Water Environment Federation

Valuing the Circular Water Economy:
A $47 Billion Opportunity for U.S. Utilities

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NOTE FROM THE EXECUTIVE DIRECTOR

Water demand is rising, driven by population growth, industrial expansion, and the growing needs of the digital economy. At the same time, climate change and aging infrastructure are putting increasing pressure on our freshwater systems.

At the Water Environment Federation, we believe the solution to these problems lies in a circular water economy. One that reduces waste, recovers resources, and regenerates ecosystems. These challenges are technical, institutional, and economic, but circular water strategies aren't just environmentally responsible, they're smart business. They can strengthen infrastructure, reduce costs, and unlock long-term value for both communities and the private sector. Implementing circular water strategies through WEF's framework creates a clear path to a One Water management approach where all water sources are integrated and managed holistically, recognizing their inherent value to our communities.

This white paper offers a directional benchmark for the total economic value of a circular water economy in the U.S., while also laying the groundwork for scaling these insights globally. We're proud to publish this report and are eager to share these insights across our network, global platforms, and future engagements.

We hope this work helps spark new ideas, partnerships, and investments in a more resilient water future.

Ralph Erik Exton
Executive Director, Water Environment Federation

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Executive Summary

Water is foundational to every aspect of modern life. We rely on it not only for drinking and sanitation, but to grow our food, fuel our industries and economy, and sustain ecosystems. These essential services are all intricately linked to the natural water cycle. However, the conventional approach to water management of extract, use, and discard has become increasingly misaligned with this cycle, resulting in escalating costs, environmental degradation, and missed opportunities for economic value.

Across the United States, the impacts of this linear model are mounting. Groundwater aquifers are being depleted faster than they can be naturally replenished, leading to land subsidence and long-term threats to water security. Stormwater is channeled away from cities instead of being retained or absorbed, contributing to urban flooding and degraded waterways. Treated wastewater is discharged into rivers and oceans, often still carrying residual nutrients. Meanwhile, utilities are facing rising costs to maintain systems that were not designed to fully capture the available resources wastewater contains.

In this context, waste is not only environmental – it is economic. Each year, utilities lose billions of gallons of treated water to leaks that lead to a loss of energy, and extra treatment costs and capital outlays with no return. Valuable byproducts like biogas, nutrients, and wastewater are routinely discarded when they could be harnessed for energy generation, fertilizer production, or to offset freshwater demand. These inefficiencies compound over time, leading to higher operating expenses and untapped revenue streams that could otherwise strengthen water sector resilience and sustainability.

How can the United States redesign its water systems to align more closely with the natural water cycle? How can we unlock economic value, reduce systemic risk, and support the long-term sustainability of our water supplies?

A national transition toward a circular water economy offers a compelling path forward and redefines water not as a one-time-use commodity but as a renewable resource. At its core, the circular water economy is driven by three strategies:

REDUCING water usage and wastage in the delivery of water services through improved efficiency, smarter operations, and targeted demand management

RECOVERING valuable resources that would otherwise be lost, including nutrients, biogas, data, and water itself through technologies that view wastewater and stormwater as assets rather than liabilities

REGENERATING natural water systems by investing in green infrastructure and sustainable management practices that work with, rather than against, the hydrological cycle.

While circular water solutions have been demonstrated to be effective, today they are still the exception rather than the norm. The challenge is not always technical feasibility but competing financial priorities and institutional inertia: fragmented governance, outdated funding structures, and a lack of clear incentives for innovation. While many circular solutions are proven and increasingly cost-effective, they are not universally applicable, changing based on the unique contexts, needs, and priorities of different localities. Recognizing that implementation ultimately rests with local utilities, a national case for action will build momentum and elevate circular water as a strategic priority for the sector.

A national shift toward circular water practices could unlock up to US$47 billion annually in direct economic value for U.S. water utilities and municipalities. These benefits stem from avoided costs,[1] improved operational efficiency, and new revenue streams from resource recovery.

Beyond direct benefits to utilities, a circular water economy offers substantial societal and environmental value. Benefits ranging from reduced greenhouse gas emissions via biogas recovery and improved water quality due to nutrient removal, to increased resilience to drought and the creation of new jobs, can all contribute to growing and vibrant communities. Real-world examples such as Loudoun Water's recycled water program in Northern Virginia, the East Bay Municipal Utility District's Resource Recovery program in California, and Singapore's NEWater initiative demonstrate the success of circular models.

This paper serves as a catalyst and accelerant – not only reinforcing the case for circular water but also helping to bridge the gap between promising pilots and system-wide scale. The paper explores national-level opportunities and expected benefits, but is not meant to be a comprehensive implementation guide or feasibility study of specific interventions. Nor does it capture the full diversity of local conditions, constraints, or opportunities. Instead, it offers a clear signal of what is possible and a foundation for deeper engagement, investment, and action. The Water Environment Federation is committed to supporting further exploration of circular water solutions.

The opportunity is clear, and **the time to act is now.**

[1]Includes both capital and operating costs

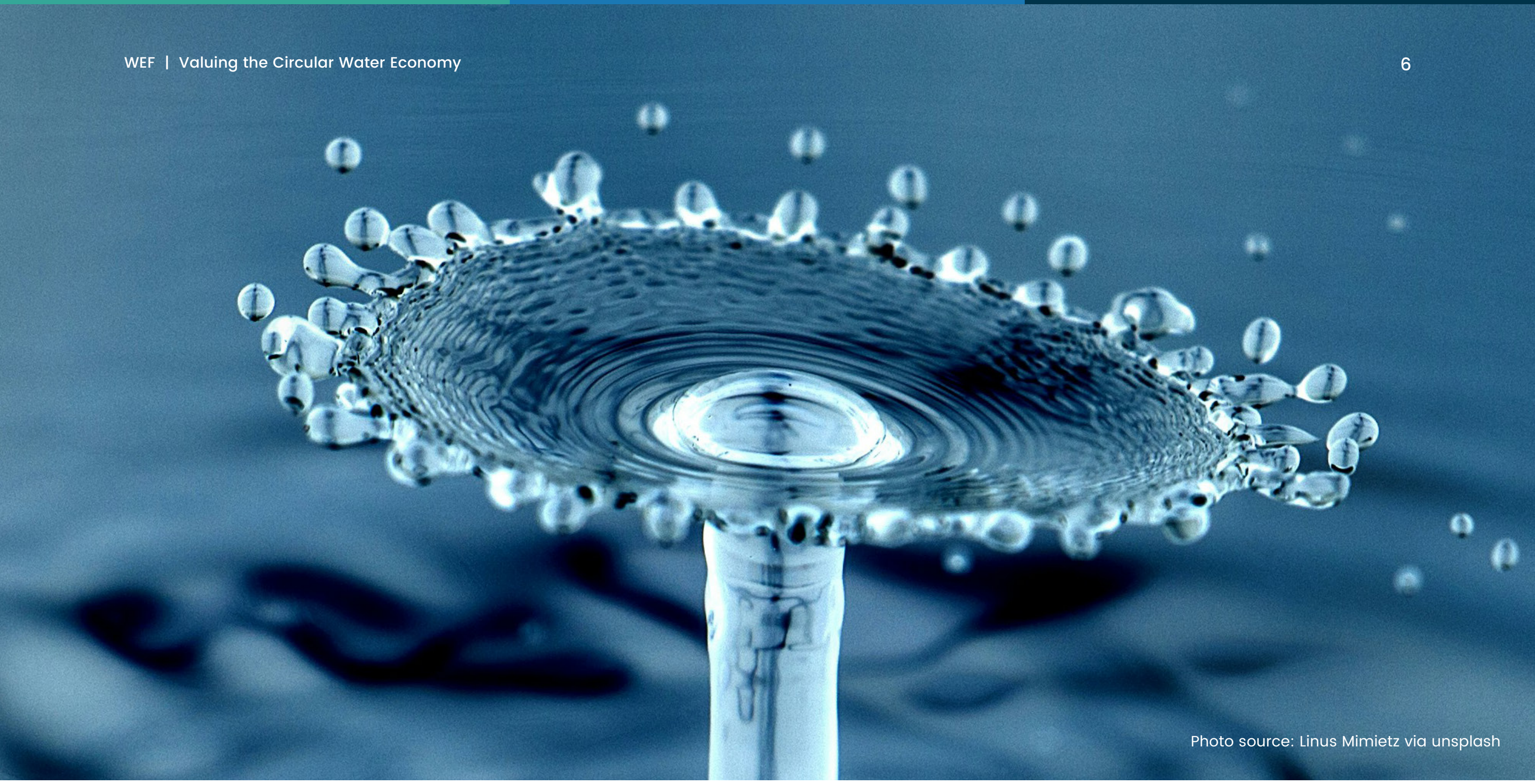


Photo source: Linus Mimietz via unsplash

Document guide and methodological note

This paper makes the case for implementing circular water systems in the U.S. by estimating its total potential economic value through a Total Addressable Market (TAM) approach. A TAM approach involves estimating the full economic value that could be unlocked if high-potential circular water interventions were adopted at scale wherever technically and contextually feasible. This approach provides a directional benchmark for what is possible, helping stakeholders understand the magnitude of circular water's potential value, even as implementation will vary by locality. More detail about the methodology can be found in Appendix B.

This analysis uses WEF's definition of the circular water economy – a process that treats water as a renewable resource, recovering its full value and using it to enhance other systems across the economy.[2] Approaches to circular water management are grouped into three categories:

REDUCE Minimize water usage and wastage through efficient practices.

RECOVER Extract valuable resources like energy or nutrients from wastewater.

REGENERATE Restore natural ecosystems and recharge aquifers through sustainable water management.

This analysis prioritized examining specific circular water interventions in each category that are expected to generate the most value. It is important to note that while the examples are grouped under one of the "three Rs", in practice these interventions often overlap and reinforce one another.

[2]Water Environment Federation. (n.d.). Circular Water Economy FAQ. https://www.wef.org/topics/hot-topics/circular-water-economy/circular-water-economy-faq/

Table 1: Prioritized interventions in this analysis

Three Rs	Interventions
REDUCE	1. Detecting leaks and repairing pipes to reduce non-revenue water and redundant treatment of water for enhanced efficiency 2. Recycling wastewater to meet freshwater demand from agriculture, manufacturing, and other sectors
RECOVER	3. Recovering phosphorus and nitrogen from wastewater for use as agricultural fertilizer 4. Using anaerobic digestion to convert waste solids into biogas to generate energy for facilities or the grid 5. Applying treated biosolids to land as nutrient-rich fertilizer
REGENERATE	6. Coordinating green infrastructure development and restoring wetlands to manage stormwater flooding 7. Using treated wastewater or stormwater to recharge surface water supplies, or replenish overdrawn aquifers and prevent saltwater intrusion

Based on this framing, this paper uses original modeling and existing literature to estimate the value of different benefits. The economic benefit figures are based on a quantitative model that builds on existing data to estimate the total economic value of direct benefits to water utilities and municipalities of a fully realized circular water economy. In addition, the broader benefits to the economy, society, and the environment are described qualitatively and explored in real-world case studies. Specific details on the methodology and key assumptions are provided in Appendix B.

This paper is not a comprehensive blueprint for implementation, but a foundational framework designed to inform and inspire local and regional efforts. Given the vast diversity of local contexts, needs, and constraints across the United States, this valuation offers a methodology and set of analytical tools that can be adapted and refined by water utilities, municipalities, and other stakeholders. While it does not quantify implementation costs – given their inherently local nature – it provides a structured approach to estimating the economic value of circular water interventions and highlights high-potential areas for investment. By offering both directional insights and methodological transparency, the analysis serves as a resource to support further feasibility assessments, policy development, and strategic planning tailored to local needs.

Introduction: Why the U.S. needs a new approach to water

The U.S. water system is under increasing strain as aging infrastructure and climate change are pushing the current linear system beyond its limits. Our existing water infrastructure and management practices follow a traditionally linear model: extract, use, and dispose. This model once served a growing nation, but it now loses vast amounts of water, energy, and nutrients while straining ecosystems. Not only is it outdated, but it is also actively undermining our resilience and prosperity.

The nation's water supply is becoming less reliable, even as demand evolves. Our water supply, reliant on rain, snowpack, and aquifers, is finite and increasingly volatile. Climate change is intensifying droughts, shrinking aquifer levels, and threatening the reliability of surface water supplies. 40 states are projected to face water shortages within the next decade, and in 2024 alone, 48 states experienced drought conditions.[3] Meanwhile, water-intensive sectors like data centers, semiconductor fabrication, and green hydrogen are expanding in already water-stressed regions. Their growth adds strain to local systems and intensifies competition for limited supplies.

Yet our current system continues to treat water as disposable. Every day, U.S. utilities lose an estimated six billion gallons of treated water through leaky pipes and distribution failures.[4] Most wastewater is discharged after one use, without effort to capture its embedded energy or recover nutrients like nitrogen and phosphorus. Stormwater is shunted away as runoff, rather than harvested or used to recharge groundwater. These missed opportunities are not just technical inefficiencies – they are lost revenue streams, higher operating costs, and heightened vulnerability.

The result is a system fundamentally out of sync with the natural water cycle. We withdraw more than we replenish, we pollute the resources we depend on, and we ignore the latent value flowing through our pipes. We forego opportunities to capture energy that could displace fossil fuels, biosolids that could become fertilizer, and reclaimed water that could serve industry, agriculture, and even households.

A circular water economy offers a better path, that captures and regenerates rather than consumes and discards. It recognizes that water has value far beyond a single use, and that well-designed systems can recover and reuse resources while restoring ecosystems. This approach is not just good environmental policy; it is an economic imperative. It reduces waste and cost, buffers against future shocks, and enables growth in sectors that depend on reliable water access.

A circular water economy reframes how we think about water: not as a disposable input, but as an asset to be stewarded, cycled, and reinvested. For a more resilient, resource-smart America, this shift is not optional. It is long overdue.

[3] NOAA/NIDIS. (2025). 2024 in Review: A Look Back at Drought Across the United States in 12 Maps. Drought.gov. https://www.drought.gov/news/2024-review-look-back-drought-across-united-states-12-maps-2025-01-08
[4] American Society of Civil Engineers. (2017). 2017 Infrastructure Report Card: Drinking Water. https://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Drinking-Water-Final.pdf

Photo source: Lex Zhao via unsplash

Three opportunities: The benefits of a circular water economy

In a circular water economy, water is no longer treated as a one-time-use resource. This isn't a single intervention, but a systems approach. Instead of following the conventional linear model, a circular approach seeks to use water more efficiently, recapture value from waste, and work in harmony with natural systems. This shift reimagines water management as a regenerative cycle that maximizes benefits for people, ecosystems, and economies.

WEF structures circular water strategies into three pillars: Reduce, Recover, and Regenerate. These encompass a diverse array of actions and innovations that enable more circular use of water resources. Together, they provide a roadmap for smarter, more resilient water management.

(1) Reduce: Enhancing system efficiency and minimizing waste allows communities to have more reliable supplies of water while reducing dependence on vulnerable or overdrawn freshwater sources, ensuring greater resilience in the face of climate variability, drought, and population growth.
(2) Recover: Capturing latent value in wastewater by claiming nutrients, energy, and economic value of the water itself transforms traditional cost centers into hubs of resource generation while reducing environmental burdens.
(3) Regenerate: Replenishing and revitalizing natural water systems restores the ecological function of aquifers and wetlands, enhances biodiversity, reduces flood risks, and delivers long-term benefits for the environment.

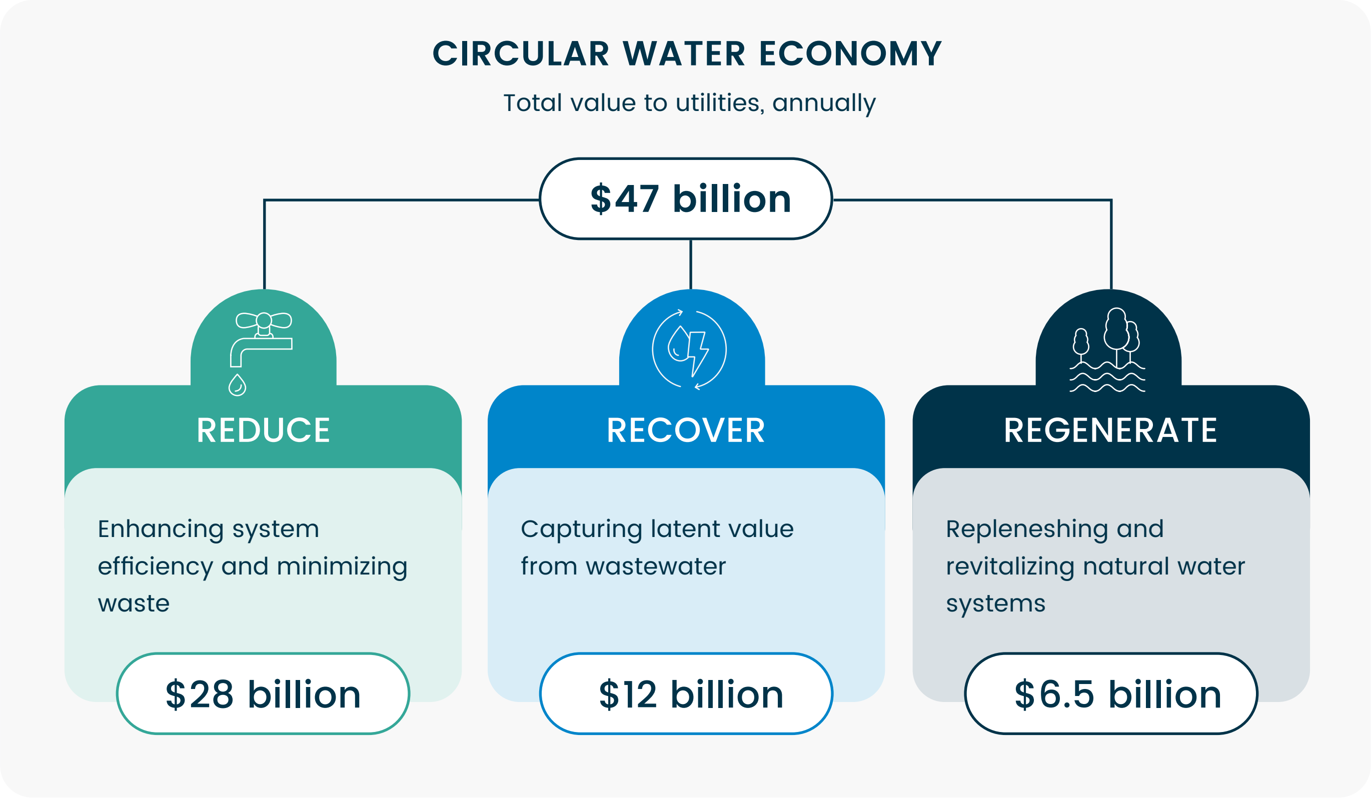
The potential of a circular water economy comes from integrating these strategies to plan, invest, and manage water as a renewable resource with enduring value. A circular water approach enables communities to stretch existing water supplies to advance environmental and social goals alongside economic growth, recover valuable resources from waste streams, and regenerate ecosystems, all while reducing operating costs and generating new value.

Circular water approaches can create value at three different levels: for water utilities, for the economy, and for society and the environment at large.

- At the utility level, circular strategies can reduce operational and capital costs, improve asset efficiency, and generate new sources of revenue by turning waste streams into valuable resources.
- For the economy, these approaches provide direct benefits to water-dependent industries by improving supply reliability, stabilizing costs, and enabling more sustainable production practices. At the same time, circular water investments can catalyze local job creation in infrastructure development, operations, maintenance, and emerging sectors such as resource recovery and green infrastructure.
- For society and the environment, a circular water economy contributes to long-term public benefits such as improved water quality, restored ecosystems, reduced greenhouse gas emissions, better public health outcomes, and more equitable access to clean water.

Our analysis suggests that fully realizing a national ambition for circular water could generate up to US$ 47 billion annually for water utilities and municipalities across the U.S.

Figure 1: Valuation Summary



[5] **Cybersecurity and Infrastructure Security Agency.** (n.d.). Water and Wastewater Systems Sector. https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/critical-infrastructure-sectors/water-and-wastewater-sector

Despite the magnitude of this opportunity, economic, political, and cultural challenges have prevented circular water interventions from being implemented at scale. There are nearly 50,000 water utilities and 15,000 water resource recovery facilities (WRRFs) across the United States, operated by municipalities with varying sizes, capacities, and priorities.[5] This diversity underscores the need for local, context-specific solutions, grounded in clear economic justification for both utilities and their communities. However, the economic value of circular water practices is often framed narrowly, limited to marginal cost savings or short-term return on investment, rather than considered through the lens of avoided costs, long-term resilience, and multi-sectoral benefits. At the same time, utilities operate in environments where risk aversion, regulatory compliance obligations, and limited fiscal flexibility discourage experimentation.

While the U.S. has not yet seen nation-wide adoption of circular water solutions, several examples across the country and around the world provide proof that these solutions are both possible and highly impactful. For example, in Virginia, highly treated wastewater will be injected into the coastal aquifer to combat land subsidence and saltwater intrusion while also exceeding nutrient goals for the Chesapeake Bay. In California, treated wastewater is purified and returned to groundwater supplies for later use as drinking water (a process known as indirect potable reuse), providing a reliable supply of drinking water to a million residents while protecting the groundwater aquifer. Internationally, Singapore has become a global benchmark for water reuse and circularity. These examples, among others, demonstrate that circular water systems are feasible, effective, and scalable, when local conditions and enabling environments align.

This study brings a new, national perspective to the full scale of the potential economic and environmental benefits of circular water. Rather than focusing narrowly on short-term financial returns, this paper estimates the broader economic value of a fully realized circular water economy to water utilities and municipalities, using a national-level model and real-world examples. By providing a structured view of the potential benefits under the 3-R framework, this analysis seeks to help utilities identify where value exists in their own systems, and what enabling conditions matter most for implementation. The goal is not to prescribe a single path forward, but to equip practitioners with the insights needed to take concrete steps toward shifting U.S. water systems towards a more resilient future.

The following sections provide a deeper description of the value of each opportunity, alongside specific case studies of successful examples. These case studies are among the most promising and successful instances of circular water solutions in the U.S. and abroad, choosing to adopt innovative technologies and regenerative, long-term solutions to address pressing water challenges.

Reduce

Photo source: Barnabas Davoti via pexels

Reduce

ENHANCING SYSTEM EFFICIENCY AND MINIMIZING WASTE

The U.S. is facing a growing reliability gap in its water supply systems. While total national water withdrawals have declined slightly in recent decades, localized imbalances between supply and demand are becoming more frequent and severe. However, these challenges can be mitigated through a range of circular water interventions that reduce demand, increase efficiency, and extend the effective life of existing infrastructure.

Approaches to reducing water use focus on minimizing waste and optimizing performance across the system. By improving how water is sourced, delivered, and consumed, these strategies help communities meet demand without increasing withdrawals from stressed natural sources. This includes fixing leaks, upgrading infrastructure, and deploying technologies that use less water to achieve the same or better outcomes. Reducing losses and inefficiencies not only preserves scarce resources but also lowers utility costs, delays capital investment needs, and enhances the reliability of service in the face of climate and population pressures.

One clear solution is the reduction of wasted water through leak detection and other management technologies. Leak detection and management technologies have demonstrated the ability to reduce non-revenue water (i.e., treated drinking water that is lost before reaching customers) in underperforming systems. Utilities are increasingly deploying acoustic sensors, pressure loggers, and real-time monitoring networks to identify and prioritize leaks. These systems are often integrated with predictive analytics, allowing operators to anticipate failure points and schedule proactive maintenance, reducing water loss, energy use, and unplanned service disruptions.

Systemic water reuse also presents a significant opportunity to fundamentally reduce demand for freshwater withdrawals. Water reuse strategies, including non-potable applications for cooling, irrigation, and industrial processes, offer a more reliable, drought-resilient supply of water. Treated wastewater can be delivered through dedicated pipe systems and integrated into industrial parks and agricultural zones where end uses do not require potable water. In some cases, indirect potable reuse, where highly treated effluent is reintroduced into groundwater or surface water sources, has helped augment regional drinking water supplies. More advanced systems are enabling direct potable reuse, where highly treated wastewater is blended directly into drinking water systems under strict regulatory oversight. These reuse pathways reduce dependency on imported or overdrawn water sources and create greater supply security for high-demand users.

Fully realizing the opportunity for leak detection and water reuse across the U.S. could yield up to US$28 billion annually in direct value to water utilities. This value comes primarily from modeling two areas: the value of a more efficient water distribution system with less leakage and the value of increased water reuse at a national scale. By reducing the amount of lost treated water, utilities can reduce the cost of treating and distributing an additional 20% of water that ultimately never reaches end-users, which would result in cost savings of over US$10 billion per year. In addition, a conservative estimate of water reuse becoming more mainstream in the U.S., could provide an additional US$18 billion per year to utilities. Water reuse in particular was benchmarked against Nevada, which boasts the highest water reuse rate in the country with 85% of their wastewater recycled;[6] however, given the national average is approximately 7% based on the most recent EPA estimate, there is significant room for improvement across states and localities.[7]

SPOTLIGHT: WATER REUSE

In the face of increasing water stress, water reuse offers a practical and scalable way to improve overall system efficiency and diversify supply. Loudoun Water in Virginia and Singapore's NEWater program exemplify the local and national potential for water reuse, meeting significant portions of industrial and public supply demand for water through treated wastewater.

CASE STUDY 1

LOUDOUN WATER – RECYCLING WASTEWATER TO MEET DATA CENTER DEMAND

Challenge: Loudoun County in Virginia has emerged as a strategic hub for digital infrastructure, housing more than 30 million square feet of data center space.[8] This concentration of data centers has created an enormous demand for industrial cooling water, creating significant demand for the region's water supplies. With projections for continued growth in data infrastructure, Loudoun faced a critical problem: how to sustainably meet escalating industrial water needs while preserving water resources for essential human and environmental uses.

Circular water solution: In response, Loudoun Water implemented a large-scale water reuse program to better meet the increased industrial demand for water. The program included:

- **Development of the Broad Run Water Reclamation Facility** in 2008 to treat wastewater to standards suitable for use.
- **Construction of a separate recycled water distribution system** (i.e., "purple pipe" for non-potable water) for data center cooling, construction washdown, and other industrial uses.

Outcomes: As a result of its implementation of water reuse for industrial cooling, Loudoun Water has been able to meet the equivalent of over 40% of the water demand from data centers. In 2024, Loudoun Water delivered 736 million gallons of recycled water to customers out of the currently estimated 1.85 billion gallons per year needed for data centers.[9,10] At current pricing structures, this represents nearly US$1.5 million in additional revenue for Loudoun Water annually.[11]

The benefits also extend beyond Loudoun Water, as the water reuse program has allowed the county to reap the benefits of a robust data center industry that produces US$800+ million annually in local tax revenue.[12] More broadly, the reuse program has reduced withdrawals from the Potomac River and other freshwater sources by the same hundreds of millions of gallons, contributing to the ecological health of a major regional watershed and, reducing the greenhouse gas emissions per gallon of water supplied, thanks to the lower treatment requirements of recycled water.

[6] **Garrison, N., Stack, L., McKay, J., Gold, M.** (2025). Can water reuse save the Colorado? An analysis of wastewater recycling in the Colorado River Basin states. UCLA Institute of the Environment and Sustainability. https://www.ioes.ucla.edu/wp-content/uploads/2025/03/Water-Reuse-Report.pdf
[7] **U.S. Environmental Protection Agency.** (2012). 2012 Guidelines for Water Reuse. https://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf
[8] **Loudoun County Economic Development.** (n.d.). Data Centers. https://biz.loudoun.gov/key-business-sectors/data-centers/

Enabling factors: Loudoun Water's success in developing its water reuse program hinged on proactive planning by decisionmakers, close collaboration with private companies, and strategic pricing for scaling.

Proactive planning and investment: Anticipating water demand from emerging data centers, Loudoun Water developed the Broad Run Water Reclamation Facility in 2008 as part of a broader economic and infrastructure strategy. Early investment enabled the county to meet rising demand and benefit economically before potable water supplies became strained.[13]

Public-private collaboration: Loudoun Water partners with over 3,700 commercial customers to integrate recycled water into operations and ensure regulatory compliance. For data centers, it co-develops demand forecasts and fit-for-purpose water quality standards with operators.[8]

Financial incentives: Recycled water is offered at rates up to 50% less than potable water, alongside tax exemptions for data center equipment. These incentives provide value to customers while maintaining viability for the utility.[8,10]

CASE STUDY 2

SINGAPORE NEWATER – ADVANCING NATIONAL RESILIENCE THROUGH HIGH-QUALITY WATER REUSE

Challenge: Singapore, one of the most water-stressed countries in the world, faces severe constraints on natural water availability. With no significant groundwater, limited land for reservoirs, and growing domestic and industrial demand, Singapore historically depended heavily on rainfall and imported water from Malaysia.[14] The volatility of climate conditions and limited local catchment capacity posed major risks to national security.

At the same time, Singapore's transformation into a global hub for high-tech industries, including semiconductors, biomanufacturing, and pharmaceuticals, amplified the need for a stable and scalable water supply. Policymakers recognized the urgent need to diversify and fortify water sources in ways that keep up with economic growth and overcome geographical constraints.

Circular water solution: To address this challenge, PUB – Singapore's National Water Agency – launched NEWater in 2002, a groundbreaking initiative to reclaim wastewater and purify it to ultra-clean standards. This program included:[15]

- **Advanced treatment using a three-stage process** that uses state-of-the-art technology to produce high-quality recycled water known as NEWater in Singapore.
- **Targeted supply to water-intensive sectors**, like semiconductor manufacturing plants and industrial manufacturing, some of which require water quality that is purer than drinking water.

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[9] **Loudoun Water.** (n.d.). Reclaimed Water Program. https://www.loudounwater.org/commercial-customers/reclaimed-water-program
[10] **McKay, T.** (2024). Northern Virginia's "data center alley" is thirstier than ever. IT Brew. https://www.itbrew.com/stories/2024/08/26/northern-virginia-s-data-center-alley-is-thirstier-than-ever
[11] **Loudoun Water.** (n.d.). Rates, Fees, Charges & Penalties. https://www.loudounwater.org/rates-fees-charges-penalties
[12] **Mamon, G.** (2025). Data centers can bring high-paying jobs and millions in tax revenue. Is that what Southside will get? https://cardinalnews.org/2025/04/10/data-centers-can-bring-high-paying-jobs-and-millions-in-tax-revenue-is-that-what-southside-will-get/
[13] **Turner, M.** (2025). Loudoun County, Virginia: Data Center Capital of the World – A Strategy for a Changing Paradigm. https://www.loudoun.gov/ArchiveCenter/ViewFile/Item/13979
[14] **Wood, Johnny.** (2022). How Singapore is recycling wastewater to become water-stress resilient. World Economic Forum. https://www.weforum.org/stories/2022/11/singapore-wastewater-recycling-water-stressed
[15] **Public Utilities Board Singapore.** (n.d.). NEWater. https://www.pub.gov.sg/Public/WaterLoop/OurWaterStory/NEWater

- **Reservoir augmentation for indirect potable use**, particularly during dry periods, by blending NEWater with raw water in reservoirs.

Outcomes: Today, NEWater serves as a key pillar in Singapore's water security and enables the country to close the water cycle and reuse water endlessly. The completion of the 206km-long Deep Tunnel Sewerage System in 2027 will enable every drop of wastewater from industries and households to be collected and conveyed by gravity to centralized water reclamation plants for treatment, before further purification at NEWater factories. NEWater has made the leap from a novel, unproven study dating back to the 1970s to a fully sustainable and leading example of water reuse. The expected completion of two upcoming NEWater factories, along with ongoing research and innovation to enhance efficiency of the technology, will further expand Singapore's production capabilities.

As a result, NEWater has supported Singapore's economic growth while bolstering its water resilience. Recycled water is especially important in strategic growth sectors, including semiconductors and biopharmaceuticals, that contribute to over 10% of national GDP.[16,17] This increases competitiveness for Singaporean businesses by avoiding water-related disruptions and providing more affordable water. As a climate resilient water source, NEWater strengthens Singapore's water security in the face of exacerbating climate change by buffering against increasingly erratic rain and drought events.

Enabling factors: A centralized, coordinated water governance system, combined with clear regulatory pressure on industry and intentional public trust-building enabled NEWater to become a leading global benchmark for water reuse.

Integrated national water governance: PUB manages the full water cycle, enabling alignment across regulation, planning, and operations. Centralized oversight has allowed for long-term, coordinated strategies which in turn guide the setting of national reuse targets extending to 2060.[18]

Industrial policy synergy: PUB combines regulation with support to drive industrial water reuse. For example, large semiconductor manufacturing plants needed to recycle at least 50% of their water starting in 2024, with complementary incentives such as technical assistance and recognition programs to support compliance.[19]

Public trust and engagement: To build acceptance of recycled water for potable use when NEWater was introduced in 2002, PUB launched the NEWater Visitor Centre as part of an extensive public education program which included education campaigns, branding and outreach that promoted NEWater as a safe, high-quality water source. For over two decades, the previous NEWater Visitor Centre educated the public on water reuse technologies and benefits, helping establish recycled water as part of daily life.[20]

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[16] **Medina, A. F.** (2024). Why Singapore is the Top Choice for Semiconductor Companies in 2024. ASEAN Briefing. https://www.aseanbriefing.com/news/why-singapore-is-the-top-choice-for-semiconductor-companies-in-2024/

[17] **JTC Corporation.** (2025). Get to know Singapore's biopharmaceutical and biotechnology ecosystem. https://www.jtc.gov.sg/about-jtc/news-and-stories/feature-stories/singapore-biomedical-ecosystem

[18] **Irvine, K., Chua, L., Eikass, H.S.** (2015). The Four National Taps of Singapore: A Holistic Approach to Water Resources Management from Drainage to Drinking Water. Journal of Water Management Modeling. https://www.chijournal.org/C375

[19] **Public Utilities Board Singapore.** (2025). Singapore Industrial Water Revolution. https://www.pub.gov.sg/Resources/News%20Room/Featured%20Stories/2025/Singapore%20Industrial%20Water%20Revolution

[20] **Public Utilities Board Singapore.** (2024). NEWater Visitor Centre to close on 31 July 2024. https://www.pub.gov.sg/Resources/News-Room/PressReleases/2024/06/NEWater-Visitor-Centre-to-close-on-31-July-2024

Recover

Photo source: Wenderson Costa via pexels

Recover

CAPTURING LATENT VALUE FROM WASTEWATER

Wastewater treatment practices in the U.S. largely overlook the significant economic and environmental value embedded in wastewater: nutrients, energy, and even the water itself. Today, fewer than 10% of WRRFs have the means to recover biogas, a potent source of energy often treated as a valueless byproduct, while nutrient-rich waste solids are similarly incinerated or landfilled.[21]

However, circular resource recovery offers substantial opportunities for utilities to generate value from these wasted streams of resources. Rather than treating wastewater as a burden to be disposed of, recovery strategies view it as a source of untapped potential: rich in energy, nutrients, and reusable water. Through technologies like enabling anaerobic digestion, nutrient extraction, and water recycling, utilities can transform treatment facilities into engines of resource generation. These interventions reduce environmental impacts, lower operational costs, and create new revenue streams, turning waste into assets that support both sustainability and economic resilience.

Technologies such as anaerobic digestion allow utilities to convert waste solids, such as sewage sludge and organic waste from food processing, into biogas – a usable form of energy. This gas can be used to generate electricity and heat for the treatment plant itself, helping lower energy costs, or it can be cleaned and sold as renewable fuel. Utilities can also accept high-strength organic waste from businesses, such as food scraps or grease from restaurants, which boosts energy production and generates revenue through disposal fees.

In addition, biosolids – the treated solids left over from the wastewater process – can be safely applied to farmland as a soil amendment, improving soil quality and supporting agricultural productivity. Some utilities are going a step further by installing systems to recover nutrients like phosphorus and nitrogen from wastewater. These nutrients can be turned into fertilizer products that are sold to farmers or other industries, while also reducing the risk of water pollution from excess nutrient discharges.

Recovering all accessible resources from wastewater and residuals could generate up to US$12 billion annually in direct value for U.S. utilities. This estimate is based on modeling three key areas: biogas recovery through anaerobic digestion, nutrient recovery from wastewater for use as fertilizers, and biosolids use in land application. Biogas recovery has significant upside, as it immediately enables WRRFs, often one of the largest energy consumers in a locality, to offset energy costs, and related greenhouse gas emissions, by generating renewable power. However, given that wastewater contains five times more energy than is required to treat it, biogas recovery can lead to not only cost savings, but potentially additional revenue and zero-emission operations.[22] This combined value could account for US$9 billion annually for U.S. utilities. The remaining US$3 billion represents the potential value of the nutrients and biosolids in wastewater, both of which can be used as fertilizer.

[21] **U.S. Environmental Protection Agency.** (n.d.). Types of Anaerobic Digesters. https://www.epa.gov/anaerobic-digestion/types-anaerobic-digesters
[22] **Fluence Corporation.** (n.d.). How Much Energy Exists in Wastewater? https://www.fluencecorp.com/how-much-energy-exists-in-wastewater/

SPOTLIGHT: BIOGAS RECOVERY

Biogas recovery represents one of the highest potential opportunities to recover value from water and deliver both operational and environmental benefits for utilities. As a result of successful biogas recovery programs, the East Bay Municipal Utility District in California became the first WRRF in North America to achieve self-sufficiency, while VCS Denmark continues to be a leading international example of energy and resource efficiency. Biogas recovery has the potential to turn WRRFs, typically one of the largest consumers of energy in a municipality, into a net generator of electricity.

CASE STUDY 3

EAST BAY MUNICIPAL UTILITY DISTRICT – RECOVERING ENERGY AND REVENUE FROM WASTEWATER AND ORGANIC WASTE

Challenge: Situated in the densely populated Oakland-Berkeley corridor of California, the East Bay Municipal Utility District (EBMUD) has long faced mounting pressures from rapid urbanization, rising service demands, and intensifying climate stressors. With nearly three-quarters of a million residents in its service area, the region faced strain on both water supply reliability and wastewater management systems.[23,24] At the same time, California's increasingly extreme heat events and climate-driven mandates have heightened the need for resilient, low-carbon infrastructure. These dynamics, compounded by tightening state regulations around water reuse, energy efficiency, and organic waste management, have underscored the imperative for EBMUD to evolve into a more climate-adaptive and circular water utility.

Circular water solution: In response, EBMUD implemented a program that generates energy through anaerobic co-digestion of municipal waste solids and high-strength organic waste from external sources. This integrated approach enables EBMUD to simultaneously reduce energy costs, recover valuable resources, and contribute to regional climate targets.

- **Biogas production via anaerobic digestion**, which fuels on-site combined heat and power systems to supply renewable electricity and heat.
- **Co-digestion of waste solids with organic waste** from food processors, grease haulers, and industrial facilities, creating a new revenue stream while supporting regional waste diversion.
- **Beneficial use of biosolids**, including land application and landfill cover, returning nutrients to the environment and minimizing disposal needs.

[23] **East Bay Municipal Utility District.** (n.d.). Wastewater Collection & Treatment. https://www.ebmud.com/wastewater/collection-treatment
[24] **East Bay Municipal Utility District.** (n.d.). Drought Information. https://www.ebmud.com/water/drought

Outcomes: EBMUD became the first WRRF to achieve energy self-sufficiency in North America, not only reducing its reliance on external energy, but also creating numerous additional streams of revenue. As a result of generating more than 55,000 megawatt hours of renewable energy, EBMUD saves approximately US$2 million annually on facility power costs, and the surplus brings in an additional US$1 million per year.[25,26] Given that EBMUD also collects food and other organic waste to bolster its biogas production, it also reaps the benefit of tipping and other associated fees[27] from waste producers, resulting in an additional US$16.8 million in 2023 and making the entire Resource Recovery program financially self-sufficient.[28]

EBMUD's Resource Recovery program also benefits nearby companies and the environment, providing cost-effective disposal services and diverting organic waste from landfills. EBMUD accepts over 4,000 trucks per month, which carry 20 million gallons of liquid waste from food processors and grease haulers.[26]

Enabling factors: EBMUD's success was enabled by a unique combination of institutional initiative, external policy drivers, and community stewardship.

- **Statewide policy alignment:** California's environmental policies, such as SB 1383 on organic waste diversion and the Low Carbon Fuel Standard, created regulatory certainty and strong market signals for investment in biogas energy.[29]
- **Internal innovation and leadership:** Originally started in 2002, EBMUD invested early in pilot-scale co-digestion and demonstrated operational and economic feasibility before scaling up, expanding its electricity generation capacity in 2012 with a proven model that could attain regulatory acceptance.[30]
- **Cross-sector partnerships:** EBMUD built strategic agreements with waste haulers, food manufacturers, and local jurisdictions to secure a reliable feedstock of organic waste, creating mutual value across sectors.[31]

CASE STUDY 4

VCS DENMARK – RAPIDLY TRANSFORMING WASTEWATER TREATMENT INTO ENERGY GENERATION

Challenge: Reducing energy consumption and environmental impact while complying with stringent discharge regulations has become a central challenge for European wastewater utilities like VCS Denmark. Serving over 400,000 residents in the Odense region, VCS Denmark operates under tight EU effluent standards that require advanced nutrient removal and sludge management.[32] This was compounded by the fact that VCS Denmark's main facility was also one of its oldest, with aging infrastructure and discharging its waste into a small, local river. In addition, Denmark's national climate policy targets, including a legally binding goal of carbon neutrality by 2050, accelerated the pressure on utilities to eliminate fossil energy use and move toward circular, energy-positive models. Thus, in 2010, VCS set an ambitious goal of achieving carbon neutrality and energy independence in just five years.

Circular water solution: By 2013, VCS successfully transformed its flagship Ejby Mølle facility into a model circular facility by integrating advanced sludge treatment, biogas production, and energy recovery technologies. The most current version of this system entails:[33]

[25] **East Bay Municipal Utility District.** (2012). A Commitment to the Environment. https://www.ebmud.com/download_file/force/2046/809?energy-fact-sheet-03-12.pdf
[26] **Hake, J.** (2017). Key Factors to Enable the Anaerobic Digestion of Food Waste at WWTPs. EBMUD. https://www.energy.gov/sites/prod/files/2017/07/f35/BETO_2017WTE-Workshop_JohnHake-EBMUD%281%29.pdf
[27] A tipping fee is the charge per ton that waste generators must pay to dispose of waste at a facility
[28] **East Bay Municipal Utility District.** (2023). Sustainability Committee Agenda – Tuesday, November 14, 2023. https://www.ebmud.com/application/files/8116/9957/4969/11142023_sustainability_staff_reports.pdf
[29] **CalRecycle.** (n.d.). California's Short-Lived Climate Pollutant Reduction Strategy. https://calrecycle.ca.gov/organics/slcp/
[30] **Green Nylen, N., Kiparsky, M., Milman, A.** (2022). Cultivating effective utility-regulator relationships around innovation: Lessons from four case studies in the U.S. municipal wastewater sector. PLOS Water https://doi.org/10.1371/journal.pwat.0000031
[31] **Goldstein, N.** (2023). Codigestion At Water Resource Recovery Facilities. BioCycle. https://www.biocycle.net/codigestion-water-resource-recovery-facilities/
[32] **European Commission.** (n.d.). Urban Wastewater. https://environment.ec.europa.eu/topics/water/urban-wastewater_en
[33] **Jacobs.** (n.d.). From Grid-Dependent to Grid-Positive: The Ejby Mølle Breakthrough. https://www.jacobs.com/projects/grid-dependent-grid-positive-ejby-molle-breakthrough

- **Development and implementation of a novel filtering technology** to reduce energy consumption and increase treatment efficiency, known as a membrane aerated biofilm reactor
- **Ongoing development of advanced anaerobic digestion processes** to reduce biosolid output while increasing biogas production, using the microbial hydrolysis process
- **Strict compliance with nutrient limits**, maintaining nitrogen levels below 6.0mg/L and phosphorus levels below 0.5mg/L, without needing additional carbon in the treatment process

Outcomes: **Ejby Mølle's rapid transformation allowed VCS Denmark to achieve energy-positivity in only three years and cost less than originally budgeted.**[33] In 2024, the facility generated 150% of its energy needs, supplying the surplus energy to the grid for additional revenue and municipal water heating. This additional revenue offset the initial capital investment of US$2 million, and VCS Denmark has only continued to improve its proven track record of paying back the cost of treatment improvements through energy savings, with an additional US$15 million investment for improved heat pumps in 2020 being expected to be successfully paid back in 10 years.[34] VCS Denmark's ongoing investments into technology advancements in its other facilities also unlocked its ability to produce biochar, an even cleaner fertilizer product than biosolids, creating another source of revenue.[35]

Beyond these direct benefits to the utility, VCS Denmark is similarly protecting the environment, while also strengthening the natural nutrient cycle. The generation of renewable energy is estimated to reduce greenhouse gas emissions by thousands of metric tons of CO2 annually, while providing a local source of nutrient-rich biochar for land application, reducing the need for chemical fertilizers.

Enabling factors: **VCS Denmark played a pioneering role in developing new water treatment technologies, continuing its legacy of being at the forefront of the technological advancements in wastewater management.**

- **Technology transfer and research**: Collaboration with private-sector technology providers enabled effective deployment and testing of high-yield biogas systems.
- **Innovative operational culture**: VCS Denmark actively fosters a culture of innovation and continuous improvement, including in-house R&D and performance benchmarking, adopting advanced technologies well beyond regulatory requirements.
- **Regulatory alignment**: EU Water Framework Directive and Danish national sustainability goals incentivized innovation in nutrient removal and energy recovery.

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[34] **Water Vision Demark.** (2021). Economic Benefits of Energy Efficiency in Danish Wastewater Treatment. https://www.vandvision.dk/wp-content/uploads/2021/09/Memo-on-the-Economic-Benefits-of-Energy-Efficiency-in-Danish-Wastewater-Treatment-002.pdf
[35] **VCS Denmark.** (n.d.). Advanced Wastewater Treatment - Tour. https://www.vcsdenmark.com/about-us/advanced-wastewater-treatment-tour/

Regenerate

Photo source: David Kovalenko via unsplash

Regenerate

REPLENISHING AND REVITALIZING NATURAL WATER SYSTEMS

The U.S.'s traditional linear approach undermines the very ecosystems and hydrological cycles they depend on. Groundwater sources are frequently overdrawn without regard for long-term sustainability, leading to consequences of land subsidence, saltwater intrusion, and irreversible loss of storage. Overextraction of groundwater that outpaces natural recharge is akin to the extraction of any non-renewable resource. This has been especially prevalent in vulnerable regions like California's Central Valley, parts of Texas, and Florida. At the same time, stormwater is typically treated as a nuisance rather than a resource, channeled through gray infrastructure that exacerbates urban flooding, water pollution, and habitat degradation.

In contrast, approaches to regenerating our natural resources offer a pathway to repair and strengthen natural water systems by aligning water management with ecological processes. Regeneration strategies treat ecosystems – including wetlands, aquifers, and watersheds – as active infrastructure. By capturing stormwater, restoring degraded landscapes, and enhancing groundwater recharge, these efforts not only improve water quality and availability but also deliver broader co-benefits: reduced flood risk, increased biodiversity, carbon sequestration, and climate resilience. Regeneration is about working with nature to secure water for the long term.

One leading approach, managed aquifer recharge (MAR), involves using excess water to replenish depleted aquifers. Treated wastewater or stormwater can be directed into the ground through wells, basins, or infiltration zones. This helps stabilize groundwater levels, slow land subsidence, and protect against saltwater intrusion, while also maintaining flows that support rivers, wetlands, and ecosystems downstream.

Meanwhile, nature-based stormwater solutions are designed to absorb and filter rainfall where it lands. Features such as green roofs, permeable pavements, and restored wetlands can reduce runoff that would otherwise overwhelm sewers or pollute waterways. These interventions not only enhance infiltration and recharge, but also help cool urban areas, reduce localized flooding, and create public green spaces.

Maximizing our use of excess water to regenerate natural systems could create value of up to US$6.5 billion annually in avoided infrastructure costs and added value of aquifer recharge. This value comes from two main drivers: the cost savings associated with replacing or deferring traditional stormwater infrastructure through green infrastructure solutions, and the marginal value of MAR in stabilizing local groundwater supplies. Green infrastructure can mitigate the damage done by overwhelmed drainage systems and erosion of infrastructure by reducing runoff by 77-100%.[36] MAR, when deployed strategically, can alleviate groundwater depletion, and secure long-term supply reliability for utilities dependent on aquifers.

However, even more so for this opportunity than the previous two, it is important to note that this figure reflects only a portion of the total value of the benefits of restoring and recharging natural water cycles. Restoring natural systems delivers substantial additional economic, social, and environmental benefits, such as flood resilience, urban cooling, habitat regeneration, and public health improvements, that accrue to communities, property owners, and ecosystems beyond the utility boundary.

[36] **U.S. Environmental Protection Agency (EPA)**. (n.d.). Mitigate Flooding with Green Infrastructure. https://www.epa.gov/green-infrastructure/mitigate-flooding

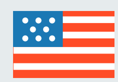

Photo source: Adobe Stock

SPOTLIGHT: MANAGED AQUIFER RECHARGE

Once dismissed as waste, treated effluent and stormwater are now increasingly recognized as sustainable water resources to be used for regeneration via managed aquifer recharge. The Orange County Water District in California has pioneered this approach through its system of treating wastewater to near-distilled quality before recharging it into local aquifers for a more drought-resilient supply. Similarly, the Hampton Roads Sanitation District converts wastewater into high-quality recharge water that reduces nutrient discharges into the Chesapeake Bay and helps restore pressure in overdrawn aquifers vulnerable to saltwater intrusion. While the benefits and rationales differ depending on local context, MAR presents a significant opportunity to address water supply and environmental issues in a more regenerative and economically feasible manner.

CASE STUDY 5

ORANGE COUNTY WATER DISTRICT – BUILDING THE WORLD'S LARGEST POTABLE REUSE SYSTEM FOR WATER SECURITY



Challenge: Orange County in southern California faces chronic water scarcity due to its semi-arid climate, limited local water sources, and reliance on imported water from the Colorado River and Northern California. These imported sources are increasingly vulnerable to climate change, use restrictions, and environmental degradation. Additionally, over-extraction of groundwater has led to concerns of seawater intrusion, threatening the quality and sustainability of the Orange County Groundwater Basin. To address these challenges, the Orange County Water District (OCWD) and the Orange County Sanitation District (OC San) sought a sustainable, locally controlled solution to enhance water reliability, protect groundwater resources, and reduce dependence on imported water.

Circular water solution: In partnership, OCWD and OC San developed the Groundwater Replenishment System (GWRS), the world's largest potable reuse project, to close the loop on urban water use and address long-term regional water security. Operational since 2008 and reaching full capacity in 2023, the GWRS embodies a mature circular water model built on advanced purification and groundwater recharge.

- **Development of an advanced water purification facility** that applies a three-step treatment process to treat secondary effluent to potable standards.
- **Managed aquifer recharge via injection and infiltration** to recharge over two dozen basins in Anaheim and Orange County, supporting the replenishment of the Orange County Groundwater Basin and forming a hydraulic barrier against seawater intrusion.
- **Interagency integration** by connecting OC San's wastewater infrastructure with OCWD's groundwater management operations through shared conveyance and pumping systems.

Outcomes: Through the GWRS, 100% of Orange County's reclaimable wastewater is recycled through indirect potable reuse. With an overall investment of US$900 million, Orange County meets 35% of total water demands with recycled wastewater that recharges critical groundwater sources.[37] Rather than discharging this valuable wastewater into the ocean, Orange County is instead able recycle up to 130 million gallons per day at $800 per acre-foot.[37] The cost of this recycled water is also less than the cost of water from imported sources, such as the Colorado River and Northern California, making it economically advantageous. This recycled water that recharges critical aquifers thus plays a key role in creating a drought-resilient water supply, stabilizing groundwater levels.

Enabling factors: The close interagency collaboration, phased scaling, and leveraging of state and federal support were critical in making the GWRS a leading example of aquifer recharge in the U.S.[38]

- **Interagency collaboration:** The GWRS is the result of a long-term partnership between OCWD and OC San, initiated in 1997 and guided by a joint board committee through planning and implementation from 2008 to 2023.
- **Phased scaling and testing:** The GWRS expanded in three stages, from 70 million gallons per day in 2008 to 130 million gallons per day by 2023, allowing new technologies to be piloted and systems validated before each incremental investment.
- **Financial planning:** The US$900+ million project was funded through a mix of local revenue, state grants (e.g., Propositions 13 and 1), state revolving fund loans, and federal programs (e.g., WIFIA, Title XVI), enabling phased expansion without overburdening utility budgets.

CASE STUDY 6

HAMPTON ROADS SANITATION DISTRICT – CREATING A MULTI-BENEFIT AQUIFER RECHARGE PROGRAM

Challenge: Southeastern Virginia sits at the confluence of two compounding water challenges: degrading water quality in the Chesapeake Bay and chronic over-extraction of regional groundwater reserves. For decades, industries and utilities in the region have drawn heavily from the Potomac Aquifer System which supplies drinking water to much of the region. Excessive groundwater withdrawals, far beyond natural recharge rates, have resulted in sharply declining water levels, land subsidence, and increasing risks of saltwater intrusion. At the same time, the Hampton Roads Sanitation District (HRSD) has been under growing regulatory pressure to reduce nutrient discharges into Chesapeake Bay. Under the Chesapeake Bay Total Maximum Daily Load (TMDL), HRSD faces stringent limits on nitrogen and phosphorus in its treated effluent.[30]

Circular water solution: HRSD developed the Sustainable Water Initiative for Tomorrow (SWIFT), a pioneering indirect potable reuse and managed aquifer recharge program. This program involves:

- **Development of an advanced treatment process** to produce water that meets or exceeds drinking water standards and reduces nutrient discharges into the Chesapeake Bay.
- **Injection of SWIFT Water into the Potomac Aquifer** through a series of recharge wells, replenishing overdrawn groundwater sources.

[37] **Orange County Sanitation District.** (2023). The Completion of the Groundwater Replenishment System. https://ocwd-prod.s3.amazonaws.com/wp-content/uploads/GWRS-Fact-Sheet_April-2023.pdf
[38] **Orange County Water District**. (n.d.). Frequently Asked Questions. https://www.ocwd.com/gwrs/frequently-asked-questions/

Outcomes: Once fully implemented, SWIFT is projected to achieve recharge rates of 65% or higher at two of HRSD's WRRFs, enabling HRSD to generate excess nutrient credits that have been used to offset local stormwater management needs. The initiative is expected to cost approximately US$1.2 billion in capital expenditures, with annual operating costs estimated at US$20 million.[30] With the building of the 1 million gallon per day SWIFT Research Center to refine the process, HRSD is on track to recharge the Potomac Aquifer with approximately 50 million gallons per day of drinking-water-quality effluent by 2033.[39]

Beyond regulatory compliance and financial returns from nutrient credits, SWIFT delivers broad regional benefits: its recharge activities will reverse declining aquifer pressures and protect drinking water access for hundreds of thousands of residents across eastern Virginia.
By replenishing aquifer pressure at strategically located recharge wells, SWIFT reinforces a natural hydraulic barrier against saltwater intrusion, protecting the long-term viability of wells serving both public systems and industrial and private domestic users throughout the region. SWIFT also mitigates land subsidence and directly supports the restoration of Chesapeake Bay, with the reduction in nutrients resulting in improved water clarity, reduced algal blooms, and healthier aquatic habitats.

Enabling factors: HRSD's SWIFT program exemplifies a strategic, science-driven approach to aquifer recharge, combining phased implementation, proactive regulatory alignment, and research partnerships to ensure the safe, high-quality reuse of treated wastewater for long-term water security.

- **Phased implementation:** HRSD is launching SWIFT through a stepwise approach, starting with initial studies in 2014, pilot testing in 2016, and a 1 million gallon per day demonstration facility in 2018.[40] This is now paving the way for full-scale recharge of up to 50 million gallons per day by 2033.[39]
- **Proactive regulatory alignment:** Although already in compliance with Chesapeake Bay TMDL requirements, HRSD took early action to prepare for potentially stricter future regulations. Working with the Commonwealth of Virginia, HRSD also facilitated legislation that created the Potomac Aquifer Recharge Oversight Committee to ensure independent oversight and regulatory alignment throughout implementation.[30]
- **Research and collaboration:** HRSD partnered with universities and research institutions to develop and validate advanced treatment and monitoring systems, ensuring recharge water meets potable quality standards.[41]

[39] **Bott, C.** (2025). Personal communication.
[40] **Amos,** D. (n.d.). Full-Scale Implementation of Groundbreaking SWIFT Program. Hazen and Sawyer. https://www.hazenandsawyer.com/projects/full-scale-implementation-of-groundbreaking-swift-program
[41] **Sakry, C.** (2023). SWIFT is changing the future for Virginia's groundwater supply. Virginia Tech College of Engineering. https://eng.vt.edu/magazine/stories/spring-2023/swift-water-lab.html

SUMMARY OF CASE STUDIES

Table 2: Overview of context and results

CASE STUDY	CHALLENGE	CIRCULAR WATER SOLUTION	OUTCOMES	ENABLING FACTORS
1. Loudoun Water (Virginia, USA)	Rapid growth of data centers created surging demand for industrial cooling water, straining local freshwater sources.	Developed a water reuse system with a dedicated "purple pipe" network to deliver recycled water for industrial uses.	Met over 40% of data center cooling water needs, added US$1.5M in utility revenue, and reduced Potomac River withdrawals.	Early infrastructure investment, public-private collaboration, and pricing incentives
2. NEWater (Singapore)	Severe water scarcity due to lack of groundwater, limited rainfall, and growing industrial demand.	Launched NEWater, a national-scale water reuse program targeting industrial supply and indirect potable reuse.	Provided a resilient, affordable water supply underpinning 10% of national GDP and secured water independence.	Strong centralized governance, aligned industrial policy, and strategic public trust campaigns.
3. East Bay Municipal Utility District (California, USA)	Increasing urbanization and climate pressures strained wastewater and energy systems.	Implemented co-digestion of organic waste with wastewater to produce biogas and recover resources.	Became North America's first energy self-sufficient WRRF, saving US$2M annually and generating US$16.8M from waste fees.	Alignment with state climate policy, early pilot programs, and securing waste sector partnerships
4. VCS Denmark (Denmark)	Faced aging infrastructure, stringent EU discharge regulations, and national carbon neutrality mandates.	Transformed its plant with energy-positive sludge treatment, advanced digestion, and nutrient removal technologies.	Became energy-positive in three years, offsetting capital costs through energy savings and generating new revenues.	National climate targets, technology innovation, and continuous process upgrades
5. Orange County Water District (California, USA)	Chronic drought and seawater intrusion threatened water supply reliability.	Built the world's largest potable reuse system (GWRS) to replenish groundwater basins.	Meets 35% of water demand, avoids $110M in water import costs, and enhances drought resilience.	Long-standing interagency collaboration, phased scaling, and diverse public funding
6. Hampton Roads Sanitation District (Virginia, USA)	Degraded Chesapeake Bay water quality and excessive aquifer withdrawals led to subsidence and saltwater intrusion.	Created an aquifer recharge system (SWIFT) using highly treated wastewater to exceed nutrient discharge targets and rebuild groundwater pressure.	Will restore aquifer health, generate nutrient credits, and protect regional water access with projected US$1.2B investment.	Science-led phased rollout, regulatory alignment, and R&D partnerships

Table 3: Summary of circular water approaches, by "3R" framework

CASE STUDY	REDUCE	RECOVER	REGENERATE
1. Loudoun Water (Virginia, USA)	Reduced reliance on freshwater by recycling water	Treated wastewater for productive reuse in data centers	Improved local water balance by offsetting withdrawals from the Potomac River
2. NEWater (Singapore)	Decreased freshwater imports and surface water use through aggressive water recycling	Recycled high-purity water through advanced treatment and used it in industry and indirect potable reuse	Created a more climate change-resilient national water system
3. East Bay Municipal Utility District (California, USA)	Reduced organic waste going to landfills and decreased energy consumption at the treatment plant	Recovered biogas and nutrients through co-digestion of wastewater and food waste	Created environmental value by producing renewable energy and reducing GHG emissions
4. VCS Denmark (Denmark)	Lowered energy consumption and discharge pollutants through process optimization	Recovered energy and nutrients from sludge digestion and advanced treatment processes	Created resource loops by becoming a net producer of energy and nutrient fertilizers
5. Orange County Water District (California, USA)	Reduced imported water dependency by recycling wastewater to meet local needs	Purified water for groundwater replenishment and indirect potable reuse	Restored aquifer levels through large-scale recharge
6. Hampton Roads Sanitation District (Virginia, USA)	Decreased nutrient discharges into the Chesapeake Bay by diverting treated water to recharge	Recycled wastewater for high-quality treatment and beneficial groundwater injection	Regenerated depleted aquifers to prevent subsidence and saltwater intrusion, while protecting ecosystems from nutrient overload

FROM INSIGHT TO IMPLEMENTATION:

How can we scale circular water?

HERE'S A ROADMAP

Achieving a circular water economy is both an environmental imperative and an economic opportunity to deliver measurable returns, reduce risk, and increase resilience across communities. It demands a systematic transformation of how water is valued, managed, and governed across different regions, sectors, and institutions.

Circular water solutions are achievable. Institutional alignment, public trust, flexible regulation, and blended finance are essential to moving from concept to execution. Where these factors are in place, circular solutions are already gaining traction.

We must replicate and scale what works. Local leaders can use this valuation framework to target investments with the greatest potential return. Demonstration projects and pilot programs will help build support, attract capital, and reduce barriers to adoption. Figure 2 illustrates how we can move from ideas to action.

Figure 2: Pathway to mainstreaming and scaling a circular water economy (Illustrative)

How can stakeholders take the first step? The case studies in this report reveal common themes and discrete actions for different stakeholder groups (Table 4). While this is not intended to be comprehensive, and more work is needed to fully validate these actions, they're a great starting point to drive conversation and investment in circular water solutions.

For utilities, a site-specific evaluation of the business case and ROI of circular water solutions is critical. This should be paired with mutually beneficial partnerships with industry and community groups. Such partnerships help distribute risk across beneficiaries and establish an implementation pathway, as demonstrated in the Singapore and EBMUD case studies.

Industry must be proactive in solution design and long-term planning. Collaborative planning with utilities ensures that infrastructure investments are aligned, risks are shared, and community trust is built through unified messaging that reflects shared priorities.

For regulatory agencies, policies and clear guidance are critical to scaling circular practices. Regulatory and governance structures that encourage and incentivize planning and implementation of circular solutions can streamline approvals and build confidence among project developers. Technical guidance can further support streamlined permitting by aligning expectations for permit compliance and reporting needs.

Technology providers and financial institutions are key. Technology providers can work with utilities and industry to pilot and validate solutions while creating tools to assess cost-effectiveness. Financial institutions can also support innovation by investing in technology startups and designing new funding mechanisms to advance projects with both public and private benefits.

Working together accelerates progress.

Table 4: Near-term priorities for advancing circular water, by stakeholder group

Stakeholder group	Priority next steps
Utilities	• Ensure a viable business case for circular practices by optimizing rate structures, pricing incentives, and cost recovery models. • Encourage internal innovation through phased implementation and pilot programs that build buy-in and reduce risk. • Build cross-sector partnerships with waste haulers, industrial users, and technology providers to identify shared infrastructure opportunities. • Proactively build public trust in circular solutions through targeted education and communication efforts.
Industry	• Co-design infrastructure solutions with utilities to meet industrial needs through fit-for-purpose reuse, resource recovery, or aquifer recharge. • Engage in public-private water planning efforts to ensure long-term supply security and align on regulatory and infrastructure timelines. • Pilot on-site reuse or closed-loop systems in water-stressed regions or high-consumption facilities. • Support public messaging and case-making by highlighting circular practices in sustainability disclosures, facility tours, or supplier guidance.
Policy and regulatory agencies	• Prioritize circular approaches in infrastructure funding and permitting by embedding eligibility and evaluation criteria in public programs. • Develop model policies and technical guidance to help localities adopt reuse, green infrastructure, or biosolids use, and other circular water solutions. • Coordinate cross-agency and cross-sector planning to align water reuse with energy, housing, and economic development goals. • Invest in workforce training and certification for operators, engineers, and planners to scale technical capacity for circular systems.

Technology and innovation ecosystem	• Create real-world testbeds for pilot deployment and validation of new circular water technologies. • Develop shared tools and data platforms such as ROI calculators, site-screening tools, and resource recovery estimators. • Launch innovation challenges or sandbox initiatives to foster collaboration between startups and utilities.
Finance and investment	• Fund feasibility and pre-development work to make circular water projects investment-ready. • Structure blended finance vehicles that combine public funding with ratepayer revenue or private capital. • Channel catalytic capital into high-potential technologies for reuse, energy recovery, or biosolids valorization. • Support outcome-based financing mechanisms such as nutrient credit markets or environmental impact bonds.

DRIVING THE TRANSITION TOGETHER

The actions outlined above offer a starting point for coordinated progress Lessons from recent successes can help stakeholders identify near-term opportunities and shape longer-term strategies. Progress depends on sustained collaboration with utilities, industry, regulatory agencies, and other partners to unlock viable and scalable solutions.

WEF is advancing the Circular Water Economy by equipping stakeholders with knowledge, partnerships, and proven strategies. This builds shared understanding, convenes cross-sector leaders, and elevates successful models for faster adoption. While implementation must be led locally and supported by national policy and investment. WEF remains committed to supporting people driving change on the ground.

Water matters, and this is our pivotal moment in the United States. Circular water offers a powerful, lucrative opportunity to transform water systems into engines of resilience, innovation, and long-term value.

Appendix A: Glossary

Anaerobic digestion
A biological treatment process in which microorganisms break down organic materials in the absence of oxygen, often used in wastewater treatment to produce biogas and reduce solids.

Biogas
A renewable energy source produced during anaerobic digestion of organic matter such as wastewater sludge, used for heat, electricity, or fuel.

Biosolids
Nutrient-rich organic materials derived from the treatment of sewage sludge that can be used as fertilizer or soil amendment.

Circular water economy
A water management approach that emphasizes reducing waste, recovering resources, and regenerating natural systems by treating water as a renewable, recyclable asset rather than a disposable input.

Direct potable reuse (DPR)
The process of introducing highly treated wastewater directly into a potable water supply system without an environmental buffer, requiring advanced treatment and safeguards.

Effluent
Treated wastewater that flows out of a treatment plant, which may be discharged into the environment or reused for various purposes.

Green infrastructure
Nature-based solutions such as rain gardens, wetlands, or urban green spaces that manage stormwater, improve water quality, and provide ecosystem co-benefits.

Indirect potable reuse (IPR)
The practice of introducing highly treated wastewater into a natural system (such as a reservoir or aquifer) before using it as drinking water, providing an environmental buffer.

Managed aquifer recharge (MAR)
A technique of intentionally recharging groundwater supplies using treated wastewater, stormwater, or excess surface water to restore aquifers, often via infiltration basins or injection wells.

Non-revenue water (NRW)
Water that has been produced and is lost before it reaches the customer due to leaks, theft, or metering inaccuracies, representing inefficiencies in distribution systems.

Nutrient recovery
The process of capturing valuable nutrients like nitrogen and phosphorus from wastewater streams and converting them into fertilizers or other useful products.

Tipping (fees)
The act of unloading waste materials from a vehicle at a designated facility such as a landfill, transfer station, or materials recovery facility.

Total Maximum Daily Load (TMDL)
A regulatory term in the U.S. Clean Water Act describing a plan for restoring impaired waters by identifying the maximum amount of a pollutant a waterbody can receive while still meeting water quality standards.

Water reuse
The process of treating and repurposing wastewater for beneficial uses such as agricultural or landscape irrigation, industrial uses, and potable reuse.

Appendix B: Methodology and key assumptions

This analysis uses a Total Addressable Market (TAM) approach to estimate the total value of a fully realized circular water economy for utilities. A TAM approach quantifies the maximum potential value that could be captured if high-potential circular water interventions were deployed at full scale, wherever technically feasible and contextually appropriate across the country. It is a directional estimate of the total market opportunity, meant to illustrate the upper bound of economic value that circular water practices could unlock in an optimized scenario.

For each of the 3-Rs, the most important drivers of value were selected. The analysis identified circular approaches with the largest scalable value potential based on available data, real-world feasibility, and expert input. Interventions with more limited economic impact were excluded from quantitative modeling for simplicity, though they may remain important for environmental, social, or regulatory reasons. Their exclusion does not reflect a lack of value, but rather a decision to prioritize the clearest and most material economic contributions to the topline valuation.

Table 1: Prioritized interventions in this analysis

Three Rs	Interventions
REDUCE	1. Detecting leaks and repairing pipes to reduce non-revenue water and redundant treatment of water for enhanced efficiency 2. Recycling wastewater to meet freshwater demand from agriculture, manufacturing, and other sectors
RECOVER	3. Recovering phosphorus and nitrogen from wastewater for use as agricultural fertilizer 4. Using anaerobic digestion to convert waste solids into biogas to generate energy for facilities or the grid 5. Applying treated biosolids to land as nutrient-rich fertilizer
REGENERATE	6. Coordinating green infrastructure development and restoring wetlands to manage stormwater flooding 7. Using treated wastewater or stormwater to recharge surface water supplies, or replenish overdrawn aquifers and prevent saltwater intrusion

The TAM approach avoids double counting potential benefits by valuing each intervention as a distinct, standalone opportunity with clearly defined boundaries. This is especially important given the overlapping nature of many circular water solutions, where benefits can be interrelated or reinforcing. Each intervention (e.g., leak reduction, water reuse, or biogas recovery) is assessed independently based on its unique value contribution, with conservative assumptions to isolate its incremental impact. When synergies and overlapping exist, the analysis attributes values to only one intervention to prevent duplication.

This estimate leverages both novel estimates and existing research to quantify the total valuation. Specific topics, such as non-revenue water and nutrient recovery from wastewater are better understood, allowing this paper to benchmark and confirm the model's estimates are in line with current understandings and market estimates. Other topics, including the value of avoided infrastructure costs and managed aquifer recharge, remain relatively underexamined and therefore required additional assumptions to be made. Specific assumptions are listed under each source of value.

The model included upper and lower bounds for each value driver based on ranges in key input variables. These included adoption rates, unit values, and capture efficiencies. The bounds reflect uncertainty in the underlying data as well as variability in real-world implementation conditions. The final economic value was then calculated as the midpoint between these bounds, providing a balanced estimate that captures potential variability while avoiding over- or underestimation.

Importantly, this is not a forecast: it does not predict future adoption rates, account for local barriers, or reflect the timing or costs of real-world rollouts. Rather, it provides a benchmark to inform strategic discussions about investment, prioritization, and long-term potential, assuming full uptake under ideal conditions.

REDUCE – SOURCE OF VALUE 1: AVOIDED COSTS OF TREATING NON-REVENUE WATER

Value of non-revenue water (annually) = VLRP

Where V = total volume of treated water,[42] L = percentage of treated water lost,[43] R = percentage of losses that are real (e.g., leaks, pipe bursts),[44] P = average price of treated drinking water.[45]

Assumptions

- **Real losses:** Only real losses were considered as part of the avoided costs, given that non-real losses due to inaccurate meter readings result in lost revenue for utilities, but do not directly impact the overall volume of water used in the system.
- **Cost of treating water:** The average price of treated drinking water for end users was treated as equivalent to the cost of treatment and distribution to utilities, given that public utilities are not profit-maximizing entities therefore assuming the rate-payer price to be a close proxy for utility operating expenses.

[42] **U.S. Geological Survey.** (2018). Total Water Use in the United States. https://www.usgs.gov/special-topics/water-science-school/science/total-water-use-united-states
[43] **Bluefield Research.** (2025). Water Losses Cost U.S. Utilities US$6.4 Billion Annually. https://www.bluefieldresearch.com/ns/water-losses-cost-u-s-utilities-us6-4-billion-annually/
[44] **Ibid.**
[45] **World Population Review.** (n.d.). Water Prices by State 2025. https://worldpopulationreview.com/state-rankings/water-prices-by-state

REDUCE – SOURCE OF VALUE 2: ADDITIONAL REVENUE FROM WATER REUSE

Value of water reuse (annually) = $V_{waste}ADP_{recycled}$

Where V_{waste} = total volume of wastewater produced,[46] A = proportion of wastewater available for reuse,[47] D = estimated demand for water reuse,[48] and $P_{recycled}$ = average price of recycled water.[49]

Assumptions

- **Estimated demand for water reuse:** Demand for water reuse was estimated on a state-by-state basis, given differences in local needs. State demand for water reuse was first tied to agricultural water use, given that agriculture is the largest consumptive user of water in the U.S. Then, based on states' water scarcity, states were categorized to a High (80%), Medium (50%), or Low (30%) level of expected demand for reuse. These numbers were benchmarked against Nevada, which has the highest current rate of statewide water reuse in the U.S., estimated to be 85%.[6] The national demand for water reuse was then estimated, based on a weighted average of each state's demand and the state's overall volume of water use.
- **Discount for recycled water:** The price of recycled water was discounted to reflect the typically lower prices offered for use of recycled water. These discounts ranged from 10-50% of the average price of treated water.[49, 50]
- **Potential for increase:** While not directly factored into the model, water reuse represents one of the key pathways for significant impact at scale for the circular water economy. While not all parts of the U.S. may see an immediate need for water reuse, a completely closed system of circular water could unlock even more value over time.

RECOVER – SOURCE OF VALUE 3: AVOIDED COSTS AND/OR ADDITIONAL REVENUE FROM BIOGAS RECOVERY FOR ENERGY

Value of biogas (annually) = $V_{waste}METP$

Where V_{waste} = total volume of wastewater produced,[46] M = amount of methane per unit of wastewater,[51] E = energy in methane,[51] T = percentage of wastewater volume treated by WRRFs that can access anaerobic digestors,[52] P = price of energy.[53]

[46] **U.S. Environmental Protection Agency.** (n.d.). Sources and Solutions: Wastewater. https://www.epa.gov/nutrientpollution/sources-and-solutions-wastewater
[47] **Rauch-Williams, T. et al.** (2018.) Baseline Data to Establish the Current Amount of Resource Recovery from WRRFs. https://www.accesswater.org/publications/-326675/baseline-data-to-establish-the-current-amount-of-resource-recovery-from-wrrfs
[49] **WateReuse.** (n.d.). Access to Safe & Affordable Water: The Case for Investment in Water Reuse. https://watereuse.org/wp-content/uploads/2021/09/Policy-Brief-Affordability-v5.pdf
[50] **New York City Department of Environmental Protection.** (n.d.). Water Reuse Fact Sheet. https://www.nyc.gov/assets/dep/downloads/pdf/water/drinking-water/water-reuse-fact-sheet.pdf
[51] **Qadir, M. et al.** (2020). Global and regional potential of wastewater as a water, nutrient, and energy source. Natural Resources Forum. https://onlinelibrary.wiley.com/doi/full/10.1111%2F1477-8947.12187
[52] **Environmental and Energy Study Institute.** (2017). Fact Sheet | Biogas: Converting Waste to Energy. https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy
[53] **U.S. Energy Information Administration.** (2025). Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State. https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a

Assumptions

- **Access to anaerobic digestors:** Given technical scale requirements, anaerobic digestion is generally only viable for medium to large WRRFs. Thus, this model only considers the volume of wastewater treated by WRRFs for which anaerobic digestors are technically feasible.
- **Technological limitations:** Like all of the other elements in this analysis, current technological limitations were held constant. In other words, this model estimates the value of biogas based on the amount of biogas that can be recovered by current technological means. However, advancements in technology could unlock additional potential value not reflected in this model.

RECOVER - SOURCE OF VALUE 4: ADDITIONAL REVENUE FROM NUTRIENTS (BIOSOLIDS AND NUTRIENT EXTRACTION)

Value of nutrients (annually) = $\Sigma V_{waste}NRP$

Where V_{waste} = total volume of wastewater produced,[46] N = amount of a given nutrient per unit of wastewater[51,54,55,56] R = average recovery rate, based on current technology[57,58,59,60] P = price of nutrient, based on fertilizer analog;[61] summed over all relevant nutrients.

Assumptions

- **Nutrients:** This analysis considered four nutrients specifically – nitrogen, phosphorus, potassium, and sulfur – as the largest drivers of value.
- **Recovery rate:** The recovery rate was estimated based on the variety of techniques for nutrient extraction for each nutrient. These were input as ranges, with the average being taken, to not overestimate the potential recovery rate based on current technology.
- **Nutrient recovery vs. biosolids:** Given that nutrient recovery and nutrients in biosolids for land application are accessing the same nutrients in the raw wastewater, more emphasis was put on direct nutrient recovery to capture the value of all forms of nutrients in wastewater.

[54] **U.S. Environmental Protection Agency.** (2000). Wastewater Technology Fact Sheet: Trickling Filter Nitrification. https://www3.epa.gov/npdes/pubs/trickling_filt_nitrification.pdf
[55] **Butler, T.** (n.d.) Sewage Parameters 4 Part 1: Phosphorus (P). Butler Manufacturing Services Limited. https://butlerms.com/education-blog/sewage-parameters-4-part-1-phosphorus-p
[56] **Dewil, R. et al.** (2006). The Analysis of the Total Sulphur Content of Wastewater Treatment Sludge by ICP-OES. Environmental Engineering Science. https://www.liebertpub.com/doi/abs/10.1089/ees.2006.23.904?journalCode=ees
[57] **Qin, Y. et al.** (2023). Nitrogen recovery from wastewater as nitrate by coupling mainstream ammonium separation with side stream cyclic up-concentration and targeted conversion. Chemical Engineering Journal. https://www.sciencedirect.com/science/article/abs/pii/S138589472205817X
[58] **Witek-Krowiak, A.** (2022). Phosphorus recovery from wastewater and bio-based waste: an overview. Bioengineered. https://pmc.ncbi.nlm.nih.gov/articles/PMC9275867/
[59] **Khatri, I., Garg, A.** (2022). Potash recovery from synthetic potassium rich wastewater and biomethanated distillery effluent using tartaric acid as a recyclable precipitant. Environmental Technology & Innovation. https://www.sciencedirect.com/science/article/pii/S2352186422002942
[60] **Hu, X. et al.** (2023). Recovery of bio-sulfur and metal resources from mine wastewater by sulfide biological oxidation-alkali flocculation: A pilot-scale study. Science of The Total Environment. https://www.sciencedirect.com/science/article/abs/pii/S0048969723011622
[61] **Sullivan, D. M., et al.** (2022). Fertilizing with Biosolids. A PNW Extension Publication. https://extension.oregonstate.edu/sites/extd8/files/documents/pnw508.pdf

REGENERATE – SOURCE OF VALUE 5: AVOIDED COSTS OF DAMAGES FROM URBAN STORMWATER FLOODING

Value of green infrastructure for urban stormwater flooding (annually) = DE

Where D = annual cost of damages due to urban stormwater flooding[62] and E = potential effectiveness rate of green infrastructure in mitigating damages.[36]

Assumptions

- **Cost of damages due to urban stormwater flooding:** The American Society of Civil Engineers estimated, in 2021, that urban stormwater flooding resulted in US$9 billion in damages annually.[62] Recognizing that flood damages affect a range of stakeholders and that utilities are not unilaterally responsible for all stormwater infrastructure, this number was taken as a starting point for the overall cost of damages borne by municipalities and utilities.
- **Effectiveness of green infrastructure:** Recognizing the many different types of green infrastructure, a range of effectiveness rates was estimated based on EPA case studies of underground infiltration trenches, rain gardens, underground storage and infiltration systems, and regional stormwater ponds.[36]

REGENERATE – SOURCE OF VALUE 6: MARGINAL VALUE OF MANAGED AQUIFER RECHARGE WITH TREATED WASTEWATER AND STORMWATER CAPTURE

Value of managed aquifer recharge (annually) = $(V_{waste}A + V_{storm})P$

Where V_{waste} = total volume of wastewater,[46] A = percentage of water used originally sourced from groundwater,[63] V_{storm} = volume of stormwater retained through green infrastructure available for groundwater recharge,[64] and P = estimated value of groundwater recharge.[64]

Assumptions

- **Marginal water recharged:** This model only considers the marginal value of the additional water, in the form of either treated wastewater or stormwater, being recharged to aquifers. It does not capture the broader economic value of aquifers in the U.S. (which would be on the order of trillions of dollars) to avoid overestimating the value of managed aquifer recharge.
- **Price of groundwater recharge:** This analysis bases its logic and estimated price of groundwater from an EPA study: "Estimating Monetized Benefits of Groundwater Recharge from Stormwater Retention Practices" (2016).[64]
- **Upper bound volume:** The calculation is scaled to the current volume of water drawn from groundwater sources to avoid overstating the potential value of recharge efforts. While recharge can be done with wastewater originally drawn from any source, particularly on a local basis, we assumed that the upper limit for recharge on a national basis would not exceed the overall rate of withdrawal from groundwater sources.

[62] **American Society of Civil Engineers.** (2021). 2021 Report Card for America's Infrastructure. https://www.infrastructurereportcard.org/wp-content/uploads/2020/12/2021-IRC-Executive-Summary.pdf
[63] **U.S. Geological Survey.** (n.d.). How important is groundwater? https://www.usgs.gov/faqs/how-important-groundwater
[64] **U.S. Environmental Protection Agency (EPA).** (2016). Estimating Monetized Benefits of Groundwater Recharge from Stormwater Retention Practices. https://www.epa.gov/sites/default/files/2016-08/documents/gw_recharge_benefits_final_april_2016-508.pdf