TECHNICAL PAPER

DISTRIBUTED WATER INFRASTRUCTURE FRAMEWORK AND POSSIBILITIES

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Water Environment Federation
the water quality people®

Prepared by:

WEF Distributed Water Infrastructure Task Force

WEF DISTRIBUTED WATER INFRASTRUCTURE TASK FORCE

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

EXECUTIVE SUMMARY

Around the world people are facing mounting water challenges with acute stresses caused by population growth, changing climate, water scarcity, and resource constraints. Considering all options for protecting public health and the environment while ensuring safe, affordable, dependable, and resilient water infrastructure is critical.

The purpose of this report is to briefly discuss the issues with current water resource management systems, and to present a detailed analysis of Distributed Water Infrastructure (DWI) as an important, viable, and effective solution to current and future challenges with water resource management.

The Distributed Water Infrastructure Task Force (DWITF), established by the Water Environment Federation (WEF) in 2022, examined the current state of infrastructure and considered how future needs can be met. Through this process, we evaluated the differences between centralized, distributed, and decentralized water infrastructures, including the specific characteristics of each approach.

The majority of design approaches used today are variations of systems developed for challenges faced 50 or more years ago. DWI systems offer proven approaches using technologies that can be more safe, efficient, cost effective, flexible, and reliable than centralized systems. We must develop a better understanding of the costs and benefits of different water infrastructure and management approaches.

In this report, the DWITF presents a clear definition of DWI, highlighting its different aspects, benefits, and challenges, so that its role in and benefits for water resource management can be fully understood and championed.

The DWITF defines and analyzes the different aspects of DWI, including control, implementation, owner, and beneficiary elements necessary to achieve the shared goal of safe, affordable, dependable, and sustainable water management. The report highlights DWI challenges, such as public misconceptions and lack of government funding, regulations, and policies. It also defines the benefits of DWI, including affordability and social justice.

The report identifies a series of recommendations and pathways for innovation and improvement to assist in understanding the variety of needs and requirements. These recommendations include efforts to create appropriate policies and regulations, opportunities for education and outreach, and solutions for challenges related to organization and ownership models, finances, community, technology, and equitable access to water services. Supporting case

studies give insight and examples of the array of sustainable benefits offered by DWI systems.

Present and emerging technologies are already available to build resilient infrastructure through the diversification of water portfolios, and DWI provides a relevant and applicable approach for innovation at all scales and in all types of water resource management systems.

A call-to-action concludes the report, encouraging water professionals to "unite to be the force that shifts the water paradigm," to confront one-size-fits-all methods, and to embrace the social and technological benefits offered by Distributed Water Infrastructure.

INTRODUCTION

The need for resilient, sustainable, and quick-to-implement solutions for water distribution infrastructure is widespread and growing. Communities around the world are at an inflection point as leaders rebuild our water/wastewater infrastructure to match current and future needs; scientific understandings and technological advances are now available to elevate resource efficiencies. The time has come to recognize Distributed Water Infrastructure (DWI) as a strategic and essential component of all water-related infrastructure.

The novel applications that collectively define the portfolio of DWI are currently in the "innovators" phase of the technology adoption curve in most U.S. communities — it takes time and understanding for a society to embrace emerging technologies, and even longer for them to become commonplace. Take the distributed electric power generation through rooftop photovoltaic cells as a model. Twenty years ago, rooftop solar, still a relatively new technology application, was deemed too expensive and inefficient for home-scale applications and faced many barriers by electric power utilities, which were built around large, centralized oil and gas-based power plants. As society recognized distributed renewable energy as a critical component to solving the planet's climate crisis, rooftop solar became common in most cities, and part of nearly every electric utility's portfolio.

The same trajectory can become a reality for DWI, with current efforts to recognize and implement DWI as a viable solution for water recourse management.

To support these efforts and raise DWI awareness, the Distributed Water Infrastructure Task Force (DWITF) was created, providing effective and focused leadership through collaboration with Water Environment Federation (WEF) committees, WEF members, regulators, municipalities, and others. One of the DWITF's first efforts includes the creation of this report. It establishes background on the definitions, benefits, considerations, areas for further advancement. The report also encourages further investment in financial, regulatory, and system integration of smaller-scale systems, particularly those that use novel technology and/or new applications.

Over 60 water professionals from a wide variety of backgrounds were invited to participate in the development of this report and contributed ideas, authorship, and review of the document. The DWITF specifically sought to highlight a diverse set of voices, including those who work as entrepreneurs, inventors, municipal and government leaders, engineers, and citizen advocates. We included experts experienced with communities ranging from megacities with strong financial and human resource capabilities to small communities that are chronically under-resourced. We worked to include human considerations such as finance, regulation, design, and ownership, as well as environmental considerations like climate adaptation, resource recovery, pollution elimination, and water conservation. Although the topic is immense, our goal is to introduce key elements, raise visibility, and make recommendations to advance the understanding and incorporation of DWI into the broader repertoire of solutions.

What is Distributed Water Infrastructure?

Within the context of the Water Environmental Federation (WEF), Distributed Water Infrastructure Task Force (DWITF), and this report, we define Distributed Water Infrastructure (DWI) as water infrastructure or systems serving single or multiple properties within one neighborhood or district that are managed by a professional management entity known as Responsible Management Entity (RME).

DWI systems serve a range of customers providing water supply, wastewater management, water reuse, and related functions, i.e., stormwater management, nutrient recovery, water energy recovery, and other such applications. DWI systems are unique insofar as they are not traditional systems based on a septic tank and soil absorption fields nor are they public utilities regulated by utility commissions. The technical, operational, and financial concerns of DWI systems are different from onsite water supply and recycling systems due to the defining quality of distributed infrastructure requiring professional comprehensive system management, like that of centralized systems.

The term Decentralized Water Infrastructure has been widely used; for the purposes of this paper, however, decentralized systems will be defined as water infrastructure or systems that serve individual properties and are owned and managed by the property owner. Decentralized systems may serve a single occupant or several occupants of a property, and the systems may be connected to other water infrastructure assets.

The distinction between Decentralized and Distributed (Table 1) can be found in the requirements for management. Decentralized systems can be managed by the property owner. Distributed systems require a recognized RME that exhibits requisite technical, managerial, and financial capacity to either own the water assets outright or be contracted and responsible for the performance of the system.

Table 1: Decentralized vs. Distributed Water Infrastructure

Aspect	Decentralized Water Infrastructure	Distributed Water Infrastructure
Definition	Water infrastructure or systems that serve individual properties and are owned and managed by the property owner.	Water infrastructure or systems serving single or multiple properties within one neighborhood or district that require either ownership or management by a professional management entity (Responsible Management Entity, RME).
Example Assets	Onsite wells, septic systems, rainwater cisterns or rain barrels.	Building, neighborhood, or district water, stormwater, wastewater or water reuse systems.
Public Health Risk	Health exposures are limited primarily to users that live or work at this location.	Health exposures affect a larger population that include residents, visitors, students, employees, business customers, etc.
Performance Risk and Responsibility	Property owner assumes risk and responsibility for compliance and system performance.	Qualified RME assumes risk, controls delegation of responsibility for compliance/system performance, and manages operations professionally.
Financial Risk	Property owner is fully responsible for asset management and system performance costs.	RME assumes the financial risk entirely as the system owner or shares the financial risk with the property owner via a professional service contract.

The DWITF recognizes that there are many regions and jurisdictions that use the terms "decentralized" and "distributed" interchangeably. Specifically, the U.S. Environmental Protection Agency (EPA), and Swiss Federal Institute of Aquatic Science and Technology (also known as Eawag) offer definitions that industry leaders acknowledge and accept. The overlap of these definitions is expected, yet the DWITF emphasizes the distinction between definitions within this report for clarity. These key distinctions are primarily associated with risk, responsibility, and management: who assumes risk, who controls the delegation of responsibility for compliance/system performance (e.g., licenses, qualifications, etc.), and whether there is professionally trained management within operations.

Distributed Water Infrastructure Task Force

In September of 2019, the Environmental Protection Agency (EPA) released the

National Water Reuse Action Plan (WRAP) for public comment (United States EPA, 2020). Since that public comment period, the Action Plan has continued to develop, building upon existing science, research, policy, and technology, using both national and international experiences to encourage and accelerate water reuse across water sectors, such as agriculture, industry, potable water and wastewater systems. The Action Plan describes how agriculture, industry, and communities have demonstrated the value of locally managing and reusing water, largely in response to various forms of water crises such as drought, source water contamination, or costs for extending larger systems.

Managing water to promote reuse also presents major opportunities for planners, designers, and RME to design, build, and manage DWI while appropriately and effectively treating to "fit for purpose specifications" and meeting public health and environmental requirements. The EPA acknowledges that this approach can promote effective and efficient management of water infrastructure systems to improve the security, sustainability, and resilience of the U.S. water resources.

In 2021, WEF took several well-received steps to explore the growing interest in DWI. That spring, WEF and its members partnered with UNLEASH (United Nations backed global innovation program developed to tackle UN Sustainable Development Goals) to brainstorm innovative solutions to the sanitation challenges faced by the small towns and rural residences in Alabama's Black Belt region.

In June 2021, then-WEF President Lynn Broaddus hosted a Distributed Infrastructure Roundtable for twenty-three participants. At the time, WEF's membership structure had committees (now called communities) for those working on collections systems, management, biosolids, and other sub-specialties, but not one for people working on small-scale or distributed systems. The roundtable gave voice to the growing cadre of professionals interested in these systems.

In the subsequent months of 2021, WEF added programming related to distributed technologies. WEFTEC 2021 intentionally incorporated DWI exhibitors and speakers, and the standing-room only crowds gave a clear indication of attendee interest. WEFTEC 2021 also hosted a learning exchange for practitioners in DWI. Those conversations highlighted the needs and interests of water professionals who were working on innovative, small-scale systems.

Building on the activities of 2021, over the summer of 2022, WEF's Committee Leadership Council announced the creation of the Distributed Water Infrastructure Task Force (DWITF) and elicited a call for leadership and liaisons from other WEF committees. As part of its broad set of responsibilities, the DWITF wanted to put forward a paper to explain DWI and its role within existing water infrastructure. The task force also wanted to identify barriers and recommendations that, considered collectively, could increase society's options for sustainable management of water and sanitation.

This attention on small-scale infrastructure is well timed. Such infrastructures often reduce water and energy consumption, provide increased resilience and nimbleness, and support local water cycles by reducing long-distance transport of water, WEF's most recent strategic plan calls on WEF to lead the transformation to a circular water economy — DWI is a critical tool in this transformation.

Wise management of water resources continues as a multisector challenge. Within the WEF membership, and with members of many other partner non-profit and professional organizations, DWI issues influence watershed decisions, utility management approaches, and challenges associated with wastewater microbiology, particularly the pathogen and infectious disease concerns. Groups with interest in DWI include National Environmental Health Association (NEHA), National Onsite Wastewater Recycling Association (NOWRA), Building and Plumbing Code Enforcement Agencies (ICC and IAPMO), and others. This DWI report intends to have wide applicability throughout the water industry.

Evolution of Water Infrastructure

The Clean Water Act in 1972 sought to implement centralized wastewater infrastructure as the primary means of eliminating water pollution; as a result, centralized wastewater systems serve approximately 75% of the U.S. population today (United States EPA, 2024). At the outset, decentralized wastewater systems (generally septic systems and cesspools within communities) were considered temporary solutions to be replaced by centralized systems, and the technical, financial, and managerial aspects of these systems remained unaddressed.

By contrast, the Safe Drinking Water Act of 1974 focused on the public health risks associated with potable water supplies that served 25 or more individuals and was typically adopted by states as the standard for all water supplies. Thus, it provided a more balanced view between individual on-site wells, small community systems, and larger regional supplies. The two laws evolved on non-intersecting paths, with different scientific drivers and different financial mechanisms. This evolution separated into two distinct categories: water pollution elimination (i.e. environmental health) and safe drinking water supply (i.e. human health).

Providing centralized solutions for everyone was not possible given the lower density populations and more complex environmental challenges found in rural areas. By the mid 1970s, high-growth suburban municipalities were striving to control sprawl through planned unit developments and cluster developments, helping to preserve open space and allowing for better planning of all infrastructure. However, such controlled growth was not adequately achieved with individual septic systems and smaller community scale systems.

The U.S. Congress and the EPA expressed interest in the utilization of decentralized wastewater management options in the late 1990s, in the development of the Decentralized Wastewater Management Guidelines (United States EPA, 2000) and the accompanying Management Handbook in 2004 (United States EPA, 2004). The guidelines recognize that all wastewater treatment systems, from traditional septic systems to those using advanced treatment, need to address system management.

Resolving the matter of septic management was left to individual states and communities. Decentralized wastewater systems, the category label originally used for septic systems, became formally recognized on a federal level in the early 2000s. As systems design and technology improved, the EPA put forth voluntary management guidelines. Nonetheless, the issues faced by centralized systems continue to take priority nationally.

The EPA Management Guidelines describe two levels for professional management as RME operation and RME ownership. In these models, the RME can operate a system under contract with an owner or the RME can own and operate the system.

Under the RME Ownership model the objective is to provide professional management of the planning, siting, design, construction, operation, and maintenance of wastewater treatment, beneficial reuse and dispersal systems through ownership and management of systems within defined service areas. Under the RME Management model, the objective is to ensure that systems consistently meet their stipulated performance criteria through an entity responsible for operation and performance of systems within their service areas. Regardless of the model, the residents and customers in the affected community are responsible for paying for a vital service.

As population growth continued in rural areas, many states improved the design and management protocol for decentralized systems and began allowing cluster or community systems for multiple homes, with requirements for better financial and management controls. Such cluster-scale options became important in growth areas where limited water allocation and restrictive soil, geologic, and groundwater characteristics limited development with individual systems. In addition, land use regulations began allowing homeowner associations (HOAs) to be responsible for a wide array of shared community systems, such as recreation facilities, roads, drainage, stormwater, and in many cases, water and wastewater infrastructure.

However, success rates and experiences with alternative infrastructure ownership models varied depending on how they were controlled. In some instances, regulators recognized that community-scale systems were vital to municipalities and provided necessary oversight, assuring the systems' success. When done well, these distributed systems became the long-term water and wastewater infrastructure for their communities. Many of them have been able to address site, soil, and resource allocation issues using distributed systems.

In addition to improved management of smaller community systems, beneficial uses of treated water progressed throughout the industry. Many systems implemented spray and drip distribution of treated effluent as enhanced means of groundwater recharge and as key system components that were well-adapted to rural and suburban areas and easily implemented with smaller infrastructure. Such advances provided better protection of water resources through nutrient reduction or recovery and improving water balance within watersheds.

The green building movement highlighted the need for better small-scale water resource solutions for all new growth, with a focus on urban areas previously served solely by centralized infrastructure. This movement not only increased attention to this need, but it also accelerated innovation. The U.S. Green Building Council's LEED program, together with the efforts of cities such as San Francisco and New York, helped drive water resource recovery projects forward. During this era of new technology and new applications the term "distributed infrastructure" emerged, referring to new hybrid system models that followed implementation and management practices common to centralized systems.

The historical improvements in siting, sizing, designing, permitting, and managing have fostered the opportunity to apply distributed water reuse and resource recovery as core components of water infrastructure. The EPA Water Reuse Action Plan recognizes the potential to incorporate DWI in water management programs. Because the improvements associated with distributed systems are beginning to be incorporated into local rule, the opportunities for distributed water reuse are emerging as a significant aspect of resource recovery within local programs, and businesses focused on stormwater/rainwater capture and use are experiencing unprecedented demand (Stark, 2024).

SYNERGISTIC SEGMENTS OF WATER INFRASTRUCTURE

Achieving a holistic understanding of water infrastructure requires analyzing infrastructure from various perspectives. Distributed Water Infrastructure evolved from and functions within a water infrastructure paradigm divided into control, implementation, owner, and beneficiary segments. In turn, these segments are composed of overlapping commercial, public agency and individual roles, relationships, and responsibilities; together, they must achieve the shared goal of safe, affordable, dependable, and sustainable water.

Achieving the desired shared goals depends largely on providing the right resources and finding the right balance of risk and reward for the individuals and institutions that operate within each water infrastructure segment. Even though DWI systems offer many advantages that outweigh prospective detriments, DWI systems are the result of gaps in the existing paradigm that encouraged many to seek better alternatives. Understanding the dynamics of how each segment is motivated and deterred is critical for understanding why DWI's exist, why there are so few, and what needs to change for DWI to become a core component of all water infrastructure.

By detailing the unique roles and responsibilities, operating practices, and challenges within each segment of water infrastructure, we can better understand and portray their individual needs, resistance/appetite to change, and perspective regarding DWI. Figure 1 presents a diagram distinguishing the four segments — Controller, Implementer, Beneficiary, and Owner — according to their responsibility, who they are, and their roles, together with what barriers and challenges they face.

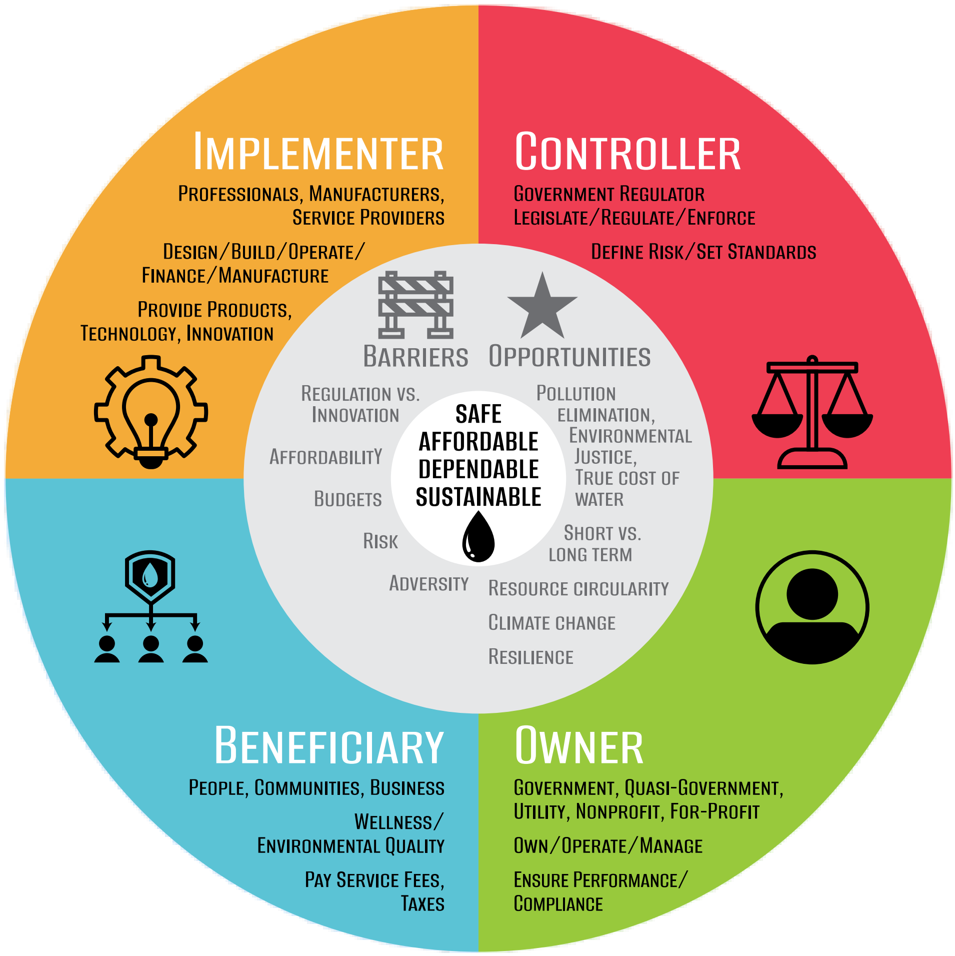

Figure 1: Synergistic Segment Roles and Responsibilities

Controller

All aspects of the water service industry are controlled by legislation and regulations that identify public health and environmental risks, establish public health protections, and determine acceptable levels of pollution. Legislation enables water-related regulations and controls for the allocation of funds. It has varying degrees of control and/or oversight of how funds are used and what customers can be charged for services. The controllers are the institutions and agencies that discover and define risk, establish performance requirements to protect public health and the environment, and ensure dependable and trusted service across all forms of infrastructure — decentralized, distributed, and centralized.

Controllers also determine who is responsible for water infrastructure, establish the boundaries of service areas, determine how significant industrial users manage their use of the infrastructure, and establish a minimum level of service that must be provided to customers. In addition, government entities monitor systems to assure that their regulations are enforced and often penalize owners for not meeting compliance requirements.

Beyond legislation and regulations, the controller dictates the allocation of funding, which to date has focused almost entirely on centralized infrastructure, leaving the 25%–30% of the population that utilize decentralized and distributed systems to their own devices (NOWRA, 2018). This funding helps to reduce cost burden, allowing for reduced user rates for the customers that have centralized services. To date, however, it lacks any significant access by DWI, which offers benefits to a wide spectrum of customers that are both within and outside of centralized service areas.

The controller is motivated to be diligent in identifying current and pending risks and keeping water services affordable and accessible to everyone. The "One Water" awareness currently present within the water industry could now empower the controllers to consider the role that DWI can play in reaching the common goal of safe, affordable, dependable, and sustainable water services.

To achieve widespread application of DWI and help reach the common goal, the controller segment must be empowered to revise regulations and update accepted standards to promote DWI alternatives, where applicable, from various perspectives, including financial, performance, ownership, and implementation.

Implementer

The Implementation segment consists of an array of businesses that provide essential services to system owners for delivery of the assets, operating supplies, and services.

This segment of the water infrastructure industry is diverse and includes engineers, builders, manufacturers, chemical and product suppliers, and other services such as contract operators, hauling and disposal, specialty repair services, and power supply utilities. The implementation segment has great influence over the means and methods that owners utilize to fulfill their obligations to both beneficiaries and controllers.

Other services such as finance, insurance, and legal services are included in this segment too. Services vary based on location, system capacity (centralized vs. DWI), and the specific nature of treatment — groundwater, surface water, domestic wastewater, industrial wastewater, level of treatment, etc. Implementers follow regulations and standards specific to their services and often, mainly within the public infrastructure market, are required to post performance bonds that establish direct financial risk. As a result, Implementers that service the centralized infrastructure market are organized as large-scale infrastructure engineers, builders, manufacturers, and their innovation and solution sets are targeted to that market.

Those that service the DWI market have traditionally been mid-sized businesses that often utilize design-build-operate contracts to streamline procurement process and absorb a higher degree of performance risk that sometimes includes RME/ownership responsibilities. Consulting engineers who service the centralized infrastructure market tend to be risk-averse and oriented towards quality of service, thus they do not typically service the DWI market.

The scale of DWI businesses allows for diversification in systems and services integration that can go beyond water to include elements such as renewable energy, heat energy, and nutrient recovery. Unlike the centralized infrastructure market that is mature and structured to serve monopoly owners that have been in place for many decades, the DWI market has a competitive profile that requires businesses to drive innovation forward to remain competitive.

Beneficiary

The customer is typically the direct beneficiary of the water utility service that strives to provide safe, affordable, dependable, and sustainable water management in all its forms. However, the entire community benefits from the growth and economic vitality the infrastructure facilitates.

Beneficiaries drink the water, enjoy water recreation, pay the fees that fund the owners, pay taxes that fund controllers, and vote for the politicians who legislate the regulations and manage the regulatory agencies. In addition, beneficiaries enjoy the overall wellness and quality of life that comes with having a clean water environment.

Therefore, beneficiary education about water is critical for establishing a broad understanding of the value of and risk associated with water. A 2021 Gallup poll indicated that 56% of Americans worry greatly about contamination of drinking water and 53% worry greatly about pollution of rivers, lakes, and reservoirs (Brenan, 2021). Yet, an opinion poll conducted by the American Water Works Association indicates that 73% of American adults with public (centralized) water supply view the water at their taps to be safe (Morning Consult, 2023). These opinions are impacted when droughts require water use restrictions, when contaminated water supplies trigger boil water alerts, and when overflowing sewers discharge raw sewage into waterways. However, these opinions still reflect a general sentiment that beneficiaries with access to centralized water infrastructure are happy as long as the rates remain affordable. This is even considering the American Society of Civil Engineers (ASCE) Infrastructure Report Card, which most recently issued grades of C- for drinking water, D+ for wastewater, and D for stormwater.

The green building movement that began in the late 1990s created beneficiary compassion and motivation beyond short term economic value. It promoted DWI systems because they were more affordable on a comprehensive life-cycle basis and more dependable in the face of natural and man-made threats, provided better protection of public health and environmental quality, and adapted better to global challenges such as aquifer depletion, emergent pollutants, and climate change. As a result, many DWI systems became part of green buildings that are located in areas served by centralized infrastructure. Such projects have demonstrated how DWI can effectively overlap with centralized infrastructure, helping to achieve incremental water infrastructure improvements without large scale infrastructure projects.

Owner

The Owner provides the necessary asset management and operation services that ensure compliance with regulations and service the beneficiary needs. The owners, therefore, hold primary responsibility for system performance and customer satisfaction, and their success requires efficient management and careful planning to meet the needs of their customer base affordably while supporting a vibrant local economy. This applies to both centralized and DWI systems, and can be achieved with contracted management services.

The system owner may be both the asset owner and the RME, but in some circumstances, the owner might contract with a management entity to operate and maintain and to assume performance responsibility for DWI.

Distributed Water Infrastructure sets up an ownership paradigm that is competitive, and owners must provide better customer value to win market share, both within and beyond current centralized infrastructure service areas. This approach encourages innovation and has the potential to reward DWI owners that exceed regulatory requirements and provide other resource recovery services beyond water. Services such as water reuse, thermal energy recovery, evaporative cooling services, renewable energy production, nutrient recovery, and food waste composting are examples of such related services that readily fit within the DWI model. Therefore, DWI is a more competitive and higher risk/reward model of water infrastructure ownership when compared to conventional centralized system ownership.

Relationships Between Synergistic Roles

The relationship between these synergistic roles is often based on necessity and requirements within the regulatory framework. Additionally, there are financial exchanges that occur between these segments for an individual project to meet the requirements set forth within the rule. Figure 2 presents a diagram distinguishing the exchange of goods and services that may occur during the life of a DWI project.

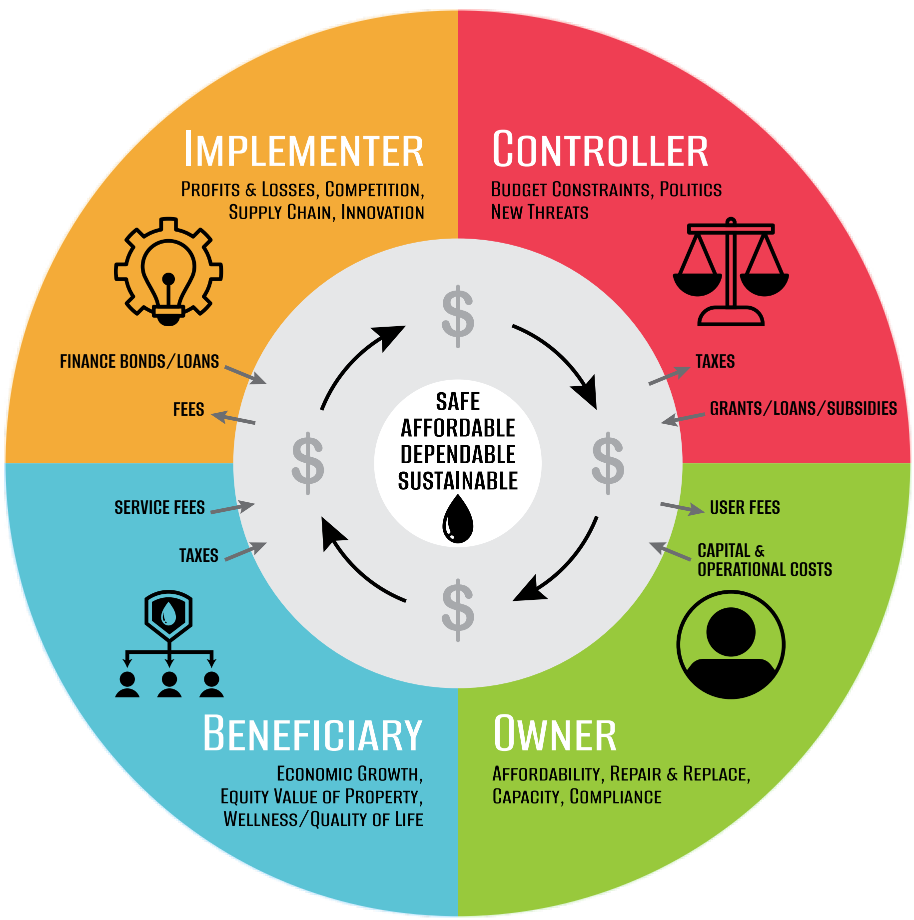

Figure 2: Synergistic Segments Financial Responsibilities

BENEFITS OF DISTRIBUTED WATER INFRASTRUCTURE

For nearly half a century, tying communities together with publicly owned water distribution and wastewater collection systems, along with the accompanying centralized treatment plants, has been the apex of infrastructure design. However, infrastructure design is evolving as communities and the environment change. DWI can be an effective approach for addressing multiple goals that go beyond basic service delivery and permit compliance. Some of these benefits are highlighted in this section.

Providing Fit-for-Purpose Service

Like industrial systems that are designed for specific uses and desired water characteristics, DWI can be tailored to its users' needs. This unique characteristic allows system customization, rather than an inflexible one-size-fits-all approach. For instance, DWI could allow for the treatment of some water to potable standards or apply less stringent treatment processes, which also means less demand for energy and/or chemical inputs, for appropriate applications (e.g. irrigation, clothes washing, or other non-potable uses).

Minimizing Disruption to Local Hydrology

Distributed water practices typically reduce inter-basin transfer and aquifer depletion. Keeping the water local provides the opportunity for localized water balancing.

Raising the Bar on Distributed Water in NYC

What began in 2003 as a bold water conservation initiative orchestrated by the Battery Park City Authority, now numbers 10 non-potable water reuse systems distributed around New York City (NYC), many of which have been operating for more than 15 years. With projects demonstrating excellent water conservation performance, NYC more recently began targeting combined sewer overflow mitigation in addition to water conservation.

The Domino Park Redevelopment District in Brooklyn now stands to raise the distributed water performance bar even higher and help minimize CSO (combined sewer overflow) discharge by treating 99% of the wastewater produced from five high-rise buildings, providing supply of non-potable reuse water, and releasing highly treated excess non-potable water to the adjoining East River. Slated to open in 2026, this project is revitalizing the waterfront, reducing potable water demand by approximately 50%, and eliminating 400,000 gallons per day of wastewater that would otherwise contribute flow upstream of a CSO discharge.

"Distributed water infrastructure projects are helping New York City to optimize capacity in our centralized infrastructure and support sustainable urban development. The Domino Park project is the first reuse project to employ a true public-private financial partnership through a grant program and rate discounts from the City. We see this approach of shared responsibility for sustainable water management as a model for the future," stated Alan Cohn, Senior Policy and Science Advisor, NYC DEP.

For further information see https://www.epa.gov/waterreuse/water-reuse-case-study-brooklyn-ny

Surviving Superstorm Sandy

In 2012, Superstorm Sandy devastated wastewater treatment plants along its path. The Passaic Valley Sewerage Commission's Newark Bay facility[i] was inoperative nearly a month before secondary treatment was restored and took more than eight months for full compliance. Fifteen miles east, flooding affected ten of New York City's 14 centralized plants and nearly half of its 96 pumping stations.

However, 80 building-scale treatment systems in New York City and elsewhere in the Northeast U.S. were fully operational within 24 hours of the storm — as soon as power could be restored. These small systems, built and operated by Natural Systems Utilities (NSU; Hillsborough, New Jersey), relied mostly on membrane bioreactors. Widespread power outages temporarily shut down treatment, but because the facilities were not damaged with floodwaters, operators were able to quickly get back-up generators in place to keep services humming. NSU CEO Emeritus Ed Clerico recalled that experience and said, "Membrane bioreactors can shut off for a bit and come back quickly. We were never long without power, thanks to good coordination from our team."[ii]

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[i] *https://www.nj.gov/pvsc/home/forms/pdf/Superstorm_Sandy_Update_2014a.pdf*

[ii] *High Marks: Distributed, building-scale treatment systems can recover quickly by avoiding flood zones. Lynn Broaddus. Water Environment & Technology. May 2022. p. 73.*

Reduced Leakage or Infiltration

Alternative collection and distribution technologies (often used in DWI systems), such as variable grade low-pressure sewers or self-contained building-scale systems, result in little to no leakage or inflow. Because systems are typically smaller, QA/QC during installation can be easily done. Smaller systems allow for straightforward operation and maintenance, such as leak detection, identification, and remediation of problem areas.

Rapid and Efficient Project Delivery

Given the smaller nature of DWI, project mobilization and execution times typically take one to two years and are coordinated with related property development activity or specific infrastructure improvements. This timeline contrasts with the decades often required for the deployment of centralized projects. The asset readiness and infrastructure funding can be coordinated with the customer base so they are in alignment and the costs are more closely executed with associated payback.

Security and Resilience

Resilience is the ability to avoid or to operate following catastrophic events. With the growing recognition of water as a finite and valuable resource, coupled with increasing risks and impacts of potential water-related issues, water security and resilience has become a growing concern with centralized water infrastructure development and sustainability.

Distributed Water Infrastructure typically does not span long distances, cross streams or floodplains, or prevent shared use of transportation corridors. This flexibility in placement prevents exposure and potential damage from routine natural forces and disasters. When they do experience an outage, DWI systems can rebound quickly due to the modular nature and ease of working on smaller systems, which often have the capability of functioning without centralized services (e.g., capable of working on a microgrid and/or using local renewable energy supplies). As more frequent extreme weather events continue, the importance of resilience increases.

System Integration

Multiple DWI systems can integrate well with localized resource recovery practices and offer the potential to build redundancy and expanded capacity into large water or wastewater networks. This integration can be easier or more efficient with DWI because this infrastructure is often located near the customer and typically integrated into the customer's building or property. As such, DWI can more readily take advantage of other water and waste related

Adopting Groundbreaking Onsite Reuse Regulations

Led by the efforts of the San Francisco Public Utilities Commission (SFPUC), San Francisco, California, became the first municipality in the USA to adopt a groundbreaking program for buildings to collect, treat, and reuse water onsite to meet non-potable demands such as toilet flushing and irrigation.

San Francisco's Onsite Water Reuse Program established a streamlined process for allowing alternate water sources, such as rainwater, stormwater, foundation drainage, greywater, and blackwater, for reuse in commercial, mixed-use, and residential buildings.

The SFPUC supports the implementation of onsite non-potable water systems in public and private buildings through its local oversight and management for public health protection. The program includes a city ordinance that clarifies the roles and responsibilities of each city department: SFPUC, San Francisco Department of Public Health-Environmental Health, San Francisco Department of Building Inspection, and San Francisco Public Works.

While the program began on a voluntary basis in 2012 with the SFPUC first onsite blackwater treatment system at their own headquarters for toilet and urinal flushing, it became mandatory in 2015 for new development projects with a footprint of 250,000 gross square feet (gsf) or greater. In 2021, the threshold for new developments was lowered to 100,000 gsf or greater. Today, more than 40 decentralized water systems are operational and 30 are in the planning phase.[1] The SFPUC provides financial incentives to incorporate heat exchangers to produce thermal energy with greywater and blackwater systems.

opportunities without the need for lengthy and complex piping networks or facilities.

Avoided Capital Expenditures

Distributed Water Infrastructure systems accommodate economic growth and redevelopment of communities, often without the expense and disruption created by expansion of centralized systems.

Conservation, Resource Recovery and Efficiency

DWI provides many more opportunities for water and waste separation and local treatment to promote water conservation, resource recovery, and energy efficiency.

Conservation of water by offsetting additional freshwater consumption through collecting and using alternative source water can significantly reduce potable water demand. Capturing and using thermal energy from water systems can result in heating and cooling efficiency and long-term savings by employing heat exchangers to recover heat rather than consuming fossil fuels in system heating and cooling. Recovering usable resources can allow for the recycling of these resources resulting in circular economy benefits.

Many DWI examples illustrate recovery of resources and conservation of materials and energy for more efficient management. Some of these examples include:

- Nutrient recovery via urine separation, dry toilets, or vacuum flush toilet water separation can promote water conservation, waste composting, and recovery of ammonia.
- Non-potable water (precipitation/rainwater, air conditioning condensate, greywater, blackwater) can be treated as needed, distributed, and used for a variety of purposes like toilet flushing, irrigation, cleaning, vehicle washing, and other industrial uses.
- Water reuse can build drought resilience by ensuring that potable water supplies are not needed for non-potable uses, and to ensure that treated water is recharged to aquifers and to maintain base flows to streams[1].
- Energy can be produced via anaerobic digestion of organic, biodegradable waste.
- Thermal energy (heat) recovery from wastewater can reduce other energy needs and provide heating or cooling at a campus or district scale[2].

[1] *See also: https://www.epa.gov/water-research/non-potable-environmental-and-economic-water-reuse-newr-calculator*

[2] *See also: https://nationalwesterncenter.com/about/what-is-the-nwc/sustainability-regen/energy/*

Social & Environmental Justice

The lack of access to safely managed drinking water services, adequate plumbing, effective sewer services, or localized well contamination, often has an unequal impact on underserved communities — disproportionately communities of color (Fedinick & Michele, 2019) — that may be affected by underrepresented perspectives, lower socioeconomic conditions, or barriers to public funding.

Collaboratively developed community-based DWI has the potential to address historical or situational inequities faced by these underserved communities. DWI also can be implemented adaptively into the communities they serve through fit-for-purpose solutions. For example, a community's preferences, limitations, and strengths are considered, ensuring the involvement of the community. Community involvement and buy-in is crucial for the long-term success of any DWI project.

In addition, water services can represent a financial burden to certain communities. In regions with high water prices for municipal water, people pay from 4 to 19% of their income for water and sanitation services (Jones & Moulton, 2016). The adoption of DWI allows for alternative sources of water services, thus providing cost-saving options to communities. As an example, by using on-site rainwater or air conditioning condensate for their non-potable needs, communities can save as much as 38% (Yu, DeShazo, Stenstrom, & Cohen, 2015) of their costs.

Location

Distributed water and wastewater management facilities are at the customer's location — they are up close and connected to their own water resource facilities. Due to their small scale, facilities are designed to be customer friendly, becoming a core component of the neighborhood while preserving property value and quality of life for neighbors.

Service Availability

Distributed Water Infrastructure facilities do not need access to water bodies or natural features that can service large numbers of people or require large flows. Through site-sensitive design, DWI can serve everyone, including those who are widely dispersed over the region, in areas that are less accessible, and in areas that require unique system designs.

Sustainability

Many of the attributes of DWI directly reduce greenhouse gas emissions via reduced transmission of water/wastewater, low energy consumption, energy conservation, potential for resource recovery, and controllable emissions from treatment systems. In many cases, natural vegetation and geologic features can be utilized as components of the DWI processes and thereby provide secondary benefits of carbon sequestration, mitigation of heat island effect, and biodiversity improvement.

CONSIDERATIONS OF DISTRIBUTED WATER INFRASTRUCTURE

Our regulatory, educational, professional, financial, operational, and procurement systems have all been built around centralized water and wastewater systems. Large-scale water infrastructure has become the norm in industrialized society and has advantages that come with incumbency. Further consideration, however, shows that advantages of large-scale systems are not always as cost effective and easy to maintain, especially when viewed from the beneficiary's vantage point or changing regulatory environment.

Economies of Scale

Large-scale projects often appear to be more cost-effective due to economies of scale. However, this perspective is often because externalized costs (e.g. risk of over-building, environmental impact of construction, community disruption, modernization, etc.) are not included in the calculations. Though rarely incorporated into procurement decisions, life cycle analysis (including the cost of maintaining long collection and/or distribution systems) often shows DWI as the most cost competitive.

Finance

Financial institutions, both private and government, are more readily able to finance larger projects, even if they carry a higher risk, due to the administrative capacity and available expertise for evaluating and closing complex business transactions. DWI projects can lend themselves to a blended finance approach and a more public or philanthropic ownership structure due to identifiable assets. However, to date, most DWI, which is specific and higher priced, has been capitalized via private finance, sometimes supplemented by local non-profit financial grants or low-interest loan mechanisms. This approach unnecessarily drives up costs. No specific government finance programs for resource recovery or water infrastructure currently apply to DWI; non-potable water reuse systems are eligible but have not historically been able to access either Safe Drinking Water Act or Clean Water Act funds. This ineligibility doesn't recognize the community benefits of DWI to water resource management and wastewater system enhanced capacity.

Operations Efficiency

From a treated cost perspective, the operations of centralized systems can be more efficient with regards to labor costs under the current regulatory paradigm wherein personal attendance is often required. DWI offers a unique opportunity for cost-effective operations due to its size and efficiency. Automation and cloud-based monitoring and control in small systems will likely replace personal attendance, maintaining or reducing current labor costs.

Regulation

Existing regulations in most areas neither accomodate nor encourage DWI. Hence, they create barriers with regards to

North Carolina Rule Revision Allows Onsite Wastewater Reuse

In 2024, North Carolina implemented new system rules allowing onsite wastewater reuse activities permitted through local health agencies.

Onsite wastewater treatment and reuse encourages effective, sustainable, reliable, and efficient systems. Residents of Wake County, North Carolina, have embraced this through their "One-Water" approach. This effort recognizes a multi-dimensional model incorporating water management, energy management, nutrient management economics, and business management into efforts that are forward looking.

A viable and sustainable demonstration applicable to the Wake County One-Water, decentralized water management goal is fully operational at a demonstration farm near Cary, North Carolina. The project is operating largely off-grid through a combination of solar power, rainwater harvest, and reclaimed water treatment and use. Samples of the harvested rainwater and reclaimed water have been analyzed, and test results indicate all samples comply with NC Water Reuse Standards. The water is harvested and used for indoor applications (toilet flushing) and outdoors in a drip dispersal system. The system is professionally managed by a certified wastewater system operator and the county provides periodic oversight of the operation.

maximizing benefits, ownership, financing, and performance requirements. Regulations prevent government financing options, lack sensitivity to small-scale risks, and tend to require performance control mechanisms typical of large-scale systems. Other location-specific regulations increase the burden on DWI.

In addition, DWI assets are typically located on private property, complicating public ownership options. The lack of regulations specific to private ownership or public-private partnerships creates a barrier for implementation of DWI.

Risk/Reward

DWI can be managed via non-profit and for-profit entities under a wide array of contractual service agreements. These alternatives define system management arrangements, financial roles and responsibilities, and assignment of performance risks and rewards. Whereas to date most DWI infrastructure has been privately financed, current options include combinations of public and private financing. As vital infrastructure components of the built environment located on private property, DWI assets can be secured by the real estate value of the community they serve. Similar to rooftop solar leases, DWI offers a secure investment opportunity and an alternative means of financing infrastructure for beneficiaries. Further, the infrastructure can be developed on an as-needed basis rather than the more traditional all-or-nothing approach.

Delivery Mechanism

The small scale and the private nature of the DWI business allows for more efficient design-build, design-build-operate, and design-build-operate-own methods of providing the assets. Publicly funded projects are often required to use the services of engineering firms charging fixed percentages that incentivize expensive technologies and higher project costs. In fact, the complexities of working with publicly funded projects often limit owners to using large engineering firms.

On the other hand, small projects, which often are a better choice for communities and the DWI models, are not typically of interest to larger engineering firms.

Workforce Development

From engineers to operators, regulators to funders, the workforce is not yet trained to accommodate the needs of smaller scale water infrastructure. Because curricula at colleges, universities, trade schools, and continuing education opportunities are geared toward large-scale centralized facilities, traditional approaches to water treatment continue to be the standard for workforce training.

COLLECTIVE CHALLENGES & BARRIERS

Although DWI is becoming more common in water resource management conversations, DWI implementation continues to face many challenges and barriers. Those who control, use, benefit from, or own/manage these systems each have distinct challenges. We combine many of them in the following list to highlight some of the shared obstacles associated with DWI implementation.

Policy and Regulations

The water and wastewater industries are generally tailored to conventional centralized water infrastructure and based on laws that did not address or anticipate DWI when they were passed. Although this is changing, laws, regulations, and ordinances at the national, state, and local levels restrict or do not adequately support planning, finance, design, permitting, construction, operations, maintenance, and management of DWI systems.

Nationally, environmental or public health standards or guidelines for DWI are inadequate. Regulations for small-scale water provisioning and wastewater treatment may exist for rural single-family residential applications but are often absent for intermediate scales (e.g. multi-residential building, commercial buildings, neighborhoods, districts). Finally, a lack of knowledgeable and experienced designers and policy makers to develop and support codes and regulations impedes greater application of DWI.

National and International Approach for Supporting DWI

The absence of a national strategy regarding DWI education, advocacy, planning, implementation, management, and sustainability impedes progress of DWI solutions. In addition, few coalitions exist with international DWI experts that focus on a systematic approach to DWI systems.

Other issues include the scarcity of national standards (e.g. plumbing codes) and other nationally applied code applications, and limited examples of case studies and coordinated research of demonstration projects, monitoring, management, and technology transfer.

Organizational Structures, Capacity of Governments, Utilities, and Ownership Models

The Distributed Water Infrastructure RMEs are often non-governmental and may compete with municipal or other existing utilities with established management structures and jurisdictions. This conflict limits understanding of DWI and how potential integration can benefit users within a holistic utility setting.

When jurisdictions are responsible for management, they often lack management and regulatory structures for water provisioning and wastewater treatment at scales larger than single-family residential but smaller than a city. And, where necessary, some governmental agencies don't have the organizational capacity for effective program management related to DWI.

As for ownership models, DWI-focused regulatory oversight and accountability of quasi-governmental ownership is limited in assuring proper management and functionality of DWI systems. Insufficient operator certification requirements for technically complex DWI systems limit the ability of owners to guarantee proper operations and maintenance. In addition, certain ownership models can require complex contractual arrangements with delineation of responsibilities, equitable risk allocations, and benefits of each partner. The complexity of these arrangements can lead to challenges in negotiation and implementation, as well as ongoing management and priority differences and difficulty parsing financial viability with public service objectives.

Economic and Financial Challenges

Securing funding for DWI continues to be a challenge. One obstacle is the perception of many designers, consultants, and contractors that DWI are less economic or profitable because of their smaller scale. In addition, because traditional financing models favor centralized systems, DWI implementers are also challenged to secure adequate financial resources for DWI projects.

Public funding for DWI is often unavailable or inaccessible for a variety of reasons, including the lack of federal and state programs for DWI project planning and implementation. Also at different government levels, funding for DWI regulatory programs is insufficient or nonexistent, preventing initiation or expansion of DWI-related infrastructure. Without available and accessible public funding DWI projects often rely on private funding — bringing about another set of challenges.

Communities often suffer when short-term outcomes drive infrastructure decisions toward traditional approaches. Aspects like public perception and the lack of understanding about water resources and services play a role in how open communities are to alternatives such as DWI. Communities may also lack confidence in non-traditional and novel water and wastewater treatment systems and cultivate misconceptions about health, sanitation, and valuable ecosystem services (Curran, 2000).

Public perception of wastewater and stormwater discharges as problems that require expenditures can be a challenge to management. Life cycle value, sustainability, equity impacts, and resilience metrics of infrastructure choices are not transparently expressed, contributing to misconceptions surrounding DWI. As a result, resource recovery efforts are frequently overlooked and become a missed opportunity.

Other community-related challenges include poor understanding of how DWI can complement other (centralized) systems, what water supply quality means, and how treatment technologies have been advancing. Also poorly understood are the consequences of selecting the appropriate management models, including public, not-for-profit, private, or public-private partnership alternatives.

Finally, utility managers and the legal community may not be aware of tools to assist in the development of mechanisms, authorities, protections, and procedures that safeguard DWI communities, users, owners, and utilities.

Technological Challenges and Institutional Barriers

As DWI continues to evolve, new challenges continue to emerge. For example, monitoring technologies and autonomous controls have advanced quicker than their adaptation within safety and compliance regulations, posing a barrier to DWI implementation.

The lack of workforce development programs affects available workforce, and the existing core academic curriculum regarding developing appropriate skills has not kept pace with the workforce needs. In addition, funding opportunities and mechanisms that support research and development of DWI systems and improve technology innovation, readiness, and responsive implementation of DWI systems are limited.

Challenges to Equitable Access to Water Services

Access to water services is not a given, and in many locations seems to be an intractable challenge when using traditional technologies. Wastewater infrastructure development, decision making, and integration throughout the U.S., historically, was determined by groups in power and primarily based on economic drivers rather than the need for local supply and sanitation. The lack of attention to equality in sanitation reflects entrenched structural and management challenges across the U.S. and prevents communities from considering alternatives.

Currently, there is no universal basic-water approach to address the equitable supply of water resources and sanitation. Underserved communities may lack the capacity to select, fund, and implement DWI because of the lack of comprehensive data to know where the problems are (e.g., the EPA's EJScreen tool is not comprehensive).

When it comes to defining “disadvantaged communities,” differences in definitions exist at the state and local level. This can result in the exclusion of some of these communities.

Often, high-profile cases of DWI can be beneficial as an example of innovative implementation. However, these high-profile examples may also gain more attention, including financially, which can be a detriment to other less-publicized cases and result in challenges for the communities in which these are located.

Financially, communities are sometimes burdened with expenses for oversized infrastructure that they are unable to afford. This burden is especially challenging for communities whose population is declining or for whom growth projections never materialized following investments in the new infrastructure (Walton, 2019). Furthermore, small towns have the highest rates of permit violation, often because budgets are inadequate, or operators are in short supply or have competing demands. As a solution, communities may seek to tie into a larger system nearby, though “nearby” may be

Advancing Management Practices

National Blue Ribbon Commission for Onsite Water Systems (NBRC) advances best management practices to support the use of onsite water systems for individual buildings or at the local scale. The NBRC is committed to protecting public health and the environment and sustainably managing water — for current and future generations. The NBRC has made significant research contributions and advanced policies and regulations for onsite water reuse over the past several years.

As a result of the peer exchange, joint policy development, and rigorous research, there has been a shift in the perspective of many participating public health regulators who now have the appropriate framework and tools to develop regulations. States and jurisdictions including California, Colorado, Minnesota, Washington, Hawaii, Austin, Texas, and Vancouver (Canada) are advancing regulations or policies supporting onsite water reuse, while others including New York City and the states of Texas, Alaska, Ohio, and Oregon are considering similar steps forward.

Several documents have been prepared to scale up onsite water reuse water treatment systems across North America, including:

- Blueprint for Onsite Systems: A Step-by-Step Guide for Developing a Local Program to Manage Onsite Water Systems
- Risk-based Framework for the Development of Public Health Guidance
- Model State Regulations
- Model Local Ordinances
- Model Program Rules
- Making the Utility Case for Onsite Water Systems
- Guidance Manual and Training Materials for Onsite Water Systems
- Alignment of health risk-based framework with plumbing codes and standards and product certification organizations

Work underway includes an Operator Certificate Program and an international partnership to accelerate the implementation of integrated decentralized water systems. To learn more: www.watereuse.org/nbrc some distance away. This approach can be ineffective: it can require additional operations and maintenance of additional assets that may be outside of their community. Communities can also lose control over their water/sewer rates based on requirements of the connected utility.

PATHWAYS FOR INNOVATION AND IMPROVEMENT

Barriers are solutions waiting to happen. With time, motivation, creative thinking, and open minds, barriers can be overcome. The following is a compilation of the types of changes that would set the foundation for distributed water infrastructure, easing its incorporation where it makes sense.

Policy and Regulations

Engagement in policy discussions is paramount to provide recommendations to ensure favorable and supportive regulations. The goal is to advance policies that explicitly support and promote the implementation of DWI through collaboration with industry associations, research institutions, and other partners. In addition, providing opportunities for sharing experiences regarding code implementation, best practices, and case studies on localized water reuse, discussions can lead to consistent policies and standards, which minimizes confusion and facilitates greater implementation across regions.

Through discussions, implementers can provide policymakers with evidence-based arguments and case studies that demonstrate DWI benefits. This approach supports the development of consistent and integrated regulations that apply in different contexts rather than piecemeal and patchwork regulations or creation of individual solutions without guidance. For example, dense urban areas have different needs and risks than small towns or rural homes, but all want an efficient, effective, and equitable regulatory system. Model policies allow for variations and customization for local contexts and needs, enabling water reuse and resource recovery adoption across locations and at various levels of government.

Another important aspect of policy discussions is to communicate to the regulatory community the validity and effectiveness of distributed technologies and support collaborative development of guidelines that ensure compliance while recognizing the unique characteristics of DWI systems. Collaboration with regulators helps to establish clear roles and responsibilities for various partners involved in the implementation and operation of DWI, encouraging diverse and innovative solutions while ensuring accountability and compliance.

Outside of regulations, continuing to work together with industry experts, regulators, and community members supports the development of standardized testing and reporting protocols for DWI systems. These protocols include defining performance-based indicators relevant to treatment processes, real time monitoring and reporting standards, and water quality goals of distributed infrastructure. It is also important to draft templates to assist in the implementation of DWI. These templates include developing model legislation as well as memoranda of understanding (MOUs) outlining responsibilities and authorities: a system-based approach to coordinate central and decentralized systems, and standardization of operations, maintenance, and monitoring, and 'REACH codes' (State of Oregon, 2022) that facilitate DWI construction and permitting.

With defined policies, regulations, and implementing protocols, following steps include establishing a streamlined permitting and approval processes for DWI systems similar to other water systems that includes online portals for application submission and tracking and establishing dedicated teams or contact points knowledgeable in DWI systems and applications. Inter-agency access and coordination can harmonize regulatory requirements and reduce duplicate efforts. Adopting environmental or public health standards or guidelines for DWI (e.g. risk-based framework) can provide comprehensive protections beyond those contained in existing regulations. Finally, it is important to develop mechanisms, authorities, protections, and procedures that safeguard DWI communities, users, owners, and utilities.

National and International Approach for Supporting DWI

The success of DWI implementation requires national and international awareness and education. To support global efforts, the recommendation is to translate international, national, and state standards for recycled water and onsite water reuse sources into plumbing codes. For example, the Uniform Plumbing Code (UPC) and the International Plumbing Code (IPC) have developed greywater or rainwater harvesting system guidance; the American Society of Plumbing Engineers and the American Rainwater Catchment System Association have developed standards such as ARCSA/ASPE/ANSI 63-2020: Rainwater Catchment Systems; blackwater systems are under study for future code additions. The United States EPA advocates for many forms of water capture and use including the reporting of state regulatory guidance based on water sources and fit-for-purpose uses where developed (United States EPA, 2024).

Another recommended approach is to create a clearing house that tracks effective regulatory structures for DWI. This effort could be a regulatory exchange, potentially an outgrowth or internal committee of existing national associations such as the Water Environment Federation (WEF), WateReuse

Association, or National Onsite Water Recycling Association (NOWRA).

According to the United States EPA Water Reuse Action Plan (WRAP), a strategy identified for action is to incorporate onsite reuse research into codes and standards for premise plumbing. As such, the promotion, use, and contribution of data to EPA's central hub for information exchange on the implementation of DWI pilot projects and demonstration sites is a must (United States EPA, 2023). By providing updates on research, codes, and standards, a repository for guidance, codes, standards, and examples of real-world case studies can provide valuable insights and best practices for system design and integration. Through additional research and knowledge-sharing, innovative projects and ideas can lead to continuous improvement on uses and innovative applications of DWI.

Therefore, it is paramount to foster global collaboration and knowledge exchange networks among researchers, practitioners, technology developers, owners, operators, and regulators in the field of DWI to improve technological development, best practices, regulatory updates, and policy development. An example of this collaboration, supported by the U.S. Department of Energy, is the National Alliance for Water Innovation (National Alliance for Water Innovation, n.d.) which brings together industry, academic, and National Labs as partners to examine the critical technical barriers and research needed to radically lower the cost, greenhouse gas emissions, and energy of water systems. Research hubs such as this help to establish platforms, such as conferences, workshops, publications, associations, and online forums, to facilitate networking, idea sharing, the dissemination of research findings, and technology transfer.

Organizational Structures, Capacity of Governments, Utilities, and Ownership Models

Distributed Water Infrastructure requires well-established organizational structures to support successful implementation and operations. To support these efforts, recommendations include evaluating the pros and cons of different ownership and management models as they apply to DWI. Options include two models:

- A Public-Private Partnership (PPP) model, which can accelerate private enterprise while ensuring public control of implementation and performance.
- A Non-Profit model, which may fit well for the ownership of water systems, providing some of the benefits of public oversight but with less bureaucracy. Non-profits are mission-driven (rather than profit-driven), often publicly managed, and financially transparent.

To elevate all ownership models, the recommendation is to recognize non-public entities as legitimate operators that provide valuable public services. It is necessary to engage with regulatory bodies and policymakers to establish frameworks that support and validate the role of non-public utilities in managing distributed systems, including addressing territorial protections and regulatory constraints.

Finally, as traditional water utilities begin to incorporate distributed assets into their operations, training and developing DWI operator certification programs to emerging standards of practice for service providers within larger utilities will become an important step to DWI implementation.

Financing the Future

Securing finances for DWI projects are central to the efforts to support its adoption and implementation. To ensure that DWI funding is equitably available to a wide range of communities (not just larger and more prosperous areas that can afford consultants to complete applications), DWI projects, including those installed on private property, must be included in existing federal, state, and local funding programs such as State Revolving Funds to improve implementation.

Beyond government funding, the recommendation is to develop and promote innovative financing models or mechanisms that can be tailored to DWI projects. These include:

- Design-build methods or Construction Manager at Risk (CMAR)
- Public-private partnerships
- Community investment models
- Crowdfunding
- Social impact bonds

Furthermore, dedicated funding streams would provide more accessible financing options for DWI projects. Therefore, engaging with financial institutions, impactful investors, and philanthropic organizations supports the creation of specialized funds specific to implementation of DWI.

Financial efforts should be comprehensive and include aspects that go beyond fund allocation, such as partnerships between government agencies, academia, financial institutions, and industry, to better identify and fund research on innovative DWI technologies, materials, and processes to support demonstration projects, technology transfer, and community engagement. This step would add critical information to advance DWI project acceptance and implementation. Developing risk mitigation strategies that are tailored to DWI projects, with the inclusion of insurance mechanisms, guarantees, or performance-based contracts, will reduce the perceived risk by financial institutions and investors.

Other approaches that can support financial risk assessment and result in greater access and implementation of DWI include:

- Collaboration with insurance providers and industry experts to evaluate and tailor risk management solutions for DWI will result in reducing perceived risk by insurers.
- Collecting performance and cost tracking data in an online tool that includes long-term impact analyses using Life Cycle Assessment (LCA), case studies, and other research reporting on best-possible-scenarios, external costs, and impacts for DWI options.
- Assuring operational performance, inspection, maintenance, and reporting to help protect and preserve property values with DWI project implementation.
- Applying LCA and standardized unit costs with performance to compare DWI and centralized systems.

Fees and costs to the community should also be taken into consideration. The recommendations are to set construction and operating fees at levels that can sustainably support regulatory programs (while still being accessible to the community), and to ensure that local support is sufficient to cover the operation, maintenance, repair/replacement, and inspection of DWI assets.

Community Solutions

Given the community's central role in DWI, a variety of solutions can support implementation of DWI. A comprehensive educational plan is recommended to raise awareness, bridge knowledge gaps, promote better understanding of the many aspects of DWI, reduce perceived risks, and highlight the benefits of DWI. Highlighting successful case studies and implementation of DWI in a local or regional setting can foster dialogue and collaboration — supporting the overall education not only of the

Finding An Affordable Solution For Amesville

In Amesville, Ohio, septic systems tied to 87 homes were discharging surface water and needed to be connected to the municipal sewer. The Rural Community Assistance Program (RCAP) determined that installing a central sewer system for the homes would cost the homeowners $78 a month. Searching for alternatives, RCAP determined that if the state would permit three clusters of decentralized wastewater treatment systems, the cost per home would drop to $40 per month.

RCAP reported to the Small Communities Committee of the Water Environment Federation that they convinced the regional permitting office to permit the clustered approach.

The Amesville wastewater collection and treatment systems were permitted through the Ohio Department of the Environment in 2008.The installations included accommodations for 96 dwelling units within the community. Wastewater is transported to two treatment sites, each on a different stream segment. Total cost for the system was $1.5M with monthly operating costs, including debt service, around $40 per EDU/month.

Rich Earth Institute's Urine Nutrient Reclamation Program

The Rich Earth Institute's Urine Nutrient Reclamation Program (UNRP) is the first and largest community-scale urine-recycling program in the United States. Since 2012, it has operated as a distributed wastewater nutrient recovery system and served as a demonstration platform for the Rich Earth Institute's research and education. Rich Earth Institute received the nation's first permit to produce sanitized Class A fertilizer from human urine. The UNRP collects over 12,000 gallons of urine annually from 250 residents in Windham County, Vermont, through portable toilets, urine collection devices, and urine-diversion toilets in residential, commercial, and portable installations. Source-separated urine is then sanitized through pasteurization and applied as a nitrogen-rich fertilizer to participating farms.

The UNRP addresses both watershed eutrophication and the unsustainability of synthetic fertilizers by lowering the nutrient concentrations in wastewater streams and providing a local source of nutrients to farms.

communities, but also among financial institutions, policymakers, investors, water services staff, owners and implementers, developers, engineers, and other professionals. A few educational approaches are listed as follows:

Outreach and engagement: Develop educational programs for professional, investment, and participant communities and engage water and energy utilities, local governments, and community organizations in active exchanges of input and ideas so that all partners understand the local context and their common interests. These programs should use real case studies to highlight the benefits (e.g., improved water quality, resilience, and cost-effectiveness) and potential challenges of specific DWI solutions. Engage with industry conferences, workshops, and community events to build trust and promote acceptance.

Beyond the parties directly benefited by DWI, incentivizing academic institutions to develop curricula and educational programs on DWI technologies and solutions and the circular economy of water can prepare the next generation of practitioners to design, operate, and manage distributed water infrastructure programs. A specialized, trained workforce oriented around DWI technologies can also provide and support essential services to operate and maintain DWI systems.

Training and professional development: Ensure that staff and existing professionals at publicly owned utilities understand how DWI can complement centralized infrastructure. Develop training and management programs that partner with water utilities, local governments, and communities to collectively educate participants and develop skills in understanding, regulating, and implementing DWI. Provide training on planning, co-design, financing, and operation of DWI to shorten the distance between interested and affected parties and improve all facets of DWI projects. Promote the collection, treatment, and fit-for-purpose use of locally available water supplies (e.g. reuse, stormwater, condensate, rainwater, foundation drainage) and reduction in water demand to offset the need for potable water.

Partnerships: Promote collaboration between entities that share interest with DWI technologies, such as those working on green/living buildings and entities focused on climate adaptation, resilience, energy independence, circular economy, and alternative water supplies (e.g., rainwater and greywater use). This could be accomplished through partnerships with universities, NGOs, professional organizations, and government agencies to develop specialized courses, workshops, and certification/licensure programs.

Community support: Ensure that communities have access to planners, engineers, suppliers, and tradespeople who can provide DWI technologies, services, and guidance like other trades (e.g., HVAC, electrical, and plumbing). Require engineering and economic analyses of alternative

Bullitt Center

In designing its headquarters, the Bullitt Foundation set a goal of designing the greenest office building in the world, adopting the "deep green" standards of the Living Building Challenge. This meant that stormwater needed to be treated on site with nature-based techniques, and that the water supply needed to be generated on site.

The resulting design collects rainwater from a membrane-lined roof that lies beneath solar panels and is then routed to a 255,000 L (56,000 gal) concrete cistern housed in the basement six floors below. Most of the harvested water is used for vacuum toilets, irrigation, and other non-potable needs with only basic filtration.

Potable water needs are met by routing rainwater water through increasingly fine filters followed by ultraviolet disinfection and chlorination. Since the distance from storage tank to end use is generally less than 33 m (100 ft) and most of the building's use is non-potable, the amount of chlorine needed is a small fraction of what municipal water would use. Other additives typically found in municipal water — phosphate and fluoride compounds — and their accompanying environmental footprint are avoided entirely.[1]

[1] *Water Independence: Designing and operating a self-contained onsite water system. Lynn Broaddus. In Water Environment & Technology. November 2022. P. 64*

systems and funding sources so that communities can be more knowledgeable in selection of the most suitable solution for their site-specific needs.

Technological Improvements and Institutional Solutions

Improving technology innovation, readiness, and responsive implementation of DWI systems requires support for a variety of aspects of DWI — from planning to development and management. It is important to:

- Expand funding opportunities and mechanisms that support research and development of DWI systems;
- Develop appropriate and affordable real time performance monitoring systems, regularly collecting and analyzing data to identify potential failures or deviations from expected outcomes;
- Establish reporting mechanisms that can assure regulators and partners when corrective action may be needed and is completed, demonstrating the reliability and effectiveness of DWI systems;
- Recognize that remote and autonomous control technologies are advancing daily. Innovative control technologies along with new sensing, monitoring, reporting mechanisms, and dashboards can assure regulators, improve efficiency of operations, reduce operational and maintenance costs, and reduce risk to operators, owners, and financial institutions;
- Develop robust risk management plans and mitigation strategies that instill confidence in the regulatory and financial communities.

Equitable Access to Water Services

To address the challenge of equitable access to water services it is important to develop water resource management approaches and tools that elevate the value of water resources within the circular economy. Leveraging resources like the EPA's "Closing the Wastewater Access Gap" pilot project can help promote DWI and assist communities when appropriate. In addition, adopting a "Universal Basic Water" approach, can guarantee a minimum level of water per person per day for personal and public health.

Other approaches include the following:

- Require a holistic assessment of distribution, collection, treatment and reuse alternatives that considers the cost and co-benefits of DWI alongside conventional infrastructure in support of a circular economy approach to water management;
- Forge collaboration among various DWI parties, including water utilities, local governments, and community organizations to ensure all voices are heard;

- Provide pathways for communities to shape their infrastructure with DWI alternatives that address uncontrolled growth and suburban sprawl.

CLOSING AND CALL TO ACTION

The world is facing new water challenges, requiring new tools to overcome them. Systems in operation today were largely planned and designed around challenges faced fifty or more years ago. While there have been incremental updates, the technologies and thought process continue to rely on outdated understanding and needs. Today's challenges require solutions that go beyond protection from pathogens and pollution to incorporate present and pending needs to use water, energy, and nutrients with a spectrum of local to planetary constraints in mind. Leading thinkers recognize the value of a fresh approach. Dr. David Sedlak, in his book "Water 4.0," reflected:

> "Perhaps the best long-term solution to our water problems will be to abandon centralized water systems altogether.... If we can figure out ways to meet our water needs with local resources, to safely treat our wastes close to where they are produced, and to drain the streets without a centralized storm sewer system, we might break free of the cycle of costly investments and environmental damage that currently plague our current water and wastewater systems."
>
> (Sedlak, 2014)

Water professionals must unite to be the force that shifts the water paradigm. Technological advances are already available to build resilient communities through the diversification of all water portfolios, especially with climate change and natural disasters regularly threatening large-scale centralized systems. Utilities must try to avoid singular failure points, and a diversified water infrastructure spreads water supply and treatment out into smaller volumes, reducing the amount of piping and failure points, and allowing better and faster response following a disaster.

Water conservation in the form of onsite reuse is a necessary and efficient approach to fit-for-purpose water supply, returning more potential energy to the power grid and lowering overall costs. Locally, utilities can better service demand for water and reduce the need for utility expansion or expensive well operations.

Implementing an intensive conservation program such as distributed water reuse or diversified water treatment infrastructure directly affects the affordability of water by reducing the financial burden for expansion of wastewater treatment plants. Developers and small utility operators are already profiting from onsite water reuse systems, providing onsite water conservation savings back into their development portfolio. Inclusion of distributed systems into the existing public infrastructure through public-private partnerships is a fiscally responsible and equitable action.

DWI systems represent the future of infrastructure with opportunities for innovation at all scales and in all types of water resource management systems. We encourage all water infrastructure leaders to consider how DWI can be integrated into their projects.

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