional theory," *Research Policy* 43, no. 4 (2014): 772–91; and François Molle, Peter P. Mollinga, and Philippus Wester, "Hydraulic Bureaucracies and the Hydraulic Mission: Flows of Water, Flows of Power," *Water Alternatives* 2, no. 3 (2009): 328–49.

23. Giovanni Dosi, "Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change," *Research Policy* 11, no. 3 (1982): 147–62.

24. Frank W. Geels and Johan Schot, "Typology of Sociotechnical Transition Pathways," *Research Policy* 36, no. 3 (2007): 399–17; and Adrian Smith, Andy Stirling, and Frans Berkhout, "The Governance of Sustainable Socio-technical Transitions," *Research Policy* 34, no. 10 (2005): 1491–510.

25. Ulrich Dolata, "Radical Change as Gradual Transformation: Characteristics and Variants of Socio-Technical Transitions," *Organizational Sociology and Innovation Studies* (2011): 35; Audley Genus and Anne-Marie Coles, "Rethinking the Multi-Level Perspective of Technological Transitions," *Research Policy* 37, no. 9 (2008): 1436–445; Jochen Markard and Bernhard Truffer, "Technological Innovation Systems and the Multi-Level Perspective: Towards an Integrated Framework," *Research Policy* 37, no. 4 (2008): 596–615; Elizabeth Shove and Gordon Walker, "CAUTION! Transitions Ahead: Politics, Practice, and Sustainable Transition Management," *Environment and Planning* A 39, no. 4 (2007): 763–70; and Adrian Smith, Jan-Peter Voß, and John Grin, "Innovation Studies and Sustainability Transitions: The Allure of the Multi-Level Perspective and Its Challenges," *Research Policy* 39, no. 4 (2010): 435–48.

26. "Adoption Maps," International Code Council, accessed July 10, 2017, www.iccsafe.org/wp-content/uploads/Code_Adoption_Maps.pdf.

27. The author worked for BuroHappold Engineering from 2012 to 2016 and completed a similar design for a California office building project.

28. Arizona Department of Administration, *Employment Report* (Phoenix, AZ: Arizona Department of Administration, November 2017); and Arizona Builders' Exchange, *Phoenix: A Top Ten Market for New Office Supply* (Phoenix: Arizona Builders' Exchange, 2017).

29. Code of Federal Regulations, Title 40–Protection of Environment, and Title 42–Public Health, 2011.

30. Arizona Administrative Code, Title 18, Chapter 4, Article 101 (AAC R18-4-101; 1998).

31. Code of Federal Regulations, 40 and 42.

32. National Science Foundation, Protocol 151 (2001).

33. Although ADEQ and IPC do not mention rainwater to potable systems within existing code, it is promising to note that the International Code Council (ICC), the body which oversees the IPC, has been formulating and reviewing a new rainwater to potable code over the last four years.

34. Thomas and Ford, *The Crisis of Innovation*, 55 (see n. 4).

35. Arizona Administrative Code, R18-9-701.4 (2016).

36. Arizona Administrative Code, R18-11-300 (2009).

37. Arizona Administrative Code, R18-9-700 (2016).

38. Arizona Administrative Code, R-18-11-304 (2016).

39. Ibid.

40. International Plumbing Code, 1302.2.1 (2015).

41. California Assembly Bill 1738 (2016) creates a definition of "Dark Greywater" that would include kitchen sink and dishwasher water within potential recycled water systems. Washington State allows kitchen sink water to be reused as gray water in such projects as the Bullitt Center.

42. Arizona Administrative Code, R18-9-E303 (2005).

43. Code of Federal Regulations, Environmental Protection Agency, 40 Chapter 1 Part 257, 2011.

44. International Plumbing Code, 701.2 (2015).

45. King County Board of Health Code, Chapter 13.04.050 (2011); and International Living Futures Institute, "Water Petal Case Study: Bertschi Science Wing and Bullitt Center," ILFI, September 2016, accessed December 10, 2017, https://living-future.org/wp-content/uploads/2016/10/Bullitt_and_Bertschi_School_Water_Case_Study.pdf.

46. Moore and Wilson, *Questioning Architectural Judgment*, 30 (see n. 1).

47. Ibid., 3.

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