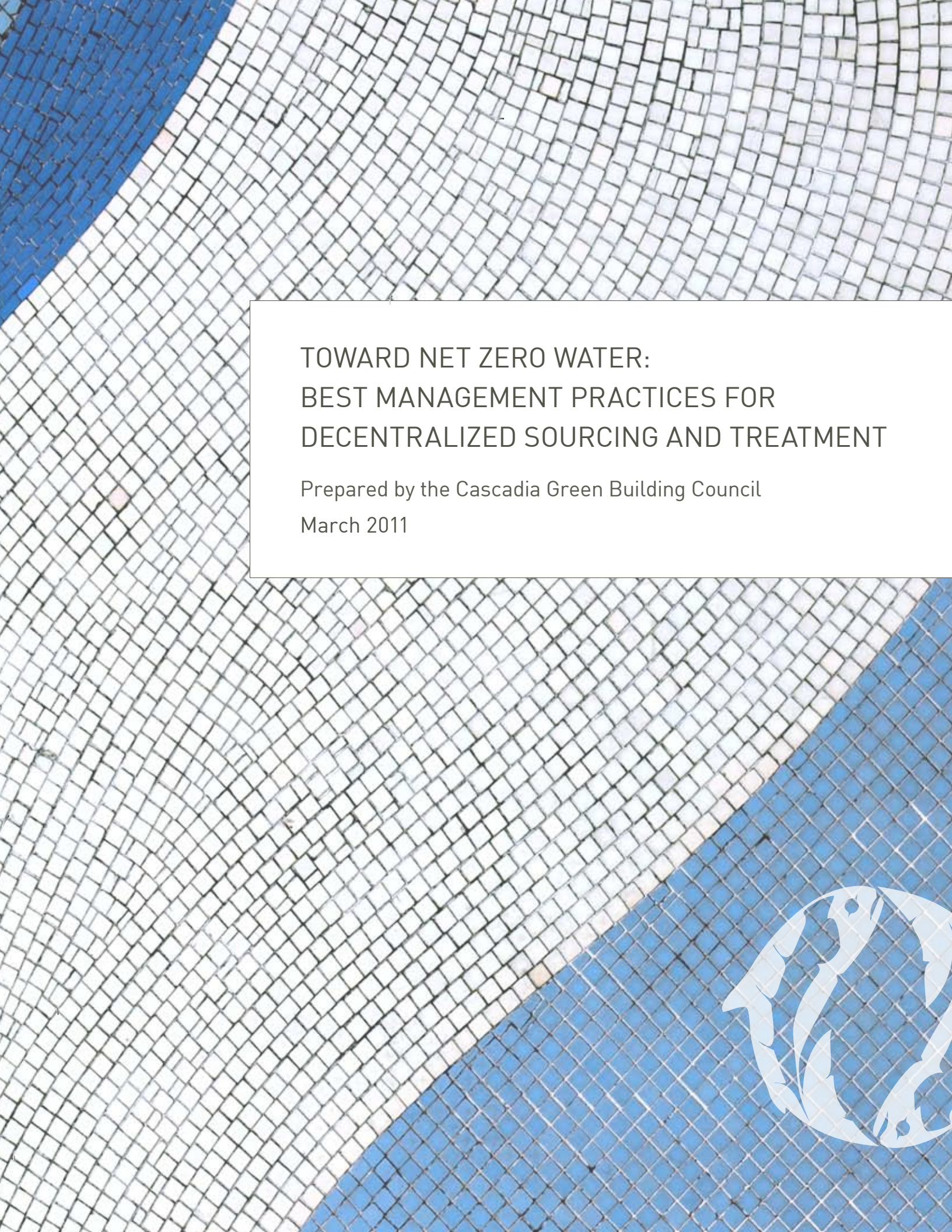

TOWARD NET ZERO WATER: BEST MANAGEMENT PRACTICES FOR DECENTRALIZED SOURCING AND TREATMENT

Prepared by the Cascadia Green Building Council

March 2011

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EXECUTIVE SUMMARY

Toward Net Zero Water is a best management practices manual on decentralized strategies for water supply, on-site treatment and reuse. It was conceived through an extensive literature review on the topics of site and district-scale water systems with a focus on best-in-class examples from around the globe. This manual is intended to assist developers and regulators of water systems to better understand these strategies and how they might be applied in American cities.

North American communities face significant water-related challenges. Growing urban populations demand expanded water and wastewater services, while aging water supply and wastewater treatment infrastructure, most of which was designed and built in the late 19th and early 20th centuries, approaches end-of-life or is in need of major overhaul. This growing crisis is further exacerbated by unsustainable water use patterns. Every day, we use potable water within our buildings for non-potable functions such as washing clothes or flushing toilets, all with little or no attempt at reuse. Further, alterations in local and global climate patterns pose additional risks to the health and resilience of our water systems.

In recent years, the green building movement has made strides to change the way people view water resources, raising awareness and increasing implementation of water conservation techniques. Despite this progress, green buildings have not come far enough, fast enough to address the challenges that face our cities' water infrastructure. A widespread adoption of more integrated systems that include supply, treatment and reuse of water at the building and neighborhood scale is an important strategy for increasing the resiliency of our water systems.

The incorporation of decentralized strategies for water supply, on-site treatment and reuse requires a major shift in the mindset of how buildings are conceived, designed, regulated, built and operated. Insight into the current conditions of our water systems and their associated environmental, social and economic risks provides the background and context for why this is a necessary shift. Movement toward a "soft path" for water management through decentralized and distributed-scaled systems offer alternatives for communities willing and/or forced to re-think their path forward.

BEST MANAGEMENT PRACTICES FOR DECENTRALIZED WATER SYSTEMS

Best management practices (BMPs) for net zero water buildings emphasize closed-loop systems, ultra-efficient measures to reduce system demands, small-scale management systems, fit-for-purpose water use and diverse, locally appropriate infrastructure. Establishing a water balance (a numerical account of how much water enters and leaves the boundaries of a project) is a critical step in understanding water flows on-site. The most successful design strategies are those that not only seek equality between water supply volume and building demand, but also address long term financial and public health risks and provide educational opportunities for building occupants.

This report contains an overview of best practices for decentralized and distributed water strategies organized by the following subjects:

- Rainwater harvesting, including strategies for potable and non-potable uses
- Greywater reclamation and reuse
- On-site wastewater treatment and reuse, including composting toilets

Best practices for the design and implementation of on-site stormwater management systems and for improving fixture efficiencies are not included in the scope of this report, though are important aspects to achieving net zero water goals.

Each BMP chapter describes major system components, how the systems work and background on appropriate scale and efficiency. Additional design considerations are suggested for system sizing, location and integration with other building systems. Case studies of innovative projects from around the globe are highlighted in each chapter. The additional resources section located at the end of the chapter describes where to find more in-depth information and technical details on decentralized BMPs.

FURTHER RESEARCH

The amount of research and literature available on alternative water systems is staggering. However, more comprehensive information and design guidance is needed on balancing available on-site water supplies, including rainwater and recycled water, with occupant demand. More on-the-ground demonstration projects also are needed to showcase BMPs and inform future net zero water efforts. Additional research is needed in the following areas to support and empower the next generation of innovative water projects:

- Broader evaluation of public health and safety risks
- Lifecycle assessment investigating the environmental impacts associated with various strategies
- Chlorine disinfection for treatment of on-site rainwater harvesting systems
- Climate change and resiliency of fresh water supplies
- Occupant behavior related to water use in buildings
- Presence of pharmaceuticals and other chemicals found in water supplies
- Increasing water demands for urban agriculture

An extensive bibliography of sources uncovered during the literature review is located at the end of the report and provides a list of references for further research.

INTRODUCTION

INTRODUCTION

"In fact, as a species we are approximately 65 percent water—it defines and shapes us in every way imaginable, physically and spiritually, from our first few months in the womb, when we are literally enveloped by it, to life outside the womb, where we need to be constantly replenished with eight to ten cups of clean water each day to survive."

—Jason F. McLennan, CEO, Cascadia Green Building Council

Good, quality water is a diminishing resource. There is growing consensus that the water crisis — accelerated by pollution, inefficient use and climate change — will soon dwarf the energy crisis in significance and severity.[1] Already, more than 900 million people on this planet do not have access to safe drinking water, and 2.6 billion are not using safe sanitation practices.[2] As a species, we must generate a healthy relationship with water if we want to survive and protect the biodiversity of the planet. Implementation of sustainable water use will require the combined efforts of regulators, designers and users. This document is intended to help regulators and designers of urban systems understand best practices for creating water systems that allow building occupants to reduce the impacts of their use.

CURRENT CHALLENGES AND OPPORTUNITIES: WATER AND WASTE

Of all the Earth's water, 97.5 percent is salt and 2.5 percent is fresh water. Of that fresh water, only 1 percent (.007 percent of the total water) is readily accessible for human use. Seventy percent of the world's water is used for agriculture, 22 percent for industry and 8 percent for domestic use. In high-income countries like the United States, approximately 30 percent of our fresh water is used for agriculture, 59 percent for industry and 11 percent

1 Furumai, H. "Rainwater and reclaimed wastewater for sustainable urban water use". Physics and Chemistry of the Earth, Parts A/B/C, 2008.

2 Corcoran, E., C. Nellemann, E. Baker, R. Bos, D. Osborn, H. Savelli (eds). 2010. Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal.

for domestic use.[3] Clearly, reducing demand from the agricultural and industrial sector should be prioritized for addressing the world water crisis. However, urban water issues will continue to be significant in an increasingly urban world. As of 2009 and for the first time in history, more humans live in cities than outside cities. We are an increasingly urban species, and our water systems are ever more important as a result.

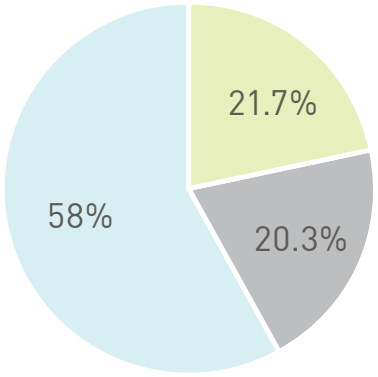
Here in the United States, we have enjoyed a half-century of nearly universal access to abundant supplies of potable water. But serious and sustained droughts in the south and long bitter fights over water rights in the west indicate this privilege is ending. Future population growth will exert more demand on water systems while climate change is predicted to decrease available supplies. Recently, a Government Accountability Office (GAO) survey found that water managers in 36 states anticipate water shortages by 2020. These challenges will require a more sustainable approach to using water resources, looking at not only how much water is used but also the quality of water needed for each use.[4]

3 "Ten Things You Should Know About Water." Circle of Blue WaterNews. N.p., October 2010.

4 Kloss, Christopher, Managing Wet Weather with Green Infrastructure: Rainwater Harvesting Policies: US EPA, 2008.

While potable water is used almost exclusively for domestic uses, Figure I-1 shows approximately 80 percent of demand for a typical residential building does not require potable water. Similar trends exist for commercial water use. Figures I-2 and I-3 provide examples of daily commercial water usage.

FIGURE I-1. TYPICAL DOMESTIC DAILY PER CAPITA WATER USE



Potable Indoor Daily Uses:	
Showers	11.6 gal.
Dishwashers	1.0 gal.
Baths	1.2 gal.
Faucets	10.9 gal.
Other uses, leaks	11.1 gal.
Non-Potable Indoor Daily Uses:	
Clothes washers	15.0 gal.
Toilets	18.5 gal.

FIGURE I-2. TYPICAL DAILY WATER USE FOR OFFICE BUILDINGS

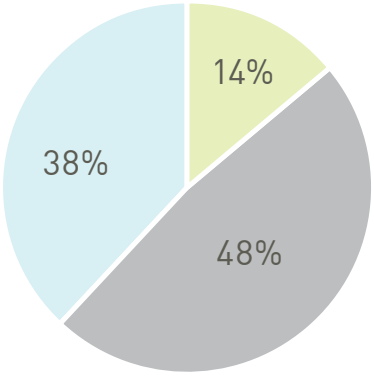


FIGURE I-3. TYPICAL DAILY WATER USE FOR HOTELS

Source: Kloss, Christopher. Managing Wet Weather with Green Infrastructure: Rainwater Harvesting Policies: US EPA, 2008.

Potable water is often utilized for purposes that could be satisfied with lower-quality water, such as toilet flushing, irrigation and laundry. Statistics also show that the vast majority of water is used in a one-time, pass-through manner with little attempt at reuse. Our centralized, big-pipe infrastructure relies on an industrial model of specialization and economies of scale.[5] Though designed and managed primarily to protect the public from pathogens and floods, these centralized systems are typically resource and energy intensive in their transport and treatment of water and pose serious social, environmental and economic risks for urban American communities. Further, these systems are riddled with inefficiencies due to the age and poor maintenance of our cities' water infrastructure, and their very design can create an imbalance in water and nutrient flows that distort hydrological and ecological regimes. According to the 2009 American Society of Civil Engineers Report Card, our nation's water and wastewater infrastructure scored a D- with over $255 billion needed to fund upgrades to these systems over the next five years.

In this time of growing water crisis, it is critical that we re-imagine our water systems in which more environmentally, socially and economically responsible system design and operation is considered along with public health benefits. Review of decentralized infrastructure with smaller-scale integrated systems that incorporate rainwater capture, fit-for-use on-site treatment and water re-use is a logical starting point for this re-imagination. These systems are the subject of this report, which addresses best practices for their implementation within U.S. cities that allow or are open to allowing the inclusion of distributed systems within the water solution for future sustainability.

Image: IslandWood

Students learn about on-site wastewater treatment at IslandWood's Living Machine®.

5 Nelson, Valerie. "New Approaches in Decentralized Water Infrastructure." Decentralized Water Infrastructure, 2008

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"Ten Things You Should Know About Water." Circle of Blue WaterNews. N.p., October 2010. Web. October 2010. (www.circleofblue.org).

CONTEXT AND BACKGROUND

SECTIONS

CONTEXT AND BACKGROUND

HISTORY OF CENTRALIZED WATER SYSTEMS

By the mid to late 18th century, most large U.S. municipalities installed underground fresh water conveyance systems. Basic stormwater systems were installed at the end of the 18th century, and by the middle of the 19th century, centralized water-carriage sewer systems became the standard over privy vault-cesspool systems.

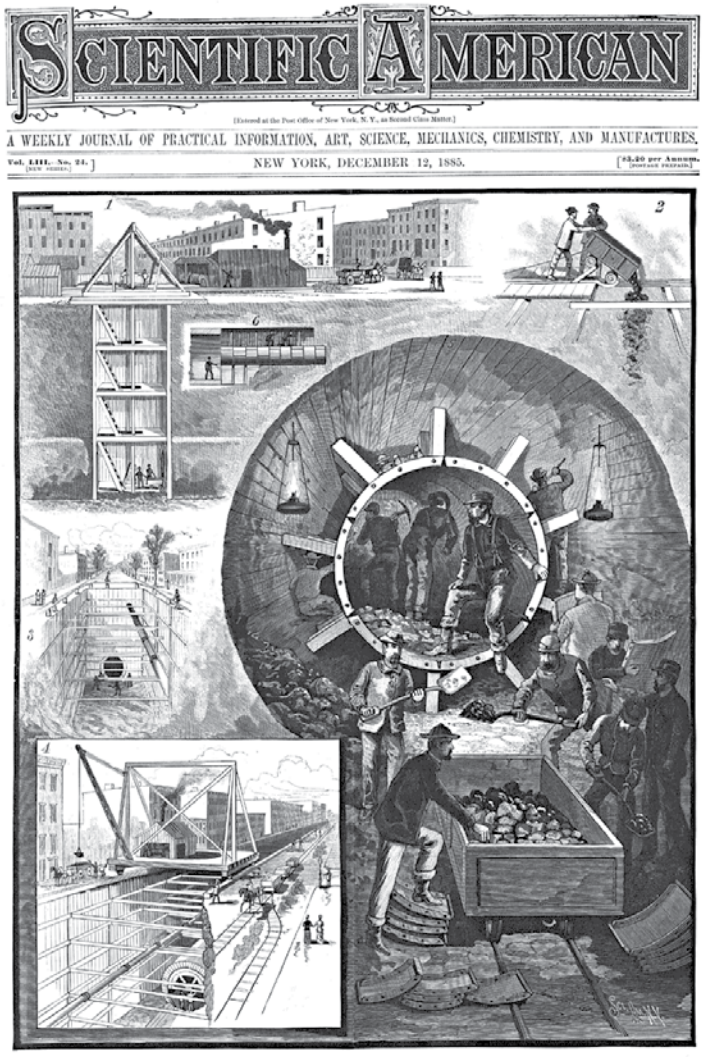
The water-carriage system solved some problems and created others, especially in more densely populated communities. Many city residents accepted the sanitation problems and foul odor as an unavoidable part of urban life.[6] Open sewers lined the streets and households cast their biological waste products into the streets below. City boosters, wishing to clean up the urban image and attract both residents and industries, advocated for centralized waste management and sewer systems.

Opponents to centralized waste management and sewers argued that a source of fertilizer would be lost, soil and water supplies would be polluted at the system outfalls and that "modern sewer systems" would create and concentrate "disease-bearing sewer gas".[7] The debate over the design of centralized systems was split between the argument for combined sewer systems versus separated sewer systems. The combined sewer systems used a single pipe to transport both stormwater and wastewater to a designated disposal location, as opposed to the separated sewer systems, which required laying two pipes. Many cities installed combined systems because they were less expensive to build.

6 Burrian, Steven J., Stephan Nix, Robert E. Pitt, and S. Rocky Durrans. "Urban Wastewater Management in the United States: Past, Present, and Future." Journal of Urban Technology. 7.3, 2000.

7 Ibid.

It wasn't until late in the 19th century that the relationship between wastewater and disease transmission became well understood. Water filtration became more common as studies demonstrated that sand filtration processes could help lower the infection rate of waterborne illnesses such as cholera and typhoid. Using chlorine to disinfect drinking water became prevalent in the early 1900s. Treatment of wastewater utilizing tanks and chemical reactions to filter, settle and bind contaminants found in wastewater became more common by 1910-1920. Dewatering techniques were also developed, successfully producing a by-product sold as fertilizer. As systems developed in the 20th century, the unpredictable flow rate of combined sewer systems made separated sewer systems the preferred choice for treatment plants. Many cities ended up with "compound systems" that included a combined sewer system in some districts and a separated sewer system in newer districts. This is the legacy of our urban water systems.


SCIENTIFIC AMERICAN

[Entered at the Post Office of New York, N. Y., as Second Class Matter.]

A WEEKLY JOURNAL OF PRACTICAL INFORMATION, ART, SCIENCE, MECHANICS, CHEMISTRY, AND MANUFACTURES.

Vol. LIII. No. 24. [NEW SERIES.] NEW YORK, DECEMBER 12, 1885. [$3.20 per Annum. [POSTAGE PREPAID.]

1885 Scientific American Magazine featuring a large infrastructure project in New York City.

Wastewater treatment became widespread after the introduction of federal funding with the Water Pollution Control Act of 1948. The WPC Act provided planning, technical services, research and financial assistance by the federal government to state and local governments for sanitary infrastructure. The WPC Act was amended in 1965, establishing uniform water quality standards and creating the Federal Water Pollution Control Administration authorized to set standards where states failed to do so. In 1970 the Environmental Protection Agency (EPA) was created.

In 1972, the Clean Water Act was passed to limit pollution of freshwater sources. In 1974, the Safe Drinking Water Act was adopted to regulate public water systems. It specified which contaminants must be closely monitored and reported to residents should those contaminants exceed maximum allowable levels. Since the 1970s, federal, state and municipal governments have closely monitored American drinking water systems. For

decades federal funding for water supply and sanitation was provided through grants to local governments. After 1987, the system was changed to loans through revolving funds that have favored big-pipe infrastructure.

Increased water quality standards and regulation, coupled with advancements in water treatment and delivery and wastewater disposal systems, have dramatically improved human health in American cities. These systems have also altered human settlement patterns by allowing communities to grow beyond the carrying capacity of their local eco-systems as "water-on-demand" and "waste-be-gone" systems became standard. These systems have required large energy and financial inputs to manufacture, install and operate. Now, this aging infrastructure is a financial burden for municipalities.

Cities across America must face big decisions about how they will continue to meet the water and wastewater needs of their growing communities while continuing to protect public health. The business-as-usual approach is to rebuild and expand the existing systems without considering alternative solutions. In evaluating alternatives, it is important to understand the associated environmental, social and economic risks of each option. As communities risk bankruptcy in order to maintain aging infrastructure, prudent consideration of decentralized and distributed systems is crucial to help address the financial resiliency of our communities.

Centralized water treatment facility.

CURRENT CONDITIONS: ENVIRONMENTAL, SOCIAL & ECONOMIC RISKS

Centralized water collection and treatment systems have greatly improved overall public health by providing access to a fresh, clean water supply. Despite these benefits, the scales and methods at which these systems currently operate pose significant environmental, social and financial risks.

ENVIRONMENTAL

Disruption of natural hydrology within the watershed

The ecological impacts of large dams and water treatment projects have become a growing environmental concern. Disrupting the natural flow of rivers, streams and groundwater percolation have far-reaching effects on a watershed's ecological health. At its healthiest, a freshwater system maintains a state of dynamic equilibrium, yielding crucial ecological services by providing habitat, barriers to toxins, nutrient transportation and filter functions.[8] To maintain this equilibrium, "mechanisms allow the ecosystem to control external stresses or disturbances within a certain range of responses thereby maintaining a self-sustaining condition".[9] Big pipe systems quickly move large volumes of water from one watershed to another. This movement can cause the groundwater table to drop at the source, creating a system imbalance. The disruption of a watershed's equilibrium can consequently cause high nutrient and pollutant concentrations in areas previously devoid of such contaminants, compromising the quality of the ecological services these systems provide.[10] Large water infrastructure projects strain the resilience of these complex watershed systems, making this very precious resource vulnerable.

Pollution into receiving bodies and vulnerability

Most sewer systems were designed as Combined Sewer Systems, where wastewater and stormwater flow into one pipe on their way to be treated. It is typical for sewer systems to be designed for peak flow loads so that even the largest stormwater event can be treated through the system. However, many older combined sewer systems are subject to flows above their capacity during heavy rains. The use of a Combined System Overflow (CSO) was an economical way to prevent sewage backups into homes and businesses by releasing overflow wastewater and stormwater into adjacent bodies of water.[11] The CSO is an obvious

8 Federal Interagency Stream Restoration Working Group (FISRWG) Stream Corridor Restoration; Principles, Processes and Practices. Washington, D.C.: FISRWG, 1998.

9 Ibid.

10 Pacific States Marine Fisheries Commission and the Oregon Fisheries Congress, "When Salmon Are Dammed.", 04 Apr 1997. Web. 7 Sep 2010.

11 King County. "Combined Sewer Overflow (CSO)." Public Health - Seattle & King County. King County, 03 Feb 2010. Web. 8 Sep 2010.

danger to the health of our waterways. Due to the rigid infrastructure of the big pipe system, it is difficult to respond to these fluctuations and concentrations of contaminants.[12]

The big pipe system leaves little room for quick, economical upgrades, as the infrastructure is a long A to B treatment system. With this in mind, change in capacity over long periods of time can prove problematic. As Rose George explains in *The Big Necessity*, "Wet weather discharge is normal. It's how the system works, whether people know it or not. Sewer designers calculate their system capacity to cope with storms and floods. New York's sewers, built in drier, less globally warmed times, were built to come with a maximum of 1.75 inches of rain falling in an hour. But times and the weather have changed." As we continue to see shifts in rainfall and snowmelt due to climate change, our sewer system's capacity to handle increasing loads will be both an environmental and economic concern.

High use of energy for transmission, treatment and materials

According to the US Environmental Protection Agency (EPA), approximately 3 percent of our national energy consumption is used solely for the purpose of providing safe drinking water and sanitation services. In California, water-related energy use consumes 19 percent of the state's electricity, 30 percent of its natural gas and 88 billion gallons of diesel fuel every year – and this demand is growing.[13]

Currently the average person living in the United States uses between 65 to 78 gallons of water per day for drinking, cooking, bathing, flushing and yard watering.[14] Though the need for conservation in our water habits is inarguably a concern, the means by which we transport our water in urban areas from supply sources and to remote treatment facilities is in need of equal attention. The big pipe system has created an extensive network of pipes, pumps and tanks to accommodate this transportation, all of which need to be maintained. Over time, cracks turn to leaks that, due to the size of these large systems, can be difficult to locate and repair. "The United States suffers about 240,000 water main breaks annually and the country loses approximately 6 billion gallons a day – enough water to supply the entire state of California".[15] This constant need for maintenance leads to increased water waste as well as the potential for groundwater and surface water contamination.

12 Slaughter, S. "Improving the Sustainability of Water Treatment Systems: Opportunities for Innovation." Solutions. 1.3 2010.

13 California Energy Commission, "California's Water – Energy Relationship: Final Staff Report," 2005.

14 Pacific Institute , "Water Fact Sheet Looks at Threats, Trends, Solutions.", 2008.

15 Urban Land Institute, Infrastructure 2010: Investment Imperative. Urban Land Institute, 2010.

SOCIAL/HEALTH

Potential health risks from chlorination process

For more than a century, cities have treated drinking water with chlorine to prevent waterborne diseases including cholera, typhoid fever and dysentery.[16] Chlorine is now added to water during the treatment process in order to destroy pathogens and hinder odors, eliminate mold and algae growth in storage tanks and prevent microbial re-growth as water is conveyed to its points of use. The Federal Safe Drinking Water Act of 1974 requires States to add chlorine to the water supply to reduce the risks associated with waterborne illness.

Trihalomethanes (THM) is a group of four chemicals that form along with other disinfection by-products when chlorine or other disinfectants react with naturally occurring organic matter in water. The trihalomethanes are chloroform, bromodichloromethane, dibromochloromethane and bromoform. THM levels tend to increase with pH, temperature, time, and the level of organic matter present.

THMs are Cancer Group B carcinogens (shown to cause cancer in laboratory animals). Trichloromethane (chloroform) is the most common in water systems. Dibromochloromethane is the most serious cancer risk, (0.6 ug/l to cause a 10-6 cancer risk increase) followed in order by Bromoform (4 ug/l), and Chloroform (6 ug/l). Current regulations limit the concentration of these four chemicals added together (total trihalomethane or TTHM levels) to 100 ug/l.[17]

Lab animals exposed to very high levels of THMs have an increased risk of cancer. Several studies with humans also have found a link between long-term exposure to high levels of chlorination by-products and an increased risk of cancer. High levels of THMs may also affect pregnancy. A California study found that pregnant women who drank large amounts of tap water with high levels of THMs had an increased risk of miscarriage.[18]

Potential health risks from other chemicals, heavy metals, pharmaceuticals

The Safe Drinking Water Act of 1974 (SDWA) developed an enforceable maximum contaminant level (MCL) for all regulated contaminants. Currently, 51 organic chemicals, 16 inorganic chemicals, seven disinfectants and disinfection byproducts (DBPs), four radionuclides and coliform bacteria are monitored for compliance with the SDWA. Amendments made to SDWA in 1996 added components that addressed source water

16 Health Canada. www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/chlor-eng.php.

17 "Disinfection By-Products—Trihalomethanes." Wilkes University Center for Environmental Quality Environmental Engineering and Earth Sciences. Wilkes University, Sep 2010.

18 "Drinking Water Chlorination." Healthy Living. Health Canada, 14 Dec 2006.

protection, operator training, funding for water system improvements and public information requirements, ensuring better water quality.

Contaminants become regulated when they occur in the drinking water supply and are considered a threat to public health. There are four types of known contaminants that are tested for which can be broken down into four groups: Microbial Pathogens, Organics, Inorganics and Radioactive Elements.

Though much has been done to prevent risks of contaminants entering our drinking water, the size and age of our water infrastructure makes the risk of alternate point contamination difficult to assess. In addition, investigations conducted in the last five years suggest that a substantial proportion of waterborne disease outbreaks, both microbial and chemical, are attributable to problems within distribution systems.

In an effort to improve water quality delivery, the National Academies Water Science and Technologies Board has identified ways to assess the risks associated with the contamination of a large water distribution system. These methods include the utilization of pathogen occurrence data, the surveillance of waterborne disease outbreak, and the execution of an epidemiology study that isolates the distribution system component.

Increased consumption of pharmaceuticals and hormones has led to the presence of these chemicals in our water stream. In 2008, the American Associated Press investigated the levels of pharmaceuticals in drinking water, finding that over 46 million Americans consume water that tested positive for trace pharmaceuticals. The effects of these trace

pharmaceuticals are not yet known as water quality standards do not currently test for them. Research conducted in Europe by poisons expert and biologist Francesco Pomati is preliminary but warrants further investigation. Pomati exposed developing human kidney cells to a water mixture containing 13 drugs that mimicked the levels in Italian rivers. He found that cellular growth was slowed by up to one-third the speed of unexposed cells.[19] Testing for the presence of pharmaceuticals and more research on the effects of these mixtures is needed.

Health risks from catastrophic system failures

Major catastrophe or malfunction of a big pipe system leaves its service population vulnerable to contamination or without access to potable water. In 1975 a valve failure combined with heavy rains contributed to rising floodwaters in Trenton and Hamilton townships in New Jersey, leaving residents with a shortage of water for ten days. Though heavy rains were present, the culprit of the shortage was a simple mechanical failure.

Hurricane Katrina's disastrous legacy in New Orleans was accelerated due to the catastrophic failure of the levee system. This severe storm also affected a number of water systems in cities across the region. The EPA estimated that more than 1,200 drinking water facilities and 200 wastewater treatment facilities were affected.[20] For flooded areas, sewage treatment is one of the last services to get back on line, as these plants often exist in the lowest lying areas. The big pipe system offers large solutions to a large population but when failure occurs, it is time consuming for the system to become operational. A one-point source of treatment also offers one point for concentrated contamination in the event of a catastrophe.

Equity in distribution

Water infrastructure that is sized to accommodate flow capacities projected 20-30 years into the future is costly to a community. As discussed in the economic section of this chapter, these high initial costs may result in a disparity in water quality depending on a recipient's proximity to the centralized system. This disparity could affect the quality of community planning and negatively impact development choices.

Disconnect from water source/waste stream

The big pipe paradigm moves our water from tap to treatment to tap again with little user knowledge of what happens in between. The instant delivery of clean water is a convenience that we take for granted. This convenience also disconnects us from an

19 Donn, Jeff, "PHARMAWATER-RESEARCH: Research shows pharmaceuticals in water could impact human cells," Associated Press, n.d. Web. 7 Sep 2010.

20 Copeland, C. "Hurricane-Damaged Drinking Water and Wastewater Facilities: Impacts, Needs, and Response," Congressional Research Service, Library of Congress, 2005.

understanding of our watershed system and where our water comes from, also affecting our understanding about how to best care of this resource.

Up to 80 percent of system costs can be attributed to collection and conveyance of water.

ECONOMIC

Capital costs of new or replaced infrastructure

The nature of the big pipe paradigm necessitates large amounts of infrastructure, which requires increased maintenance as the system ages. Population growth places additional strain on older systems, with increased density demanding increased infrastructure in urban and rural areas. According to John Crittenden of Georgia Tech University's Brook Byers Institute for Sustainable Systems, "We expect in the next 35 years to double the urban infrastructure, and it took us 5,000 years to get to this point. So we better do that right. We better have a good blueprint for this as we move to the future, so that we can use less energy, use less materials, to maintain the life that we have become used to".[21] The many costs of this increase in infrastructure and maintenance are being considered by the EPA, the Government Accountability Office, the Water Infrastructure Network and others as they project a wastewater funding gap of $350 billion to $500 billion over the next 20 years.

Costs of a combined sewer system

If the average person living in the United States uses between 65 to 78 gallons per day, 29 percent of this high-quality water is used for flushing toilets.[22] This means that on a daily basis, every American flushes approximately 19 gallons of potable water down the drain. The big pipe system is designed to combine all grades of water and to treat it to the same level regardless of how it will be used. This way of piping water creates excessive waste with economic consequences. With the operational costs for treatment to potable

21 IEEE Spectrum Podcasts. "Decentralized Water Treatment is more efficient, flexible and resilient." Web. 7 Sep 2010.

22 Urban Land Institute, Infrastructure 2010: Investment Imperative. Urban Land Institute, 2010.

standards being on average $2 per 1,000 gallons, both consumers and producers could be spending much less by reducing potable water demands. [23]

Inequity in cost distribution model & price distortion

High initial costs of big pipe systems take into consideration the future capacity of the treatment facility. Communities that do not have the resources to cover these initial expenses may opt to connect only certain portions of their community to centralized water, leaving parts of the population without access to the same standard of clean water. In addition, the total cost of big pipe systems may not be fully realized in some areas where local water is scarce, such as the desert southwest. This misrepresentation of the actual cost of providing water to these remote areas can give the illusion of abundance of a finite resource.

MOVING FORWARD: A VISION FOR NET ZERO WATER

The gap between projected demand and funding for drinking water infrastructure has been estimated by the U.S. EPA to be as much as $267 billion over the 20-year span between 2000 and 2020. The situation for wastewater infrastructure is similar and Congress is not expected to fill this gap.[24]

In April 1997, the U.S. EPA concluded that "decentralized systems can protect public health and the environment, typically have lower capital and maintenance costs for rural communities, are appropriate for varying site conditions and are suitable for ecologically sensitive areas when adequately managed".[25]

Decentralized infrastructure could be second only to improved agricultural use in addressing the nation's water sustainability challenges, but change can be difficult. Many forms of decentralized systems have long proved to be effective for improving water (and energy) system performance, but recognition of this potential has been slow to gain ground. Distributed systems operate at the margins of engineering practice, and construction of big-pipe infrastructure continues.[26]

23 US EPA. Funding Decentralized Wastewater Systems Using the Clean Water State Revolving Fund. Washington, DC: US EPA, June 1999.

24 Etnier, Carl, Richard Pinkham, Ron Crites, D. Scott Johnstone, Mary Clark, Amy Macrellis, Overcoming Barriers to Evaluation and Use of Decentralized Wastewater Technologies and Management. London: IWA Publishing, 2007.

25 US EPA, Decentralized Wastewater Treatment Systems: A Program Strategy. Cincinnati: U.S. EPA Publications Clearinghouse, 2005.

26 Nelson, Valerie. "New Approaches in Decentralized Water Infrastructure." Decentralized Water Infrastructure. 2008.

Urban water and waste systems management has been driven by technological, end-of-pipe problem solving. The current dominant paradigm has evolved in a stepwise fashion, and the longevity and investment — financial, structural and social — into these systems has locked many communities into an approach with rapidly diminishing returns. The complexity of challenges and dynamic nature of modern cities requires an integrated approach that supports adaptability and innovation. Movement toward a "soft path" for water management with decentralized and integrated technical systems and distributed and flexible mechanisms of coordination and control offers a way forward for many communities willing or forced to challenge their status quo.

THE WATER PETAL OF THE LIVING BUILDING CHALLENGE

The 'soft path' for water management emphasizes closed-loop systems, ultra-efficient measures to reduce demand, small-scaled management systems, fit-for-purpose water use and diverse, locally appropriate and commonly decentralized infrastructure.[27] This pathway is reflected in the intent of the Living Building Challenge v 2.0's Water Petal:

> "The intent of the Water Petal is to realign how people use water and redefine 'waste' in the built environment, so that water is respected as a precious resource. Scarcity of potable water is quickly becoming a serious issue as many countries around the world face severe shortages and compromised water quality. Even regions that have avoided the majority of these problems to date due to a historical presence of abundant fresh water are at risk: the impacts of climate change, highly unsustainable water use patterns, and the continued drawdown of major aquifers portent significant problems ahead."

The Living Building Challenge Water Petal includes two imperatives. The primary focus of this report is on meeting the demands of the Net Zero Water Imperative:

> "One hundred percent of occupants' water use must come from captured precipitation or closed-loop water systems that account for downstream ecosystem impacts and that are appropriately purified without the use of chemicals."

This prerequisite requires water systems to be primarily closed-loop, recirculating water back to its source for eventual re-draw. This report includes best management practices and technologies for catchment and use of rainwater, on-site reuse of greywater and on-site treatment of sewage or blackwater. Case studies provide real-world examples of how these distributed systems have been designed and implemented.

27 Chanan, A., J. Kandasamy, S. Vigneswaran, and D. Sharma. "A Gradualist Approach to Address Australia's Urban Water Challenge." Desalination. 249.3. 2009.

The Omega Center for Sustainable Living in Rhinebeck, New York, is one of the first projects certified under the Living Building Challenge. The project is a wastewater filtration facility designed to reuse treated water for irrigation and serve as a teaching tool for campus educational programs. Image: Farshid Assassi courtesy of BNIM Architects

The second imperative under the Living Building Challenge Water Petal focuses on Ecological Water Flow:

> "One hundred percent of storm water and building water discharge must be managed on-site to feed the project's internal water demands or released onto adjacent sites for management through acceptable natural time-scale surface flow, groundwater recharge, agricultural use or adjacent building needs."

This report addresses on-site wastewater treatment but does not provide best management practices specific to the design and implementation of stormwater systems. It also does not provide guidance for improving fixture efficiency or instituting other demand management strategies such as real cost pricing or public education. Other topics not discussed here but very relevant to the success of these projects include the creation of regulatory environments that allow and incentivize such systems, and the implementation of strategies that ensure proper long-term system operation.

TOWARD GREATER EMBRACE OF DECENTRALIZED SYSTEMS

In her 2008 article "New Approaches in Decentralized Water Infrastructure," Valerie Nelson offers three steps toward greater embrace of decentralized water systems:

1. Incorporation of water concerns into the green building movement and funding of community demonstration projects.
2. Support for a multi-faceted conversation about sustainable water infrastructure with public bureaucrats and managers, system designers, entrepreneurs, activists and the public.
3. Serious restructuring of water institutions and policies, including an integration of planning, funding, and regulations across the currently segmented fields of water, stormwater and wastewater; an expanded role for the private sector in technology development, systems management and finance; a closer link between professional practice and community participation; and careful management and stimulus of continuous innovation and reform.

Nelson's approach requires the removal of significant regulatory, financial and cultural barriers to decentralized systems.

CURRENT BARRIERS TO NET ZERO WATER

A variety of challenges exist for net zero water projects that seek to use best practices around water conservation, rainwater harvesting, greywater and blackwater reuse in distributed and on-site systems.

REGULATORY BARRIERS

The complexity of navigating the regulatory system around such systems at the local, state and national levels presents the largest obstacle for project teams seeking approval for net zero water projects. Currently, water is regulated across multiple jurisdictions and agencies: plumbing codes enforced by local or state building departments; local and state public health agencies regulating water supply and waste treatment; departments of environmental quality and protection regulating stormwater management, reclaimed water, and on-site wastewater treatment; and wetland and shoreline protection that may involve approvals from local, state and national agencies such as the Corps of Engineers. Some states such as Colorado have water rights laws governing rainwater harvesting, while others such as California and Arizona have provisions specific to greywater reuse or water-efficient fixtures and appliances.

Regulatory barriers to net zero water projects stem from the current bias for centralized water supply and wastewater treatment and the associated lack of an authoritative body with appropriate powers to operate, manage and regulate decentralized approaches. Particularly in urban and suburban areas where development codes and public health regulations require connections to public utilities, small-scale decentralized systems frequently lack any clearly defined regulatory pathways for approvals and instead rely on individual project teams with the will or financial means to navigate the regulatory system. Often, the regulations that do exist at the local, state and national levels overlap or conflict with each other, and sometimes there are gaps where no regulatory provisions are currently in place. Project teams are tasked with a lengthy or costly variance process to seek approvals for net zero water strategies, costs that are rarely recoverable to a project team. Furthermore, case-by-case approvals are seldom documented for the benefit of future projects or to guide future code updates.

Often overlooked are the code and regulatory barriers that exist in local land use and development codes and in covenants, conditions and restrictions (CCR) declarations of community associations. For instance, cisterns for rainwater collection systems can conflict with setback and height restrictions prohibiting their use for retrofit applications that tend toward above-ground storage. Likewise, landscaping requirements can conflict with low-impact development strategies. Such was the case in a community in Maryland

where disconnecting downspouts and creating rain gardens to manage stormwater on-site was in conflict with regulations that required mowing of the rain gardens if they exceed a certain height limitation to avoid municipal fines and penalties.[28] Other examples include development codes that require connections to municipal utilities as a condition of building permit issuance, and neighborhood-scale water systems that cross site boundaries or public right of ways that are often not supported by any codes.

Many regulatory agencies are responding to net zero water strategies, though often in disjointed and incremental ways. For example, the International Association of Plumbing and Mechanical Officials (IAPMO) — the agency responsible for the development of the Uniform Plumbing and Mechanical Codes — has released a green supplement outlining voluntary provisions for water efficiency and water reuse strategies that jurisdictions can adopt. Additionally, local and state jurisdictions are beginning to open up legal pathways for using greywater and rainwater for non-potable uses. But despite these and other efforts, regulatory resistance persists against on-site potable water sources other than wells, reuse of water for purposes other than subsurface irrigation, non-proprietary on-site treatment technologies such as constructed wetlands and waterless fixtures such as composting toilets.

In order to create support for net zero water projects, a major shift from our current regulatory framework is necessary. A more holistic approach to regulating water and waste is needed at all agency levels in order to support innovative projects and drive future policies. Much like the 1995 Energy Policy Act that mandated maximum flow rates for plumbing fixtures, more stringent national standards are needed to curb wasteful water use behaviors. State and local building codes, land use codes and development standards must align to comprehensively address on-site water supply, use, reuse and treatment practices with clearly defined roles and responsibilities for permitting, operations and maintenance of these systems. Most importantly, water regulations established to protect risks to public health will need to be assessed and updated to fully account for current environmental, social and economic risks related to centralized water systems, creating new standards in support of more integrated water systems at the site and neighborhood scales.

FINANCIAL BARRIERS

Net zero water projects rely upon on-site or distributed systems for water supply and treatment otherwise managed at the municipal level by publicly-owned utilities. As such, the cost burden for supply and treatment systems — as well as their ongoing operation, maintenance and replacement needs — are shifted from the utility to the individual project

28 Eisenberg, David, Sonja Persram. Code, Regulatory and Systemic Barriers Affecting Living Building Projects, Seattle: Cascadia Green Building Council, 2009.

owner. While this can create financial barriers for project owners, unique opportunities exist for utilities to develop fee structures and incentives to support the transfer of capital cost, expense and revenues to offset an owner's upfront investment in on-site water systems.[29]

A project owner's upfront investments in rainwater harvesting systems, water-conserving fixtures, dual plumbing for water reuse, and on-site treatment systems can create burdensome financial barriers. Even when life cycle costs are taken into account, artificially low utility rates for water and wastewater services translate to long payback periods, since not all utilities use full cost pricing to establish rates for water and wastewater services.

TABLE C-1: TRANSFERRING COSTS AND BENEFITS FROM UTILITY TO OWNER

<table>
<tr><th></th><th>CAPITAL COSTS</th><th>EXPENSES</th><th>REVENUE</th></tr>
<tr><td rowspan="3">Utility</td><td rowspan="3">New central treatment facilities
Water delivery infrastructure</td><td rowspan="2">Operations and maintenance
Insurance</td><td>User fees (rates and permits)</td></tr>
<tr><td>System development charges (utility connection fees)</td></tr>
<tr><td>New connections, repairs and rebuilds</td><td>Taxes</td></tr>
<tr><td colspan="4">Costs, Expenses, and Revenue Shifted from the Utility to the Owner</td></tr>
<tr><td rowspan="3">Owner</td><td rowspan="3">Onsite treatment system
Dual plumbing
Collection systems</td><td rowspan="2">Operations and maintenance
Insurance</td><td>Reduced water use and discharge fees, reduced permitting fees</td></tr>
<tr><td>Reduced connection fees</td></tr>
<tr><td>Repairs and rebuilds</td><td>Grants/incentives</td></tr>
</table>

Source: Onsite Wastewater Treatment Systems: A Technical Review prepared by Paladino & Co. 2008 for Seattle Public Utilities

Full cost pricing factors into account all costs — past and future, operations, maintenance and capital costs — into utility prices and can encourage conservation and reuse strategies employed by net zero water projects. Utilities can also utilize alternative pricing structures to encourage conservation such as block rates that increase the per-unit charge for services as the amount used or generated increases, or surcharge rates imposed on above-average water use.[30]

Robust financial incentives at the local and state levels can help offset financial barriers for net zero water projects. Examples include New York City's Comprehensive Water Reuse

29 Paladino and Company, Inc. Onsite Wastewater Treatment Systems: A Technical Review. Seattle: Seattle Public Utilities, 2008.

30 US EPA. "About Water & Wastewater Pricing." Sustainable Infrastructure. US EPA, 08 Apr 2010.

Incentive Program, which provides project owners a 25 percent discount on water services for reducing demand on the city's infrastructure for water supply and wastewater services. [31]

Likewise, some state agencies offer regulatory compliance credits, smaller impact fees and streamlined or simplified permit processes for projects managing stormwater on-site using low-impact development techniques. While many low-impact development projects have demonstrated 15-80 percent lower capital costs for project owners in comparison to conventional methods,[32] municipalities can provide further financial incentives through reductions in stormwater discharge fees.

Federal funding can also help offset financial barriers for net zero water projects. The American Recovery and Reinvestment Act of 2009 provided $4 billion for the Clean Water State Revolving Fund. Of that, 20 percent of each state's capitalization grant can go toward "Green Reserve" projects, which are defined as green infrastructure, energy efficiency projects, water efficiency projects or innovative environmental projects. The U.S. EPA describes decentralized wastewater systems as being well positioned for funding under the Green Reserve projects. In addition, Section 319 of the Clean Water Act provides the statutory authority for EPA's Non-point Source Program. According to the U.S. EPA, most states have non-point source management plans that allow for the use of Section 319 funds for decentralized wastewater system projects and decentralized system technology demonstration projects.[33]

Financial barriers for distributed water systems can be directly related to the regulatory barriers noted above. Backup or redundant connections to municipal water and wastewater utilities may be required by codes even when a net zero water project is designed and operated not to use them. Composting toilets sometimes require backup sewer connections and associated plumbing, creating a financial disincentive for project owners to even consider their use. Likewise, capacity charges are established by utilities to recoup sunk costs for large investments in centralized infrastructure projects and are required to be paid by all building projects located within their service area, regardless of whether or not on-site systems can be utilized to meet individual supply and treatment needs.

Some municipalities have instituted innovative fee structures, such as the City of Portland's Bureau of Environmental Services in Oregon, which allows for emergency-only connections

31 Eisenberg, David, Sonja Persram. Code, Regulatory and Systemic Barriers Affecting Living Building Projects.

32 US EPA. Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. Washington, DC: US EPA, 2007.

33 US EPA. Funding Decentralized Wastewater Systems Using the Clean Water State Revolving Fund. Washington, DC: US EPA, June 1999.

to their wastewater treatment facilities but charges large use fees in the event that the utility connection is actually needed.

Removing regulatory barriers to decentralized systems can help spur market innovations and new products available to designers and homeowners pursuing net zero water strategies, thus bringing down upfront costs and reducing life cycle cost payback periods. For years, financial incentives for energy efficiency measures and on-site renewables systems have been accelerating market adoption of lower energy products and strategies. The energy sector provides a good example of how similar approaches can be used to accelerate advancements in on-site water systems.

CULTURAL BARRIERS

In addition to regulatory and financial barriers, public perceptions about the safety of water reuse and on-site wastewater management present significant obstacles for net zero water projects. Such fears are rooted in our historical management of water and waste and the resulting public health issues that have surfaced. Previous generations suffered greatly from typhoid fever, cholera and dysentery until laws and regulations were passed to support water-carriage removal of waste from urban areas.[34] Today, education is needed to assure the public of the safety of modern decentralized water systems and inform them of their environmental, social and economic benefits.

Thanks to a history of disease outbreaks, coupled with marketing efforts by early flush toilet manufacturers, "flushing it away" is widely viewed as more civilized and advanced than any other solution for dealing with our water and waste. On-site systems are reminiscent of stepping backwards in time and technology to a less developed age. Education and awareness building among regulators, designers, engineers and building occupants is necessary to fully highlight the environmental risks associated with wasteful practices. Water that has been treated for drinking purposes, requires large inputs of energy to be conveyed to buildings, contaminated with human excrement, conveyed away again and treated with energy-intensive processes that release polluted water back into the environment does not represent our best technological advancements.

Addressing cultural barriers around decentralized water systems requires a shift in the fundamental ways in which we view water and human waste. Instead of the current "out of site, out of mind" thinking, we need to take ownership not only of how we use water inside our buildings and for irrigation, but how we operate, maintain and replace on-site systems over time. In doing so, we will treat water as the precious resource that it is.

34 Burrian, Steven J., Stephan Nix, Robert E. Pitt, and S. Rocky Durrans. "Urban Wastewater Management in the United States: Past, Present, and Future." Journal of Urban Technology. 7.3 (2000): 33-62

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BEST MANAGEMENT PRACTICES

SECTIONS

BEST MANAGEMENT PRACTICES

This document provides guidance for teams pursuing net zero water projects and offers insight to regulatory bodies seeking to better understand and evaluate the net zero projects that come across their permitting desks. Central to the success of these systems is an integrated approach to their design and careful consideration of each system's fit and efficiency, where fit is defined as the adaptation of the system to conditions on or desired at the site, and efficiency is defined as the system's ability to deliver maximum performance at minimum cost. This performance is gauged not only by financial return on investment, but also by lifecycle costs and benefits.

INTEGRATED WATER MANAGEMENT

In *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations*, Dietrich Dorner explains, ". . . in complex situations we cannot do only one thing. Similarly, we cannot pursue only one goal. If we try to we may unintentionally create new problems."

In dealing with complex systems, it is important to take an integrated or "systems thinking" approach. Systems thinking refers to defining a system's boundaries to adequately encompass significant causal relationships and understand the interconnections among resources and activities within that system. Advantages of decentralized options are often only apparent when taking a more integrated approach. For example, on-site reuse of greywater can provide a partially drought-resistant source of landscape irrigation.[35]

An integrated or systematic approach to water system design gears all water-related activities to one another, thereby recognizing the interconnected nature of water and

35 Etnier, Carl, Richard Pinkham, Ron Crites, D. Scott Johnstone, Mary Clark, Amy Macrellis, Overcoming Barriers to Evaluation and Use of Decentralized Wastewater Technologies and Management. London: IWA Publishing, 2007.

wastewater systems and allowing a concurrent evaluation of a whole system's potential costs and benefits. Augmenting existing resources through rainwater harvest, managing demand via fixture efficiencies and other conservation strategies, re-use of water prior to its release back into a larger system and on-site management of stormwater and other landscape concerns all need to be addressed in tandem, "as there is but a fine line of distinction between them."[36]

An integrated approach is necessary when attempting to create net zero water projects with closed-loop systems where all of the water used on a project is being captured, treated, used/reused and released on-site. In this report, rainwater harvest and wastewater treatment and reuse are organized into separate chapters, and stormwater and other landscape concerns are minimally addressed. This is simply a way to organize the information and is not intended to imply that the related design processes are separate or unrelated endeavors. To the contrary, an integrated approach is the single most important process to be understood when considering the best practices for designing a water system as part of a larger integrated design or process for an entire project.

ESTABLISHING WATER BALANCE

A water balance is a numerical account of how much water enters and leaves a site. A water balance sheet should contain detailed information about the amount of water used by each process. The water balance is a crucial instrument to understand and manage water flows throughout the plant, to identify equipment with water-saving opportunities and to detect leaks".[37] For a net zero water project, the amount of water entering and leaving a site should ideally reflect the natural hydrology of the site.

Bruggen and Braecken offer a "step-by-step method to optimize the water balance," in three steps:

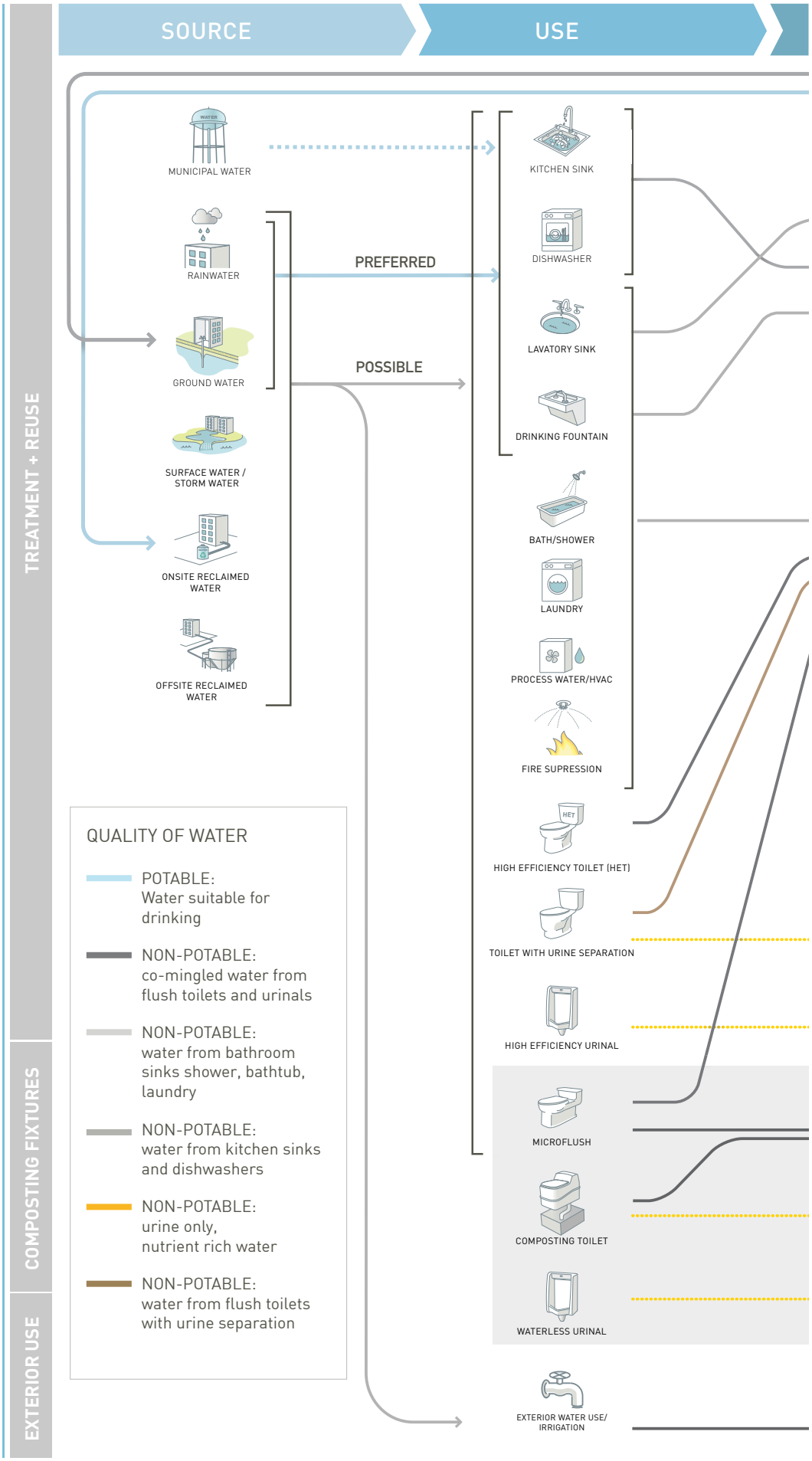
1. Investigate the current water balance in detail.
2. Combine water consuming processes and reuse water where possible for other purposes requiring a lower water quality.
3. Regenerate partial waste streams and re-introduce them into the process cycle.

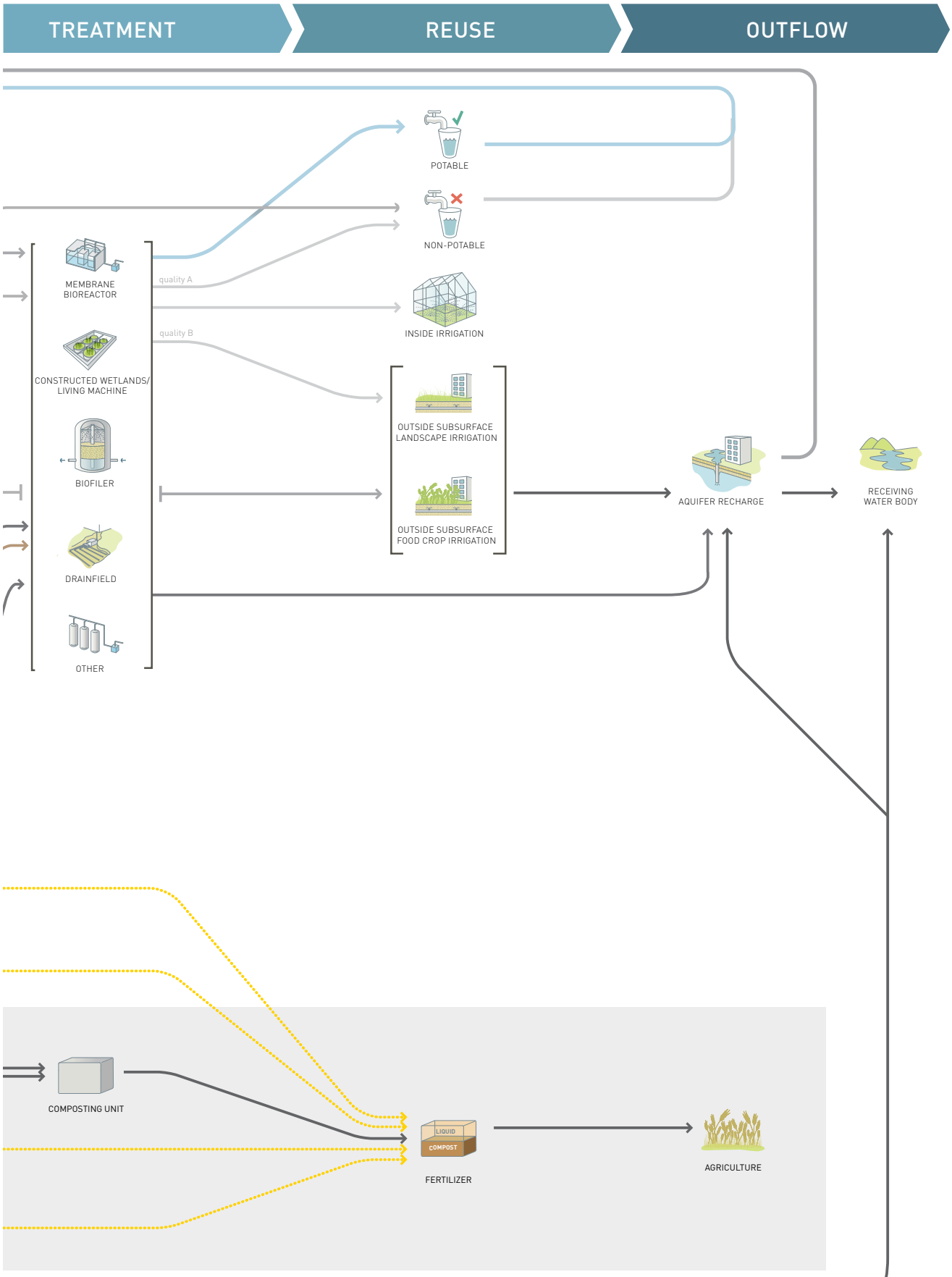
Figure B-1 provides an overview of the multiple pathways design teams may choose to take in establishing a water balance.

36 Buehrer, Mark. 2020 ENGINEERING. Bellingham, Washington. 1996.

37 Van der Bruggen, B., and Braeken L. "The Challenge of Zero Discharge: from Water Balance to Regeneration." Desalination. 188.1-3, 2006.

FIGURE B-1. DESIGN PATHWAYS TO NET ZERO WATER




TREATMENT
REUSE
OUTFLOW
POTABLE
NON-POTABLE
MEMBRANE BIOREACTOR
quality A
INSIDE IRRIGATION
quality B
CONSTRUCTED WETLANDS/ LIVING MACHINE
OUTSIDE SUBSURFACE LANDSCAPE IRRIGATION
BIOFILER
OUTSIDE SUBSURFACE FOOD CROP IRRIGATION
AQUIFER RECHARGE
RECEIVING WATER BODY
DRAINFIELD
OTHER
COMPOSTING UNIT
LIQUID
COMPOST
FERTILIZER
AGRICULTURE

FIT AND EFFICIENCY

Designers face the challenge of choosing the right water system, at the right place, at the right moment and the right scale. A water system has to consider all impacted flows and account for environmental, social and economic risks associated with the system, both on and offsite. Flows include rainwater, stormwater, groundwater, drinking water and wastewater. "In a flows perspective, flows should fit in a chain-management approach, from cradle to grave or, even better, from cradle to cradle".[38] It is critical to make the upstream, on-site and downstream flows fit together in a healthy closed loop.

CLIMATE

Regional climate is a major consideration when choosing and sizing a project's water system. For example, in the Pacific Northwest, there are some areas that receive as much as 140 inches of precipitation per year. However, those same areas receive nearly no precipitation from July through September. Across the United States, there are five different major climate zones and sizable variability within those zones.[39]

Image: Perkins + Will

The Center for Urban Waters in Tacoma, WA, harvests rainwater in two 36,000-gallon above ground cisterns.

38 United Nations Environment Programme, Every Drop Counts: Environmentally Sound Technologies for Urban and Domestic Water Use Efficiency. Delft: UNEP, 2008.

39 US Energy Information Administration. "U.S. Climate Zones for 2003 CBECS." Independent Statistics and Analysis. US Energy Information Administration, n.d. Web. 8 Sep 2010

Further, the warming of the climate due to human and non-human causes is already impacting weather patterns within each zone, and is expected to significantly and progressively alter precipitation patterns across the United States in the coming decades. An excess or lack of water with the change of precipitation patterns may present the greatest hazard we face in building durable buildings and communities.

It is also important to consider the microclimatic conditions on the project site itself. The macroclimate, or long-term weather conditions for a region, is derived from accumulated day-to-day observations often made at weather stations far away from the towns and cities where most buildings are constructed. Significant climatic variations can occur over distances of only a few miles, making it important to understand the specific conditions present and likely to evolve on the site when making design decisions. Some of the main factors influencing the microclimate of a site are: urban heat island, topography, terrain surface (natural or manmade), vegetation and obstructions.[40]

Finally, it is important to consider that climate not only impacts the availability of precipitation or groundwater for use. The amount of water required by humans and other actors within a given climate varies enormously depending on environmental and climatic conditions such as temperature and humidity.

FIT-FOR-USE

The vast majority of the water used in the U.S. is drawn from freshwater supplies of surface and groundwater then treated to potable standards as defined by the Safe Drinking Water Act. A large multifamily or commercial building can use more than 120,000 gallons of potable water in a single day.[41] Once used, the water is typically released as wastewater. Access to this treated water has greatly benefited public health, but it also has resulted in a system that utilizes potable water for virtually every end use, even when lesser quality water is sufficient. In addition to conservation methods, using and re-using alternative sources of water will be necessary for more efficient use of water resources.[42]

Treatment of water is a collective term for methods of improving the water quality by physical, chemical and/or biological means. The level of water treatment should be determined by the intended use or destination of the water. It is wasteful and not necessary to use potable water for activities such as flushing toilets or irrigating plants. Untreated or minimally treated rainwater can be used for activities including toilet flushing, irrigation,

40 Sharples, Stephen, and Hocine Bougdah. Environment, Technology and Sustainability. New York: Taylor & Francis Group, 2010.

41 Yeang, Ken. Ecodesign: A Manual for Ecological Design. London: Brook House, 2008.

42 Kloss, Christopher, Managing Wet Weather with Green Infrastructure: Rainwater Harvesting Policies: US EPA, 2008.

showering and laundry. Greywater from fixtures like lavatory basins or washing machines can be reused directly in the building, often without treatment or with only primary treatment.

FIT-FOR-SCALE

The water system also must fit with the scale of use. Different technologies and strategies lend themselves to different scales of use. This report addresses three basic scales in an urban context: the single family home, multifamily residential or commercial buildings, and a neighborhood or campus. There is great diversity even within each of these individual typologies, emphasizing the need for site-specific design.

As suggested in the Living Building Challenge, the appropriate scale for a water system may extend it beyond the boundaries of the project site.

> "Depending on the technology, the optimal scale can vary when considering environmental impact, first cost and operating costs." [43]

The scale of the system can impact the scope and boundaries of a risk assessment for the project. Systems that go beyond a project boundary also naturally expand the role of community involvement during the planning phase.

COMMUNITY INVOLVEMENT

Water system proponents should decide on the appropriate level of community participation to include in the planning stages of the project. The primary audience for engagement would logically include community members that are the intended beneficiaries of the system, along with those that have the greatest exposure to residual risk associated with the system or whom might be otherwise impacted.

Multiple models exist for varying levels of community involvement in planning local projects and infrastructure. These levels range in intensity from "consultation" to "involvement" to "engagement". Consultation implies only providing information to a community and requesting feedback. Involvement implies the need for the water system to be responsive to the community's needs, and that the project leaders should decide on the structures and decision-making processes in which to involve community members. Engagement, the most intensive form of community participation, builds a fully collaborative relationship with a community for both governance and system planning. A

43 McLennan, Jason, Eden Brukman. Living Building Challenge 2.0: A Visionary Path to a Restorative Future. Seattle: International Living Building Institute, 2009.

project team will decide on the appropriate level of community participation based on the scale of the project.

In addition to seeking community input, the project team should communicate early and often with state and local government officials and regulators. The project team should discuss the proposal and plans with the relevant officials and regulators as early as possible in the project to ensure that all issues are identified and addressed prior to the design and permitting stages.

RISK MANAGEMENT

The design of a net zero water system is intended to help address and mitigate the large-scale impacts associated with energy-intensive centralized systems. Of course, net zero water systems also expose users and communities to potential risks. These risks should be viewed in a broader sustainability context than that often used by the regulatory community.

> "Many in the building regulatory community continue to view 'green' and 'sustainability' goals as either trying to maneuver their way around minimum code requirements or as optional goals that extend beyond their regulatory scope of concern or responsibility. Meanwhile, the green building movement and . . . the Living Building Challenge encompasses a significantly more comprehensive understanding of risk. Inherent in their approaches is the aim of taking responsibility for balancing the full risk profiles of built projects — including all the current regulatory concerns — while simultaneously seeking to address large, but currently unregulated risks to present and future generations and to essential ecological integrity".[44]

Net zero water projects must address social, environmental and economic risks that are endemic to all water systems and some that are specific to distributed systems. A risk management framework is the most effective way to assure the appropriate quality of water for the proposed end use. Decisions concerning the scope and boundaries of the risk assessment may be based on operational, technical, financial, legal, social, environmental or other criteria. Criteria may also be affected by the perceptions of stakeholders and by regulatory requirements. It is important to establish appropriate criteria at the outset that correspond to the type of risks and the way in which risk levels are expressed.

44 Eisenberg, David, Sonja Persram. Code, Regulatory and Systemic Barriers Affecting Living Building Projects, Seattle: Cascadia Green Building Council, 2009.

The risk assessment process should begin with defining the extent of the water system and organizing it into a logical framework that helps ensure that significant risks are not overlooked. The project team should construct a flow diagram showing all of the steps in the system from source to end use that includes:

- All steps of the process, both within and outside the control of the project team
- Source(s) of water
- Proposed system components
- Proposed end uses
- Residuals produced from the system
- Unintended or unauthorized end uses
- Discharges or releases to the environment
- Receiving environment and/or routes of exposure
- Any additional considerations needed to maintain the quality and/or safety of the water

The flow diagram should be signed off for authenticity and status by the team leader.[45]

Once the context of the system is established with a flow diagram, simple risk assessment matrices are available for prioritizing hazards and identifying the tolerable level of risk exposure. Risks to be considered can be grouped under three basic categories: social risk, environmental risk and financial risk.

SOCIAL RISK

The provision of safe water and sanitation has been more effective than any other public service in promoting public health. Distributed water systems should be designed and operated without jeopardizing public health gains achieved historically via the adoption of centralized delivery and treatment. Of greatest concern with the use of decentralized systems is the associated health risk, especially the risk of exposure to microbial pathogens and chemicals-of-concern potentially present in rainwater and recycled water.

Table B-1 lists potential hazards that may be present in water before, during or after treatment. In addition to those presented in the table, trace constituents including caffeine, estrogen and other hormones have also been detected in the United States.

Health risks can be mitigated with appropriate preventive measures that place barriers between the rainwater/recycled water and members of the community. Examples of preventive measures include water source protection[46], water treatment, protection and

45 Adapted from New South Wales, Department of Water and Energy. Interim NSW Guidelines for Management of Private Recycled Water Schemes. 2008.

46 Source protection may include protecting rainwater from animal and human waste and controlling the quality of water discharged into greywater systems.

TABLE B-1: LIST OF POTENTIAL HAZARDS IN RECYCLED WATER

POTENTIAL HAZARD	DESCRIPTION
Biological	
Algae	Simple chlorophyll-bearing plants, mainly aquatic & microscopic in size. Under suitable conditions, some types of algae may grow in untreated or partially-treated wastewaters, producing algal toxins such as microcyctins, nodularins, cylindropermopsin & saxitoxins.
Bacteria	Unicellular micro-organisms typically smaller than 5 microns. Bacteria common to blackwater include pathogens such as Campylobacter, Salmonella, Clostridium, & Legionella.
Helminth	An invertebrate that is parasitic to humans & other animals. Helminths include tapeworms, roundworms & flukes.
Protozoa	A phylum of single-celled animals typically ranging in size from around 1 to 300 nanometers.
Viruses	Molecules of nucleic acid ranging in size from 20 to 300 nanometers that can enter cells & replicate in them. Some common viruses found in untreated blackwater include norovirus & enterovirus.
Physical	
Hypoxia	Oxygen depletion brought about by the bacterial breakdown of organic matter in the water.
pH	An expression of the intensity of the basic or acid condition of a liquid.
Screenings	The solid waste collected in the inlet screens to a treatment process including solids disposed of to wastewater.
Suspended solids	Suspended solids measures the presence of fine suspended matter such as clay, silt, colloidal particles, plankton & other microscopic organisms.
Chemical	
Ammonia	Ammonia dissolves rapidly in water & is a food source for some microorganisms, & can support nuisance growth of bacteria & algae. Ammonia can be a pollution indicator as it can formed as an intermediate product in the breakdown of nitrogen-containing organic compounds, or of urea from human or animal excrement.
Chloride	Chloride comes from a variety of salts (including detergents) & is present as an ion (Cl^-). Chloride is essential for humans & animals, contributing to the osmotic activity of body fluids. However, it can be toxic to plants, especially if applied directly to foliage or aquatic biota.
Disinfection by-products	Disinfection by-products are formed from the reactions between disinfectants, particularly chlorine, & organic material. Chlorine reacts with naturally occurring organic components or ammonia to product by-products such as dicholoroacetic acid, trichloroacetic acid & THMs & chloramine by-products.
Metals	Heavy metals, such as cadmium, chromium, & mercury may be present in raw wastewaters as a result of industrial discharges.
Pesticides	Pesticides harmful to humans & a wide range of species may enter water systems by a variety of means including stormwater runoff, personal use & illegal disposal.
Pharmaceuticals	Pharmaceuticals & their active metabolites are excreted by humans &/or disposed of directly into water systems.
Total dissolved solids	Total dissolved solids (TDS) include dissolved inorganic salts & small amounts of organic matter. Clay particles, colloidal iron & manganese oxides & silica may also contribute to TDS. Major salts in recycled waters may include sodium, magnesium, calcium, carbonate, bicarbonate, potassium, sulphate & chloride.
Total nitrogen	An important nutrient found in high concentrations in recycled waters, originating from human & domestic wastes. In high concentrations can cause off-site problems of eutrophication of receiving bodies.
Total phosphorus	Originating mainly from detergents but also from other domestic wastes, in high concentrations can cause eutrophication of receiving bodies.

Adapted from the *Australian Guidelines for Water Recycling*, 2006.

maintenance of distribution systems and storages[47], restrictions on the distribution and use of recycled water[48], and education of end users.

The most common and effective barrier used is treatment of the captured or recycled water before use. The level of treatment and disinfection depends on the source of the recycled water, the potential for fecal contamination and potential for exposure to community members, which is generally determined by its intended use and release back into the environment (See "Fit-for-use" above).

Beyond the more immediate health considerations, other social risks to address include the system's ease of operation and maintenance over its lifetime.

ENVIRONMENTAL RISK

There are a variety of environmental risks associated with any water system, including distributed systems. These include the lifecycle impacts of the system's component parts, the impacts of the system onsite and downstream flows and water quality, and the energy required for the construction and operation of the system, including any pumping and treatment process.

The pipe and pumping requirements to convey wastewater from its point of generation to its point of treatment has significant environmental impacts. Lifecycle analysis of these conveyance systems point toward greater environmental impacts as the length of pipe and the number of pump stations required increases. Systems where a series of pump stations are used to convey wastewater across elevation changes consume large amounts of energy. Conclusions can be drawn to the extremely important role of service area topography in assessing the feasibility of smaller-scale distributed systems.[49]

FINANCIAL RISK

Financial assessment of the long-term viability and sustainability of a water system is important. According to the 2004 Valuing Decentralized Wastewater Technologies report prepared by the Rocky Mountain Institute for the U.S. EPA, decentralized and distributed systems can be more flexible in balancing capacity with future growth. In smaller-scale systems, capacity can be built house-by-house, or cluster-by-cluster, in a "just in time"

47 Examples of protection and maintenance of distribution systems and storages include buffer zones, minimizing light to restrict algal growth, maintaining drainage, and backflow prevention and cross-connection control.

48 Preventive measures that restrict the distribution and use of recycled water include: signage and color coding of pipes; buffer zones; control of access; control of method, time and rate of application; user controlled diverter switches; hydraulic loading and interception drains; management plan; prohibition of recycled water in specific areas.

49 Cascadia Green Building Council, Clean Water, Healthy Sound: A Life Cycle Analysis of Wastewater Treatment Strategies in the Puget Sound Area, in progress (2011)

fashion. This means that the capital costs for building future capacity is spread out over time, reducing the net present value of a decentralized approach and resulting in less debt to the community as compared to the borrowing requirements of a large up-front capital investment. This is especially true in the event that a community sees less growth than anticipated in their initial planning, leaving them with overbuilt capacity and a large debt to be shared by fewer than expected residents.[50]

Larger centralized systems can realize economies of scale from a capital investment and ongoing operations standpoint. Likewise, lenders perceive these types of systems as less of a borrowing risk than smaller-scale or individual systems. Decentralization concentrates the financial risks of individual system failures on individuals or clusters of residents, in contrast to the insurance-like spreading of risks of failure across large numbers of users.[51] Assessment of financial risk over time will play an important role for individual building owners and the community in determining the best scale for water infrastructure.

BEAUTY AND INSPIRATION

The ultimate goal of a net-zero water building is to function like a natural ecological system, balancing intake with outflow of waters of similar or better quality. Making this philosophy and process accessible in the design will reinforce the positive contributions of the building and remind users of the greater ecological water system that is being emulated. The possibilities of water as an aesthetic and visceral force are obvious in the myriad uses such as fountains and reflecting pools, fonts, spillways and grottoes that already populate the built environment. The sound of moving water recalls nature and time; the reflections from water mesmerize and calm us. Rainwater is a manifestation of the power of nature seen even in the city, and celebrating this is an inspiring function of a living building.

50 Rocky Mountain Institute. Valuing Decentralized Wastewater Technologies: A catalog of benefits, costs and economic analysis technique, 2004.

51 Ibid.

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RAINWATER HARVESTING

SECTIONS

RAINWATER HARVESTING

DEFINITION

Rainwater harvesting is defined as water captured from a building's roof surface. Rain that reaches the ground is typically considered stormwater because its quality is often lower due to greater potential for contamination. On-site management of stormwater has unique opportunities for collection and reuse, but is outside the scope of this report.

There are three primary considerations when harvesting rainwater at any scale. First, the water collected must be sufficiently clean for its intended use. Second, it must be available seasonally with sufficient dependability. Third, the catchment area and collection volume must be sufficient to meet the water demands for which the system is intended to serve.

SYSTEM COMPONENTS

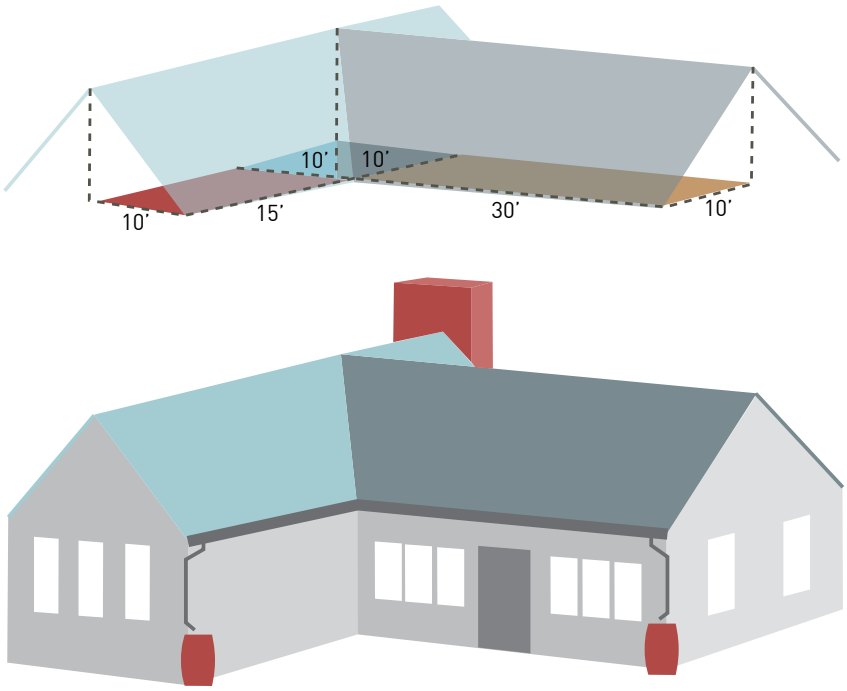
ROOFSCAPE

The rainwater catchment area is equal to the roof footprint area as opposed to the surface area of the roof (see Figure R-1). Any catchment surface must be kept clean and free of debris. This includes cutting back any vegetation overhanging roof structures and periodic washing of the roof to reduce pollen, leaves, animal droppings and other particulates. During roof washing, downspouts should be directed away from the storage tank to keep the stored water clean. If the catchment is meant for potable uses, the roof should be clad in a nonreactive material such as enameled or painted metal, water-safe elastomeric coatings, and most ceramic tiles and glass.[52] Lead flashing and asphalt roofing should be avoided since they leach chemicals into the water supply.[53]

52 Oasis Design. "Rainwater Harvesting." N.p., October 2009. Web. October 2010.

53 Cunliffe, D. A. and National Environmental Health Forum. Guidance on the use of rainwater tanks. Adelaide: National Environmental Health Forum, 1998.

FIGURE R-1 CALCULATING CATCHMENT AREA



The catchment area is calculated by measuring the footprint area of the roof rather than the actual sloped roof area.

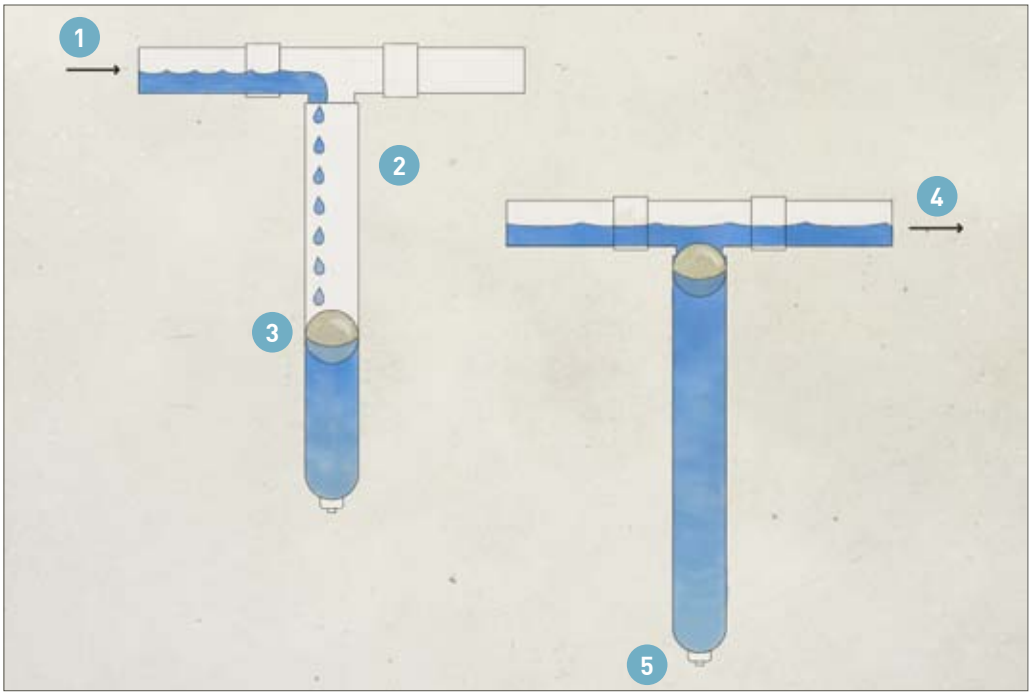
CONVEYANCE

Conveyance of rainwater may be done via gutters, scuppers, spillways, piping, rain chains and/or downspouts. As with the roofscape, the conveyance system of a potable catchment system should be constructed from materials appropriate for drinkable water. Closed-piping should be preferred where contamination is a concern; however, open scuppers and watercourses may help foster a connection with nature when well executed.

DOWNSPOUT FILTER

Once brought down from the roof, water should pass through a filter trap to remove debris and aid in the sedimentation of grit and other small particles. The trap should be easily accessible for monitoring and regular cleaning. In addition, buildings with gutters should install screens over them to prevent clogging.

FIGURE R-2: FIRST FLUSH DIVERTER



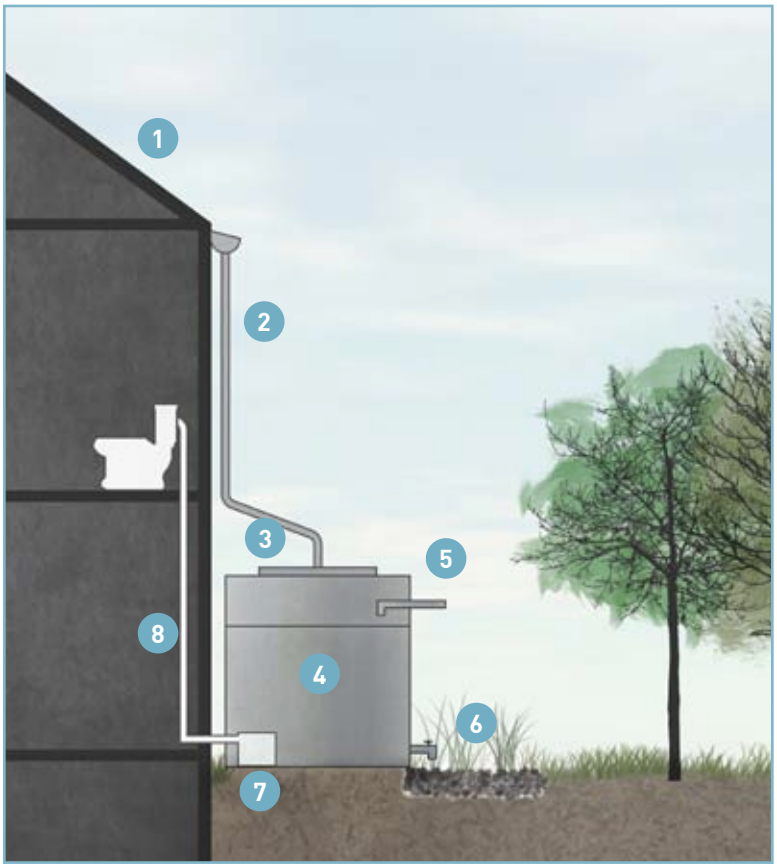
SYSTEM COMPONENTS

1. Water from Roof Catchment
2. Diverter Chamber
3. Sealing Ball
4. Water Overflow to Storage Tank
5. Screened Flow Control Valve

FIRST FLUSH DIVERTER

The first flush diverter redirects the first few minutes of rainfall into a separate standpipe or container. This first flush contains the majority of contaminants that have accumulated on the roof between rainfalls. Many systems include a small side-pipe that slowly drains this water to a soak-away area. Others choose to convey this water into the water recycling system, recapturing it for use in the building. This optional component should be considered by the designer based on location and local climate conditions.

FIGURE R-3: RAINWATER HARVESTING SYSTEM



SYSTEM COMPONENTS

1. Catchment Area
2. Conveyance
3. Downspout Filter
4. Storage
5. Overflow
6. Outlet
7. Pump and Filter
8. Distribution System

STORAGE

Rainwater storage tanks or cisterns are typically made from wood, fiberglass, galvanized steel, plastic or concrete. Concrete cisterns will leach lime into the water the first time they are filled and should be flushed out before commencing use.[54] Such cisterns should not be constructed from concrete mixes in which the lime is produced by incinerating toxic waste.[55]

Rainwater cisterns may be located either above or below ground. For systems that will store a large water volume, the lack of available surface space may dictate a below-ground cistern. However, above-grade storage avoids excavation costs and allows for more convenient monitoring and maintenance.

Cistern overflow can be directed to raingardens or infiltration areas as part of the overall design for managing stormwater on-site.

54 Cunliffe, D. A. and National Environmental Health Forum. Guidance on the use of rainwater tanks. Adelaide: National Environmental Health Forum, 1998.

55 Oasis Design. "Rainwater Harvesting." N.p., October 2009. Web. October 2010.

PUMP

Water is often pressurized for use in plumbing and irrigation. On sites that allow for gravity-fed systems, 2.3 ft of elevation can provide 1.0 psi of pressure. A number of mechanical pumps are also available when gravity-fed systems are not plausible. These pumps pressurize water as it is withdrawn from the tank and operate whenever there is a water demand. Alternatively, a lower power pump may be used to lift the water to a header tank. The benefit of this type of system is that it decouples water demand from pumping, allowing for a more energy-efficient system. These types of systems may rely on the use of solar power to fill the header tanks, allowing gravity to provide pressurization.

TREATMENT SYSTEM

Rainwater is typically treated after storage and before use. Treatment for non-potable uses, such as toilet flushing and irrigation, may only require filtration to prevent debris from obstructing conveyance pipes and pumps.

Rainwater for potable use requires much higher levels of treatment to remove possible pathogens as well as organic and chemical compounds. These types of uses require filtration as well as disinfection. A series of diminishing size cartridge filters are used, ranging from 20 micron down to 1 micron prior to disinfection in order to remove particulates.

The filtration step is followed by sterilization. Ultra-violet (UV) treatment is one proven method of sterilization to remove microorganisms from rainwater. While this process is free of chemicals, it does require energy to power the UV lamps. Sterilization may be paired with carbon filtration to absorb organics and chemicals. At a minimum, a 5 micron filter must be located before the UV lamp. This system is compact and efficient, but some components must be replaced regularly.

MONITORING SYSTEM

The last component of a rainwater harvesting system is a monitoring plan. Water levels inside the tank, the filter system and overall component function should be monitored periodically. Some tanks will gather more sediment than others and may require cleanout every two to five years. Water quality testing may be advised or required. With good maintenance, a rainwater harvesting system can insure quality water at the site for decades before replacement is needed.

TECHNOLOGY

Best practices for designing rainwater harvesting systems utilize relatively simple, low technology methods for collection and storage of rainwater. Water should enter the cistern near the bottom of the tank where it is calmed by means of a U-tube or diffuser to avoid disturbing sediment in the tank. The supply outlet is typically located just below the water surface suspended by a float in order to avoid drawing in sediment. The tank is equipped with an overflow system so that the discharge does not cause flooding or damage to adjacent buildings and properties. The tanks require regular monitoring and cleaning and are best located in an area that is protected from light, debris and animals.

In a well-functioning tank, a film layer develops on the interior surface, and beneficial micro-organisms in the sediment form an ecologic system that 'conditions' water in the tank. Care should be taken not to disturb these systems, which protect the tank walls and prevent the intrusion of harmful bacteria.[56]

FIT

Given the generally high quality of rainwater, its best use in buildings will be for potable and human contact uses like bathing [57,58]. Freshly captured rainwater will generally not be sufficient to supply all the use needs of a building. However, when paired with water recycling to meet non-potable needs and other water conservation measures, it has potential to function as the sole source under many conditions.[59] Water balance — equality between supply volume and building demand — is necessary to maintain a net zero building. In climates with fewer than 20 inches of rain per year, or in cases where the catchment area or storage potential is outpaced by demand, this balance may not be possible at the site scale and further sources such as recycling and offsite rainwater harvesting may be necessary.

56 Cunliffe, D. A. and National Environmental Health Forum. Guidance on the use of rainwater tanks. Adelaide: National Environmental Health Forum, 1998.

57 Krishna, J. H. The Texas manual on rainwater harvesting. 3rd ed. Austin, Tex.: Texas Water Development Board, 2005.

58 Dugan, Cornelius J., and Donald A. Dolske. "A Twelve Year Study of Precipitation Chemistry in Philadelphia." APT Bulletin Historic Structures in Contemporary Atmospheres 23. 1991.

59 Ghisi, Enedir, and Daniel F. Ferreira. "Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil." Building and Environment 42. 2007.

A well-sized and functioning residential rainwater system produces the highest quality of water at a volume appropriate to its intended use at the lowest cost to the owner, municipality and environment. Uses might be potable or non-potable, depending on the constraints of the climate and site and the availability of other potable sources. The intention is to provide the best fit in water quality for all end uses while reducing demand for potable water.

At the commercial and multifamily scale, best practices for rainwater catchment view water as a resource to be managed and put to beneficial use rather than a nuisance to be piped offsite. At this scale, rainwater provides an ecosystem service and catchment becomes a benefit to users, nearby communities and the natural water system. The building becomes an entity that diverts this resource for other uses before returning it downstream.

At the campus or neighborhood scale, the design, construction and maintenance of a rainwater harvesting system might be shared by the owner and operators of the municipal water and wastewater systems. Systems at this scale can provide many benefits to municipal utilities including stormwater management, reduced sewer flows and shared investment in infrastructure. The community of owners, residents and users is responsible for maintaining and operating the system, resulting in the community's knowledge of and connection to the greater water cycle.

EFFICIENCY

Rainwater harvesting shows great potential to reduce municipal water supply costs and protect adjacent ecosystems. The U.S. EPA reports that "reducing [municipal] potable water demand by 10 percent could save approximately 300 billion kilowatt-hours of energy each year" in the U.S. alone.[60] According to the University of Washington, "current expenditures and unfulfilled needs likely exceed $1 billion for the [Puget Sound] region over the next decade".[61] Rainwater harvest and stormwater management in urban areas will reduce damage to fisheries and increase the lifespan, efficacy and capacity of existing stormwater management systems. Using rainwater as a water source has additional potential to reduce the consumer's water bills, and may result in savings in sewerage charges in some municipalities.

60 Kloss, Christopher, Managing Wet Weather with Green Infrastructure: Rainwater Harvesting Policies: US EPA, 2008.

61 Booth, Derek. "Coping with stormwater—how much does it cost?" The Water Center Fact Sheets (2007). The Water Center. Jan. 2007. University of Washington.

The largest cost of a rainwater harvesting systems is the storage tank(s). Therefore, the efficient use of water within the building helps to minimize the cistern requirements and the overall cost of the system. Under current practices in the U.S. where rainwater is used for non-potable purposes such as irrigation and toilet flushing, the payback period for a harvesting system ranges from 10 to 15 years. Areas with higher municipal water costs will see a faster payback.[62] In Australia, where rainwater is used for a wider range of uses, payback times in some households were calculated at fewer than seven years. However, the Australian study found that in some arid cities with low-cost municipal water, rainwater collection has been deemed too expensive to be effectively implemented since sufficient tank sizes were prohibitively expensive.[63]

ADDITIONAL DESIGN CONSIDERATIONS

SIZING

The concept of water balance is key to the success of a rainwater harvesting system. Water balance means that the volume of water needed is met by the amount of water collected. The system design is influenced by:

1. Monthly rainfall amounts (historic data)
2. Estimated water demands
3. Size of catchment areas

Water conservation is an important part of any rainwater harvesting system design. If the use volume is high but the catchment area and annual rainfall are low, rainwater harvesting may not be feasible.

Many calculators exist to aid in determining water balance. The Washington State Department of Ecology has produced a Rainwater Harvesting Calculator to help residents size their system based on local climate conditions. Many municipalities also have simple calculators for sizing residential systems. The more detailed the climate data, the more accurate the results. The ideal data set provides daily rainfall totals collected at or close

62 Gray, Jonathan, and Jerry Yudelson. Rainwater Harvesting Becomes a Mainstream Sustainable Practice. Issue brief. Portland, OR: Interface Engineering.

63 Tama, Vivian W.Y. Leona Tam, S.X. Zeng "Cost effectiveness and tradeoff on the use of rainwater tank: An empirical study in Australian residential decision-making." Resources, Conservation and Recycling 54. 2010.

to the site. More precise calculators will also include a reduction in total catchment due to system losses such as evaporation.[64]

SYSTEM LOCATION

Location of the catchment area away from contamination by leaves, pollen, animals or industrial pollution is tantamount in the design of a harvesting system.

For larger systems where mechanical pumps and filters are required, adequate space must be allocated for these functions. Careful consideration should be given to provide easy access to these systems for maintenance.

Cisterns may be located above or below ground outside of the building footprint or located within the basement of a building. Installation of above-ground tanks avoids excavation costs, and access may prove easier than buried tanks. Above-ground systems may encounter site constraints that will influence tank shape and size, making the aesthetics more important. Below-ground tanks can allow greater capacity while freeing up surface space; however, increased installation costs associated with excavation will be incurred.

Sufficient space is needed on-site to accommodate overflows of the rainwater system. Ideally, overflows will be released to on-site infiltration areas where it seeps into groundwater and recharges local aquifers. Proper planning and design integrates cistern overflow into the overall site stormwater management plan and helps protect properties from flooding.

64 Roebuck, R.M., Ashley, R.M. "Predicting the hydraulic and life-cycle cost performance of rainwater harvesting systems using a computer based modelling tool" 7th International Conference on Urban Drainage Modeling 4th-6th April 2006 Melbourne, Australia.

SYSTEM INTEGRATION

Rainwater harvesting systems have the potential for integration into a wide number of other building systems. They are ideally suited for incorporation into on-site stormwater management strategies, allowing temporary storage after storm events and helping to reduce runoff. They are also ideal for use in landscape irrigation, offsetting the need for potable water. Further opportunities may exist to integrate rainwater cisterns into both active and passive solar systems by providing a potential location for storage of thermal energy prior to its use. Large storage tanks may both provide or require additional structural support so careful attention is needed when designing them either on or near other structures. Finally, catchment and conveyance systems may be integrated into both interior and exterior spaces of a building in such a way that they provide a valuable connection between occupants and the natural water cycles outside the building.

Cisterns should be located for easy maintenance. Integrate overflows into the site's stormwater management strategy.

CASE STUDY

DI DIEGO + FERRIS RESIDENCE

Location:	Lopez Island, WA
Architect:	INCLINEDESIGN
Engineer:	Rainbank
Owner:	C. Di Diego + J. Ferris
Scale:	Residential

The Di Diego + Ferris residence is located on Lopez Island in San Juan County, WA. In November of 2006 the owners began collecting rainwater from a metal roof above their barn. The 3,000-sf roof captures 1,800 gallons of rainwater for every inch that falls. The 20,000-gallon steel storage tank, with a 45-mil polypropylene liner, was filled during three months of a heavy winter rainfall.

Though Di Diego + Ferris initially intended to use the rainwater for irrigation purposes, they decided early on to use rainwater for all of their household and landscaping needs.

Filtration is essential for systems supplying potable water for household use. The Di Diego + Ferris rainwater catchment system was custom designed and built with state of the art filtration by Rainbank, an ARCSA (American Rain Catchment Systems Association) accredited designer. San Juan County also requires a building permit and inspections to ensure that the foundation and structure meet county regulations.

Rainwater is channeled through custom gutters to two rainbarrels located at the base of each

Images: Caroline Di Diego

downspout. Hidden from view, inside the rainbarrels are baskets holding a mesh liner and Chemex 12" coffee filters. As the roof water passes though the barrel pre-tank filtration occurs, and during the pollen season the filters are changed frequently to minimize the organic matter entering the tank. Because misty rain is common, a first flush diverter is not used and all rainwater is collected from the roof.

The water is diverted from both barrels to a sump box where it is pumped into the storage tank. The sump box is kept clean with frequent vacuuming & wiped down inside with a bleach solution.

A screened inlet hanging from a float ensures that the water is drawn from the middle of the tank where it is the cleanest, as heavy particles sink to the bottom while lighter ones rise to the top. When the tank is full there is an overflow pipe that sends excess water into the landscape. The tank is cleaned every four to five years when the cistern is low in the fall.

When water is needed the MQ pump pulls the water to a small insulated room in the barn for filtration before use. This system consists of a 5-micron sediment filter, 10-micron carbon block and ultraviolet disinfection. The filters are changed three times a year, and the ultraviolet bulb once a year. There is an additional 1-micron absolute filter eliminating pathogens in the water, located in the house 100' away from the barn. A 50-gallon pressure tank at the house temporarily stores household water and, when low, is pumped full by the MQ pump in the barn.

Rainbank recommends testing at least once a year, especially with a system like this which was recharged with well water in a year of diminished rainfall.

In many ways, the homeowners found that the switch to using rainwater over well water was beneficial. In addition to a thriving landscape, their dishes were no longer spotted by mineral residue from the well water and they were able to eliminate their water softener since there was no longer any hard well water to treat. The use of rainwater also resulted in less corrosion to plumbing fixtures and other household appliances.

Di Diego + Ferris have altered their water consumption patterns to be in sync with the availability of rainwater. For instance, they schedule power-washing and other high-water use activities during the rainy season when the cistern will be quickly refilled.

CASE STUDY

URBAN WATERSCAPE, POTZDAMER PLATZ

Location:	Berlin, Germany
Designer:	Atelier Dreiseitl, Peter Hausdorf
Owner:	City of Berlin
Scale:	District

Built in 1998, Urban Waterscape showcases rainwater harvesting at the urban redevelopment scale as part of DaimlerChrysler Potzdamer Platz. The project was designed to address flooding associated with sewer overflows, water conservation and urban heat islands.

Rainwater is harvested from the rooftops of 19 buildings with a total catchment area of 50,000-m^2. A little more than half of the 23,000-m^3 (approx. 6 million gallons) of rainwater harvested annually is used for landscape irrigation and for the pools and canals at the development site. The remainder is used in the buildings to flush toilets and urinals, and as supply for fire suppression systems. On average, 80 percent of the annual water usage for the toilet and urinal fixtures is supplied by rainwater.

The rainwater is collected in five large underground cisterns sized to provide additional storage in the event of extremely heavy rainfall. From the cisterns, water is fed into a network of canals built on the south side of the building complex.

Green roofs located on approximately 60 percent of the catchment rooftops serve multiple functions. Water evaporating off the roofs creates

microclimates that reduce urban heat islands, lowering temperatures by a measured 2 degrees C during summer months and reducing the overall cooling demands of the buildings.

The canal installation at Potsdamer Platz has helped to make the square one of Berlin's greatest tourist attractions, highlighting sustainable water use and creating a recreational waterscape for the city's citizens and visitors. Vegetation in the canals naturally filters the water from the site before it is released to an adjacent river.

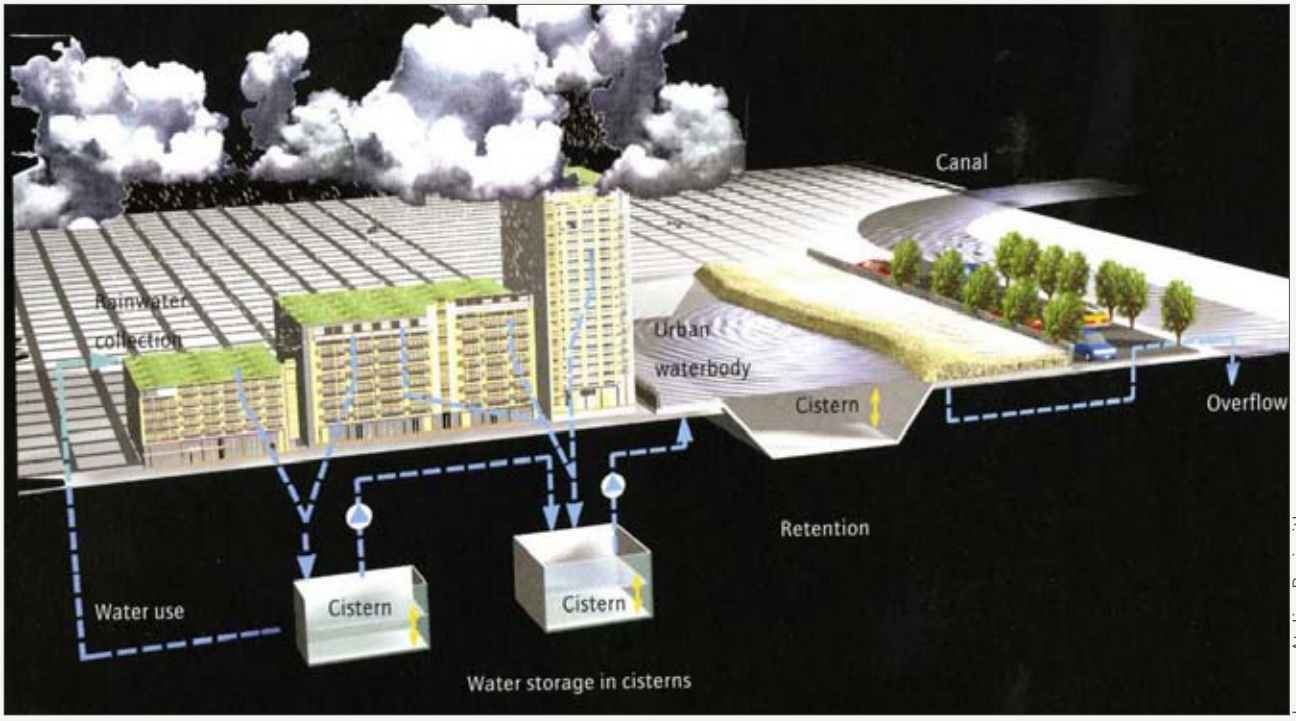


Image: Atelier Dreiseitl

ADDITIONAL RESOURCES

American Rainwater Catchment Systems Association
www.arcsa.org

Arizona Cooperative Extension - Rainwater Harvesting
http://ag.arizona.edu/pubs/water/az1052/harvest.html

Harvest H2O - Online Rainwater Harvesting Community
HarvestH2O.com

Managing Wet Weather with Green Infrastructure - Municipal Handbook
Rainwater Harvesting Policies
www.epa.gov/npdes/pubs/gi_munichandbook_harvesting.pdf

Oregon Smart Guide, Building Codes Division. Rainwater Harvesting
www.oregonbcd.org/pdf/3660.pdf

Rainwater Collection in Washington State
www.ecy.wa.gov/programs/wr/hq/rwh.html

The Texas Manual on Rainwater Harvesting
www.twdb.state.tx.us/publications/reports/rainwaterharvestingmanual_3rdedition.pdf

US Average Annual Precipitation Maps
www.wrcc.dri.edu/precip.htm

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Roebuck, R.M., Ashley, R.M. "Predicting the hydraulic and life-cycle cost performance of rainwater harvesting systems using a computer based modelling tool" 7th International Conference on Urban Drainage Modeling 4th-6th April 2006 Melbourne, Australia 546-53.

Tama, Vivian W.Y. Leona Tam, S.X. Zeng "Cost effectiveness and tradeoff on the use of rainwater tank: An empirical study in Australian residential decision-making." Resources, Conservation and Recycling 54 (2010) 178–186.

GREYWATER RECLAMATION & REUSE

SECTIONS

GREYWATER RECLAMATION & REUSE

DEFINITION

Greywater systems involve on-site capture and reuse of water that would otherwise be comingled with wastewater and conveyed offsite for treatment. The technologies and systems described in this chapter include those that capture greywater on-site without the need for extensive treatment prior to its reuse. In contrast, best management practices for combined wastewater requiring treatment prior to reuse is covered in the following chapter: Wastewater Treatment and Reuse.

There are many different ways to classify and define greywater. Generally, greywater is defined as light greywater from lavatory sinks, showers, bathtubs, laundry and other process-related water that does not come into contact with human waste. Water from toilets and urinals is excluded. Water from kitchen sinks and dishwashers is called dark greywater due to its higher potential for contamination with grease, fats and animal products.

Greywater can be further classified by its level of contamination. This is often done in order to evaluate the best opportunities for reclaiming and reusing the water. Levels of filtration and pre-treatment needed before reuse will vary based on the "shade" or strength of the particular greywater and the intended reuse application. Best practices

COMMON CLASSIFICATIONS OF GREYWATER

Light Greywater: water from bathroom sinks, shower, bathtub, laundry, drinking fountain, and equipment condensate

Dark Greywater: water from kitchen sinks and dishwashers

Combined Wastewater: co-mingled greywater and blackwater from toilets and urinals

Note that the term reclaimed water is different from greywater in that it is generally used to describe municipal wastewater that has been treated offsite and conveyed back to the building for reuse, irrigation or wetland mitigation.

for greywater reuse seek to limit contaminants introduced into the water in the first place, and to filter or treat water only as necessary for its intended reuse.

Greywater can represent a significant portion of a building's water usage. For residential buildings, as much as 50-80 percent of water used can be classified as greywater and can be reclaimed for reuse. While this figure is much lower for commercial buildings, the benefit of these systems lies in the ability to utilize greywater as a non-potable water supply source to offset potable water use in locations within the building where potable water is unnecessary.

Obstacles to wide adoption of greywater reclamation and reuse systems stem from the lack of specific codes and regulations designed to address greywater. Additionally, differences exist at the local, state and national levels in their definitions and understanding of greywater and in the agencies responsible for regulating these systems. Further complications exist when greywater is reused inside buildings which triggers building and plumbing codes issues, as well as reuse that occurs outside of buildings triggering public health and development code issues.

Greywater reclamation and reuse systems can be off-the-shelf, proprietary systems or unique systems engineered to fit a specific project. The most common non-potable water reuse applications for greywater are toilet flushing and irrigation, though greywater can also be used for exterior washing and, with appropriate levels of filtration and pre-treatment, in HVAC and process equipment. The technologies and systems presented below provide a general overview of greywater systems with a focus on those designed for toilet flushing and irrigation purposes.

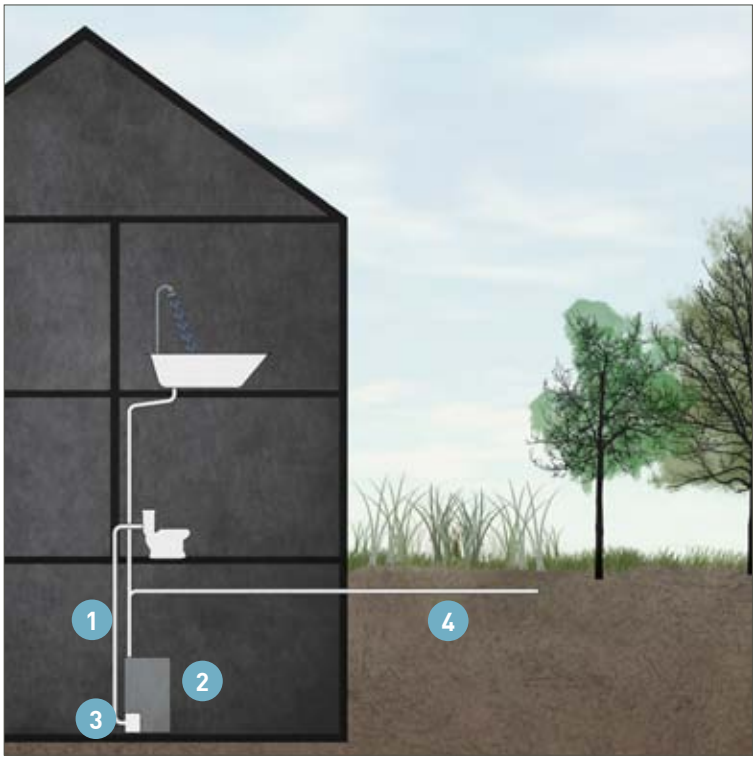
SYSTEM COMPONENTS

Components of a greywater reclamation and reuse system will vary widely based on the type of system and the reuse application. Common system components include those represented in Figure G-1.

COLLECTION AND DISTRIBUTION PIPING

Dedicated plumbing drain lines carry greywater either to a surge tank for treatment and temporary storage or directly outside to landscape areas. Conventional plumbing materials are typically used and gravity flow piping is sized accordingly. Collection pipes are typically 2"– 4" in residential systems, and 4"– 6" for commercial systems. Distribution piping is typically between 1/2" and 1-1/2" diameter for all systems. Three-way diverter valves allow for manual or automated remote activation to divert water

FIGURE G-1: GREYWATER FOR IRRIGATION OR TOILET FLUSHING



SYSTEM COMPONENTS

1. Collection and Distribution Pipes
2. Reservoir
3. Filter and Pump
4. Subsurface Irrigation

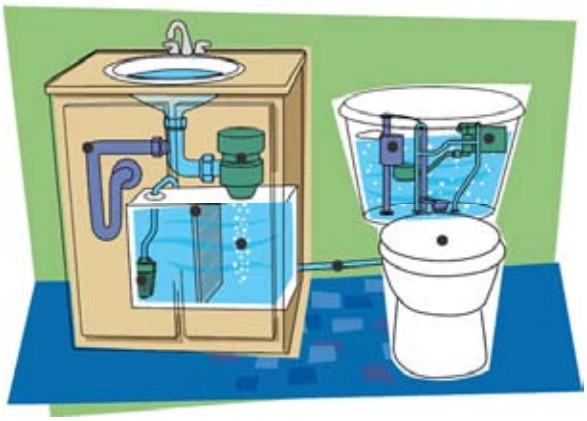
into traditional wastewater sewer lines as needed, particularly when the greywater system is subject to overloading due to periods of increased occupancy in the building.

For greywater reuse systems that involve pumping greywater to plumbing fixtures such as toilets or urinals, a dual-piping system is needed for the return pressurized supply lines. Traditionally, purple pipes have been used to indicate municipally-supplied reclaimed water sources. Green-colored piping is recommended for identifying plumbing pipes containing treated greywater.[65] In addition, distribution piping should be clearly labeled with "Non-potable Water – Do Not Drink" along with arrows showing the direction of water flow.

65 Recommendations to IAMPO on Pipe Color Code to Convey Onsite Alternative Waters. White paper submitted by Alan Rimer (Chair, AWWA Water Reuse Committee) and Don Vandertulip (Chair, WEF Water Reuse Committee and WRA Board of Directors Member).

RESERVOIR

Some but not all greywater reuse systems rely on temporary storage of the water prior to its reuse application. Systems used for toilet flushing may have a storage reservoir located directly under a lavatory sink or in a basement or other centralized location for collection of greywater.



Source: www.watersavertech.com

It is crucial to take into account that greywater degrades in less than 24 hours. Therefore, reservoirs are designed to store water only temporarily and will have an overflow valve diverting greywater into conventional sewer drains in the event that a backup or pooling occurs.

Sizing of the reservoir will vary based on the amount of greywater it is designed to hold and the level of treatment provided. Reservoirs may be made of concrete, plastic or other watertight materials. If they are located outside of the building footprint, they can be buried below grade, partially buried or secured to a foundation pad above grade. Regular maintenance and cleaning is required.

FILTER AND PUMP

For greywater reuse systems that include storage for longer than 24 hours, a recirculating aeration pump must be used to prevent harmful bacteria growth. Filtration of the greywater is essential to avoid clogging pumps. Regular maintenance and cleaning of the filters and pumps extend the performance and life of the systems.

Gravity-fed irrigation systems utilize greywater down slope, eliminating the need for pumping. However, filters are still necessary to ensure that suspended solids in the greywater do not clog irrigation distribution lines and emitters.

IRRIGATION SYSTEM

Systems designed to reuse greywater for irrigation can vary widely depending on the amount of space available on-site for subsurface drainfields, soil characteristics and type of vegetation. At the residential scale, subsurface drip irrigation is used to irrigate plants with excess greywater. Water not taken up by the vegetation percolates into the ground. Landscaped areas designed with appropriate soils and vegetation deliver greywater to the root zone of the plants, typically 4"- 8" below grade to prevent

contamination of stormwater runoff and prevent direct contact between the greywater and humans or other animals.

Non-vegetated mulch basins are shallow depressions that receive incoming greywater below the surface for the purpose of infiltration. Mulch or bark fills the basin, preventing direct contact with greywater. Branched drain systems disperse greywater to multiple irrigation zones and allow the system to handle larger volumes of greywater.

For commercial applications and locations with site constraints, greywater can be used for indoor irrigation. Interior planter boxes and vertical living walls are two possible strategies. Greywater is delivered to the root zone where it is allowed to evapo-transpirate. Overflow must be discharged into conventional sewage drains.

TECHNOLOGY

Greywater reclamation and reuse systems utilize fairly standard materials and simple technologies. Gravity-fed systems eliminate the need for pumping and the associated energy and maintenance requirements, simplifying these systems even further.

Greywater contains fewer pathogens and up to 90 percent less nitrogen than blackwater.[66] However, greywater can contain high concentrations of easily degradable organic materials such as residues from soaps and detergents. Because the water is favorable for bacterial growth, it must be used within 24 hours or treated to avoid turning anaerobic and producing odors.

Systems used for toilet flushing will often rely on small-scale filtration and chemical treatment (e.g. chlorine) prior to storage between flushes to prevent harmful bacteria from growing and potentially clogging system components. Irrigation systems introduce the greywater directly to the biologically active topsoil layer where soil bacteria can quickly break it down and make the nutrients in the water available to plants.

66 National Association of Home Builders Research Center." Greywater Reuse." Toolbase Resources. National Association of Home Builders Research Center, n.d. Web. October 2010.

FIT

Greywater reclamation and reuse systems are a good fit for single family and multifamily residential buildings based on the volume of greywater generated from sinks, showers, and laundry from these building types. For commercial buildings, the amount of greywater generated will be more limited. Greywater systems are a more ideal fit for new construction as retrofitting existing plumbing for greywater collection and distribution can be very costly.

Residential greywater systems can be retrofitted into an existing home more easily when integrated during other remodeling activities where plumbing will be exposed. Existing homes with crawl spaces provide easier access for retrofits. Diverter valves installed into existing plumbing provide the user with the option of selecting when to divert greywater for reuse and when it should be discharged to the existing sewer drain.

Greywater irrigation systems must be designed to address a site's seasonal weather conditions. Saturated or frozen ground presents challenges to maintaining infiltration rates for the greywater. Seasonal greywater irrigation systems are designed to divert greywater only during dry months to outdoor landscapes. However, greywater can be accommodated within greenhouses or in semi-arid climate regions year-round.

In urban locations where site constraints are a limiting factor, greywater can be used to irrigate green roofs or supply an indoor greenhouse.

In most jurisdictions, greywater reclamation and reuse systems are either not allowed by local regulations or there are no standards defining how and when greywater can be used. In fact, it has been estimated that fewer than two percent of greywater systems are legally installed.[67]

Regulations around greywater, however, are changing quickly. The city of Santa Fe, New Mexico has developed a "permit by rule" provision that allows building owners to install greywater systems without a permit as long as they are under 250 gallons/day.

New construction projects can rough-in plumbing for greywater systems to facilitate retrofitting in the future. In some areas of the country, this is becoming a code requirement. For example, the cities of Tucson, Cottonwood, and Chino Valley, Arizona have mandated greywater stub-outs in new residential construction permitted after June 1, 2010.[68]

67 Bahman Sheikh, PhD, PE. White Paper on Greywater. American Water Works Association, Water Environment Federation, and the WateReuse Association, 2010.

68 Ibid.

EFFICIENCY

Efficiency of a greywater reuse system depends on the amount of greywater generated, the storage capacity of the system, the intended reuse application and the system's water demands. Potable water use offset by residential greywater systems can vary from fewer than 40 and up to 100 gallons per day.

Depending on a community's water and wastewater utility fees, potable water savings from greywater reuse systems can be substantial. Manufacturers of proprietary systems used for toilet flushing claim approximate potable water savings of 4,000 to 6,000 gallons annually,[69] and a 35 to 40 percent reduction in annual water utility bills.[70]

System costs including materials and labor can vary widely, with do-it-yourself kits for single family homes for under $1,000 to more sophisticated, proprietary systems that can range from $2,500-$8,000.[71]

Incentives from water and wastewater utilities can help decrease the payback period for investment in greywater reclamation and reuse systems. For instance, the City of Tucson promotes a State of Arizona tax credit to greywater users as an incentive to encourage this practice.[72]

ADDITIONAL DESIGN CONSIDERATIONS

SYSTEM LOCATION

Greywater reclamation and reuse systems may be located adjacent to the point of use such as those that collect water from lavatory sinks in a small reservoir directly connected to a nearby toilet tank or planter box. Greywater collection systems may also be located in a basement or other centralized location and distributed back to toilet fixtures or outside for irrigation. "Laundry to landscape" type systems divert greywater directly from an appliance (e.g. a washing machine) outdoors to mulch basins via hoses or other pipe materials.

69 According to manufacturer's website: www.watersavertech.com

70 According to manufacturer's website: www.bracsystems.com

71 Bahman Sheikh, 2010.

72 Ibid.

SYSTEM SIZING AND INTEGRATION

Net zero water projects should carefully evaluate how to best integrate a greywater reuse system into a building's overall stormwater and wastewater management plan, and look for opportunities to complement the landscape design with all available water resources.

Budgeting for water use with a greywater system requires careful consideration as typically these systems do not include significant storage, if any (systems with large storage require more intensive treatment). Often there is more supply than demand or, conversely, peak demand periods may outweigh the availability of greywater for immediate use. Combining a greywater system with a rainwater harvesting system allows for the use of rainwater as a backup when greywater supplies are low. Also, since rainwater is typically stored and used for drinking water, the reuse of non-potable greywater can help minimize the size of the storage system.

The pH of greywater can range between 6.5-8.7 and is best suited for irrigating well-established plants rather than more fragile, young plants. Greywater can be used to water food crops but must be delivered below the surface to the plant's root zone and not used on root crops that are intended to be eaten raw. Greywater irrigation systems should not be used with chemically softened water as the dissolved salts can be harmful to plants, though small quantities of lightly softened backwash may not be detrimental.

CASE STUDY

AUSTRALIA GREEN DEVELOPMENT FORUM (AGDF)

Location:	Brisbane, Australia
Architect:	Bligh Voller Neild
Developer:	Pandanus Projects
Scale:	Residential

A 2004 design workshop hosted by the Australian Green Development Forum and the Brisbane City Council produced the seed ideas that gave rise to Sustainable Home Brisbane. This modern, four-bedroom demonstration project was designed to minimize its total ecological footprint while respecting the site's existing vegetation and wildlife habitats. The project operates within a closed-loop water cycle by sourcing all of its water supply through harvested precipitation, utilizing water conserving appliances and fixtures and reusing all of its greywater on-site.

Located in an area that receives an average of 47 inches of annual rainfall, the project team recognized opportunities for sourcing 100 percent of the occupant's water needs through rainwater harvesting. Four above-ground steel cisterns were installed to store 22,000-liters (approx. 5,800-gallons) of water for all potable

and non-potable uses inside the home. The system is designed with enough storage capacity to compensate for lower rainfall during the drier months of the year. The captured rainwater is treated with UV and micro-filtration before it is pumped throughout the home for toilet flushing, laundry, showers, bath, basins and kitchen sink. Overflow from the cisterns discharges to infiltration trenches in the rear garden area.

The home's greywater reuse system collects water from sinks, bath and laundry for subsurface irrigation. The system is designed to process a minimum of 500-liters (approx. 132-gallons) per day. Greywater irrigation pipes are located 100-mm (approx. 4 inches) below the surface and consist of 50-mm diameter slotted, corrugated drain encased in polyester filter media to prevent soil from clogging the pipe. Greywater is pumped to designated landscape areas in the front and rear of the property. An alarm alerts homeowners in the event of saturation, allowing them to divert overflow into the municipal sewage system.

Images: AGDF

CASE STUDY

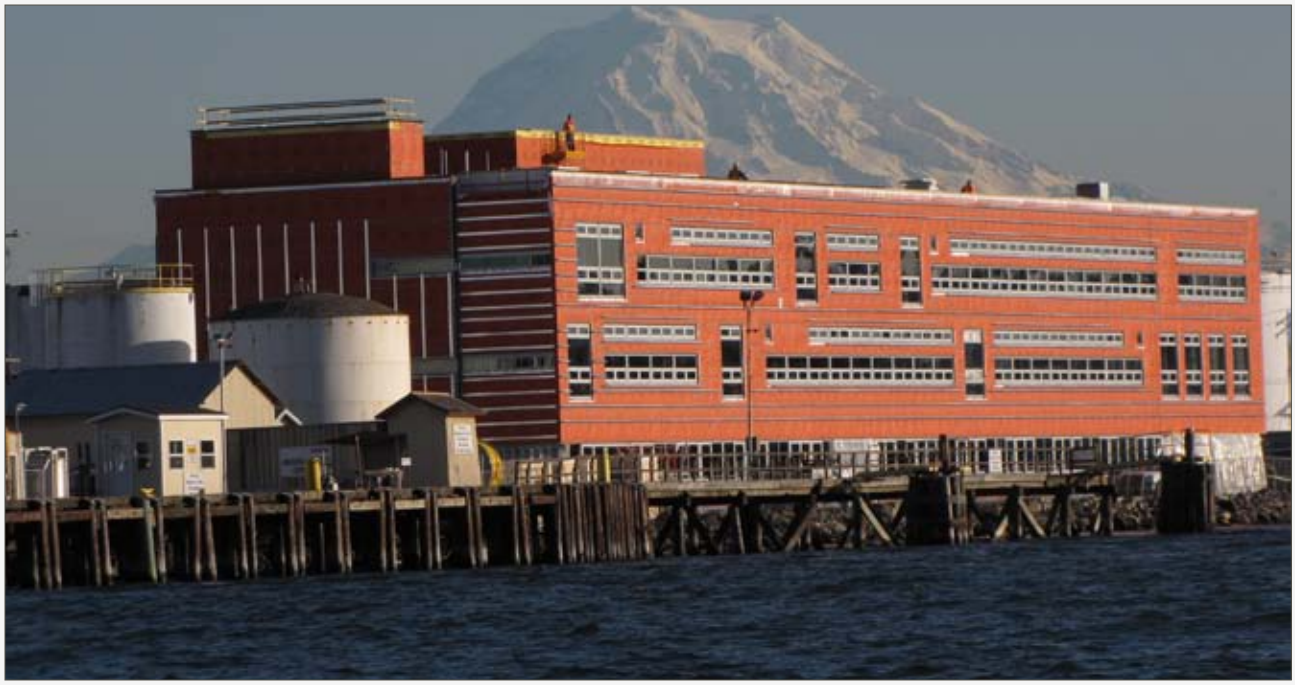
CENTER FOR URBAN WATERS

Location:	Tacoma, Washington
Architect:	Perkins + Will
Landscape Architect:	Swift & Co.
Civil Engineer:	AHBL
Owner:	City of Tacoma
Scale:	Commercial

Completed in 2010, the Center for Urban Waters is a 51,000-sf environmental services and research laboratory located in Tacoma, Washington. The facility was constructed as a public-private partnership to house the City of Tacoma's Environmental Services Division labs and offices, University of Washington-Tacoma research labs and staff from the Puget Sound Partnership. The Center brings together researchers and policymakers under one roof to develop and apply the best possible science to restoring and protecting water quality in Puget Sound.

The project includes a rainwater harvesting system coupled with captured greywater from the building to achieve an estimated 46 percent reduction in potable water use. Rainwater is collected in two 36,000-gallon above-ground cisterns and combined with rejected, clean process-water from laboratory sources. The resulting greywater is used for toilet flushing throughout the building and for landscape irrigation. An alarm alerts building operators to manually fill the tanks with municipal water if capacity falls below 10 percent.

In addition to the greywater reuse system, the Center will showcase a laboratory for collecting, monitoring, and assessing water quality effectiveness of low impact development stormwater strategies. A 12,000-sf green roof helps filter and slow runoff from roof surfaces. The majority of the green roof area will be used to collect water for offsetting potable water use inside the building and for irrigation, while some area will be reserved for testing the green roof's effectiveness for reducing stormwater runoff rates. Rain gardens located in parking areas will also be used to filter and infiltrate runoff.



Images: Perkins + Will

CASE STUDY

ONE BRYANT PARK

Location:	New York City, NY
Architect:	Cook + Fox Architects, LLP
Engineer:	Jaros, Baum & Bolles
Water System:	Alliance Environmental and Natural Systems Utilities
Owner:	Bank of America
Scale:	Commercial

Completed in 2009, One Bryant Park (OBP) was the first certified LEED-Platinum skyscraper in the world. The 54-story, 2,200,000-sf urban redevelopment project sits on a two-acre site in Midtown Manhattan. The building's integrated water management system is impressive due to the scale at which these systems are applied. Water conservation along with rainwater harvesting and greywater reuse systems reduce the building's internal demand for domestic water supply by roughly 50 percent.

Conservation is an essential component of the building's efficient water management system. Low-flow fixtures and waterless urinals save nearly 6 million gallons of domestic water annually.

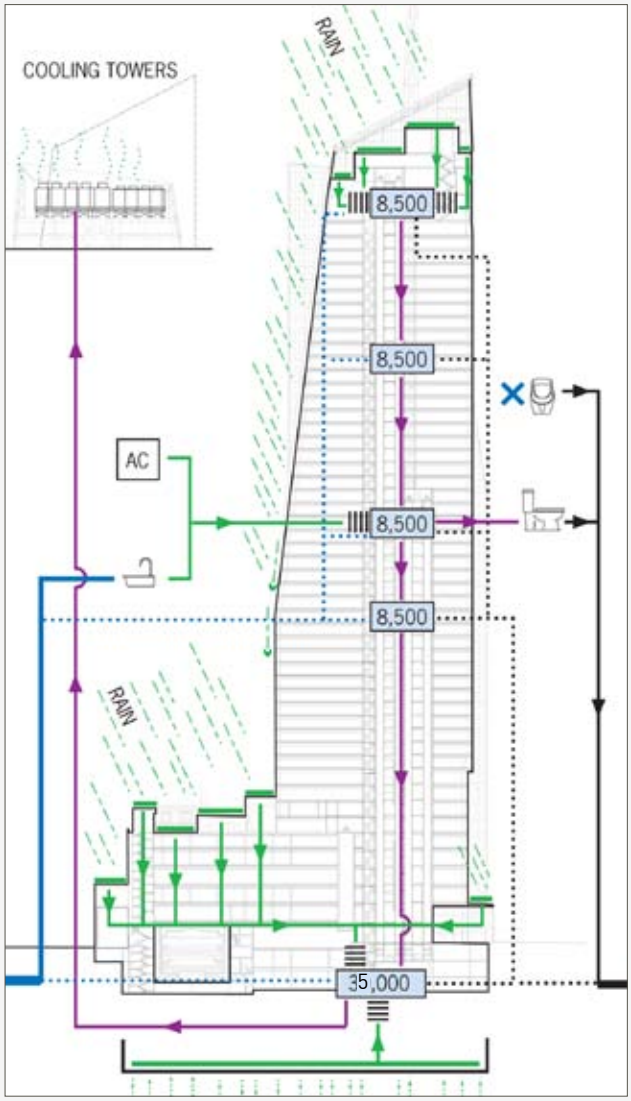
These measures not only conserve water, they also reduce CO_2 emissions associated with water and wastewater distribution, collection and treatment.

With an annual rainfall of 48 inches, the building captures rainwater from its rooftops where it is stored along with condensate collected from air-conditioning coils and light greywater from sinks. Collection tanks have the capacity to store up to 69,000 gallons of combined rainwater and greywater and are distributed strategically throughout the building to enable a gravity feed distribution system for toilet flushing.

Four 8,500-gallon tanks are located on floors 22, 29, 41 and 53, supplying water for toilet flushing for the building's upper levels. The uppermost tank stores only rainwater while the tanks on the lower levels receive rainwater overflow and greywater from lavatory sinks.

A larger, separate, 35,000-gallon rainwater cistern is located in the basement and will be used to flush toilets on the lower floors and supply makeup water for the building's cooling towers. Domestic water is stored in two additional tanks on the 53rd and 30th floors to ensure a quick water supply to tenants, provide emergency fire suppression and refill greywater storage tanks when they are low.

Greywater is collected from all lavatory sinks and is treated to the water quality necessary for its subsequent use. The initial greywater treatment design employed ultraviolet disinfection with an Amiad filter and dye system. After careful monitoring, the system has been upgraded and now includes a multimedia sand filter, residual disinfection and continuous on-line monitoring and controls. Mechanical equipment can often require a higher quality water source to help maintain mechanical system health.



Images: Cook + Fox Architects

The comprehensive water management practices at OBP also help reduce negative impacts to New York City's combined sewer system by capturing and reusing water on-site. During heavy rains, combined sewer overflow events result in raw sewage flowing directly into the Hudson River as the sewers reach capacity. OBP's rainwater harvesting system reduces stormwater runoff while the high-efficiency fixtures and greywater system reduces the generation of wastewater by an estimated 40-50 percent compared to a conventional building.

ADDITIONAL RESOURCES

Brac Systems
www.bracsystems.com

Greywater Alliance
www.greywateralliance.org

Greywater Action
www.greywateraction.org

Oasis Design
www.oasisdesign.net

Watersaver Technologies
www.watersavertech.com

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Bahman Sheikh, PhD, PE. White Paper on Greywater. American Water Works Association, Water Environment Federation, and the WateReuse Association, 2010.

National Association of Home Builders Research Center. "Greywater Reuse." Toolbase Resources. National Association of Home Builders Research Center, n.d. Web. October 2010. (http://www.toolbase.org/Technology-Inventory/Sitework/greywater-reuse).

Recommendations to IAMPO on Pipe Color Code to Convey Onsite Alternative Waters. White paper submitted by Alan Rimer (Chair, AWWA Water Reuse Committee) and Don Vandertulip (Chair, WEF Water Reuse Committee and WRA Board of Directors Member).

Image: Farshid Assassi courtesy of BNIM Architects

WASTEWATER TREATMENT & REUSE

SECTIONS

WASTEWATER TREATMENT & REUSE

INTRODUCTION

A wide range of proprietary and non-proprietary distributed technologies is currently used to manage water and waste in the built environment. These range from simple, passive systems that mimic the biological, chemical and physical processes occurring in natural wetlands to more energy-intensive activated sludge technologies. Table W-1 provides a snapshot of the various distributed technologies used to treat water and wastes.

The selection of a distributed wastewater treatment system will be influenced by site conditions, capacity needs, desired inputs and outputs as it relates to a building's overall water use and reuse goals, the chosen treatment technology (e.g. suspended vs. attached growth) and economic considerations. System selection is frequently evaluated based on its applicability to various building scales — single-family residential to commercial and neighborhood-level scales — as well as its required energy input and overall footprint size.

Additional considerations for system selection include:

- Use of chemicals
- Treatment capabilities: ability to treat trace constituents
- Capital and operating costs
- Ongoing maintenance requirements
- Availability of technology and its performance track record

Various treatment options can achieve different qualities of water based on their design and performance efficiency. Primary treatment systems only remove a portion of the suspended solids and organic materials from wastewater. Secondary levels of treatment include removal of biodegradable organic matter and suspended solids and nutrients such as nitrogen and phosphorous. Tertiary treatment systems include disinfection of treated water and advanced removal of residual suspended solids through filtration.

TABLE W-1: OVERVIEW OF TREATMENT TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	EXAMPLES
Non-water discharging containment systems	Collection and processing of human wastes without the use of water	Composting toilets Incinerating toilets Evaporation systems
Primary treatment systems	Pretreatment and settling of particulate materials Usually coupled with more advanced treatment technologies or with a drainfield which relies on soil to filter, treat, and disperse effluent	Septic tanks
Suspended growth	Treats water through active microorganisms suspended in aerated environments. Also known as activated sludge process	Sequencing batch reactors Membrane bioreactors
Attached growth	Treats water through active microorganisms attached to granule, organic or synthetic media. Also referred to as fixed-film processes	Recirculating biofilters Intermittent sand filters Fabric/synthetic filters
Hybrid	Utilize both suspended and attached growth processes to treat water	Moving bed biofilm reactors
Natural	Treats water by mimicking the biological, chemical and physical processes occurring in natural wetlands	Constructed wetlands

This chapter includes sample technologies that are capable of achieving an advanced secondary level of treatment or greater to support water reuse or the release of less polluted water back into the environment, with consideration for the beneficial use and appropriate handling of nutrients. Table W-2 provides a brief summary of four sample technologies included in this chapter.

TABLE W-2: SAMPLE WASTE AND WASTEWATER TREATMENT TECHNOLOGIES

	FOOTPRINT	OPERATING ENERGY	TECHNOLOGY
Composting toilets	Small – Large*	Zero – Low	Non-water discharging containment system Nutrient recovery
Constructed wetland	Small – Large	Zero – Low	Attached growth aerobic treatment
Recirculating biofilter	Medium	Low – Medium	Attached growth aerobic treatment
Membrane bioreactor	Small – Medium	High	Suspended growth aerobic treatment with synthetic membrane ultra-filtration

* Typically coupled with a greywater system to manage water from sinks, baths/showers and laundry. Wetland and soil dispersal area for greywater can have large space requirements. See Greywater and Reuse Chapter.

COMPOSTING TOILETS

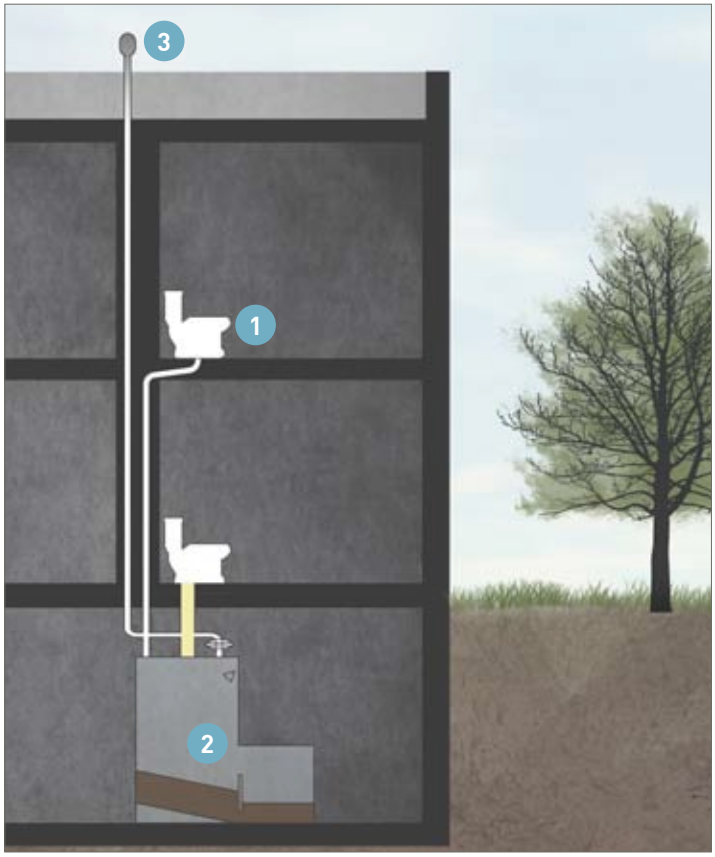
Composting toilets are non-water discharging systems. The processing of human waste is achieved with zero or minimal use of water to convey waste. This has the potential to greatly reduce a building's overall demand for wastewater handling as no blackwater is generated. Composting toilets rely upon biological and physical decomposition to turn excrement into valuable, nutrient-rich end products that can be used on- or off-site as a fertilizer or soil amendment. Composting toilets are typically paired with a greywater system to handle wastewater generated from other plumbing fixtures within a building.

SYSTEM COMPONENTS

TOILET

Composting toilet fixtures come in a variety of shapes and sizes and are similar in design to a conventional water flush toilet. The fixtures are typically porcelain, polyethylene or ABS plastic and are classified as either dry, micro-flush, vacuum flush or foam flush, depending on the technology used. Micro-flush units use approximately one pint of water per flush. Urine-diverting toilets separate liquid from solid waste at the fixture location to optimize nutrient separation and collection. Toilet fixtures can be mounted either directly above the composting chamber or located several stories above the chamber connected by a 4"-12"diameter piped chute. For foam flush and micro-flush models, chutes can bend up to 45 degrees, allowing for flexibility in the system layout at different stories of the building rather than stacking fixtures directly over a centralized chamber.

FIGURE W-1: COMPOSTING TOILET



SYSTEM COMPONENTS

1. Toilet Fixture
2. Composting Chamber
3. Ventilation

COMPOSTING CHAMBER

In many composting units, decomposition takes place in a tightly sealed plastic, fiberglass or concrete composting chamber. Some designs have sloped chambers to separate urine from feces. Others use electric or solar heat to ensure optimal temperatures for the composting process. Drums or mechanical stirring provide mixing and aeration.

All chambers include an access door for removal of composted end products and most require an overflow for the discharge of liquid wastes. Chambers are sized based on system loading and can serve individual or multiple toilet fixtures. Some designs feature dedicated urine collecting chambers that allow for the collection and processing of urine separately from solid wastes.

VENTILATION

Ventilation ensures adequate oxygen and the proper moisture and temperature levels necessary for the composting process. A ventilation system includes an air inlet and exhaust vent for removing odors, excess heat, carbon dioxide, water vapor and other byproducts of aerobic decomposition. Passive systems require little or no energy input while more intensive systems require electricity (typically 12 volts or less) for air circulation and mixing of the composting material. Solar-powered fans can be used to drive the ventilation system.

TECHNOLOGY

Composting toilets use an aerobic decomposition process to slowly break down human excrement to 10 to 30 percent of its original volume into a soil-like material called humus.[73] Organisms that occur naturally in the waste material, such as bacteria and fungi, perform the work of breaking it down. Compost worms may be added to accelerate the process.

During the composting process, optimal moisture content of the waste should be maintained at around 40 to 70 percent.[74] Additionally, excess water vapor and carbon dioxide produced in the process are mechanically vented to the outside through the unit's exhaust system. This venting also prevents the occurrence of strong odors. Mechanical or manual mixing of the waste improves aeration, and bulking agents such as wood chips, saw dust or other carbon sources can be added to provide space for microbial colonization.

73 US EPA. Water Efficiency Technology Fact Sheet. Composting Toilets. 1999.

74 Ibid.

Composting toilet technology is defined by either a continuous or batch process. Toilets that utilize a continuous process deposit new waste materials on top of the composting mass while finished material is removed from the bottom or end of unit. In this system, risk of contamination in composted end products is a concern and proper maintenance and oversight is essential. In a batch process, excrement is collected for a certain period of time and is then set aside for months or years while the composting process occurs.

Some composting toilets use no water or other liquids to carry waste to the collection chamber. Others feature a "micro-flush" utilizing 1/10 of a quart of water to flush urine only. Foam-flush toilets use a mixture of water and a compost-compatible soap to create a foam blanket that transports waste to the composting unit. With any of these technologies, the end products are either used on-site as fertilizers or hauled offsite to an appropriate handling facility. Depending on the size of the system, the time required for the composting process might range from three months to several years.

Composting toilets address potential pathogens found in human waste through the process of composting or through the natural production of predatory organisms toxic to most pathogens. One key advantage to composting toilets is that they keep valuable nutrients such as nitrogen and phosphorous in tight biological cycles without causing potential environmental risks to receiving water bodies, which occurs in conventional wastewater treatment plant operations.[75]

FIT

Because they require little or no water supply, composting toilets are a good fit for geographic locations with limited water resources, such as areas affected by drought. Likewise, because they are non-water discharging systems, locations where on-site wastewater management options are limited due to site constraints, high water tables or shallow soils make composting toilets a feasible alternative. In cold climates, composting chambers might need to be heated and/or insulated to ensure optimal temperatures for decomposition and pathogen removal.

Composting toilets are an obvious fit for areas not already serviced by municipal sewers as they eliminate the need for extensive infrastructure brought in to service a building or neighborhood development. Utilization in urban locations presents opportunities to reduce demand on existing municipal wastewater treatment infrastructure and extend the life of these systems, which are often maintained and updated through costly public funding.

75 US EPA. Water Efficiency Technology Fact Sheet. Composting Toilets. 1999.

Composting toilets may be more challenging to incorporate into retrofit applications than for new construction due to the space needed for the composting chamber. For retrofits, micro-flush or vacuum-flush toilets can be installed to convey wastes to a composting chamber located outside the building envelope.

Composting toilets are suitable for any building typology and successful examples exist at all scales. Dry toilets may be best designed into single-family houses, while micro-flush or foam flush models are better suited for multifamily or commercial buildings.

EFFICIENCY

Costs for composting toilets can range from $1,000-$5,000 for individual, self-contained units.[76] Larger-scale centralized systems can require a substantial investment on the part of the building owner or developer, though there is great opportunity for considerable savings on water and wastewater utility fees over the life of the system. The payback period on any scale system is highly dependent on water and wastewater rates, with higher rates providing a financial incentive to curb water use. Many commercial scale systems such as those used at the Chesapeake Bay Foundation Headquarters' in Annapolis, Maryland, calculated a payback in less than 10 years.[77]

Lifecycle costs and paybacks for utilizing composting toilets on a neighborhood scale project can be minimized when comparing the upfront financial investment a developer must take on to install infrastructure needed to convey wastewater from individual buildings to sewer mains, and sometimes to supply the sewer mains to the development altogether.

Composting toilets, like all decentralized water systems, require a commitment by building owners and maintenance staff to provide management and oversight of the system to ensure proper performance.

76 California State Water Resources Control Board. Review of Technologies for the Onsite Treatment of Wastewater in California. 2002.

77 WERF. Modeling Onsite Wastewater Systems at that Watershed Scale: A User's Guide. 2009.

ADDITIONAL DESIGN CONSIDERATIONS

SIZING

Sizing of a system will depend on building use, occupancy and the type of composting toilet system used. Single-family applications will utilize single fixture, self-contained systems while commercial or multifamily buildings will use multi-toilet centralized composting systems.

SYSTEM LOCATION

Self-contained units position the toilet fixtures directly on top of the composting chamber and allow for the greatest flexibility in locating the system anywhere within a building. Larger, centralized systems commonly locate composting units in the bottom floor or basement of the building with toilet fixtures above. Vacuum flush models allow toilet fixtures and composting units to be located on the same floor but require water and electricity.

SYSTEM INTEGRATION

Composting toilets can be integrated into a building's net zero water strategies with opportunities for maximizing water conservation and reuse. Utilizing composting toilets can result in reduced systems needed for managing a building's remaining wastewater, including fewer pipes and smaller areas needed for on-site treatment.

Rainwater or greywater can be used as a supply source for micro-flush models. Likewise, rainwater or greywater can be used for diluting stabilized urine from urine-diverting models to be used as a fertilizer on-site.

Systems can be designed to also accept food waste from the home or building, allowing a net zero water project to handle all organic waste materials on-site. End products from the composting process can provide beneficial nutrients to amend soils and fertilize landscapes.

Composting toilet at University of British Columbia's C.K. Choi building.

CASE STUDY

BAIRD RESIDENCE

Location:	Victoria, British Columbia
Designer and Builder:	Ann & Gord Baird
Owner:	Ann & Gord Baird
Scale:	Residential

The Baird residence, completed in 2008, is an excellent example of affordable, sustainable single-family housing. The seismically reinforced cob home was built for just under $150/sf. The extended family of six has greatly reduced its need for potable water by installing a rainwater collection system and a composting toilet, and reusing greywater on-site for irrigation.

The house includes a 2,500-sf green roof that collects 1,300 gallons of rainwater for every inch of rainfall. Four cisterns with a total capacity of 10,000 gallons store the water during the four to six months of summer drought. While the water is currently used primarily for irrigation, the rainwater system is designed for possible future upgrade to potable quality by installing a sand filter between the green roof and the cisterns and adding filtration and UV sterilization.

The Bairds spend about 10 minutes every four days attending to their composting toilet. They based their "bucket-and-chuck-it toilet" on a system from Joseph Jenkins' The Humanure Handbook. Human waste is collected in a bucket boxed into the family's bathroom. Odors are avoided by ventilating the box using a small fan, and the contents of the bucket are kept dry by periodically sprinkling of wood shavings. The contents of the bucket are

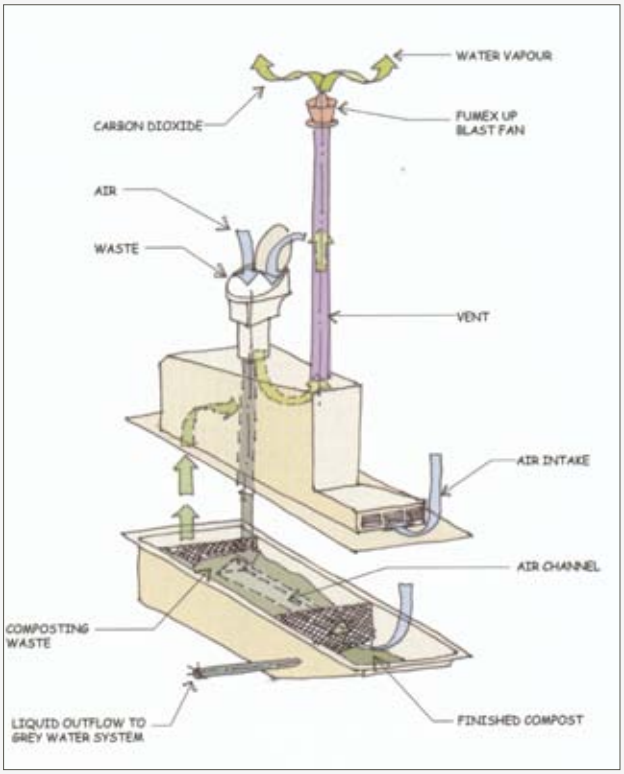
then dumped into a hot compost area in the yard to engage in an aerobic thermophillic composting process. Once the waste is fully decomposed, the nutrient-rich compost is dispersed around the garden and vegetated portions of the property.

During construction of the Baird residence, higher-than-expected costs were accrued when they realized that their municipality's building code required the installation of a working flush toilet. Once they demonstrated to the plumbing inspector that their toilet functioned and received their permit, they removed the toilet and resumed utilizing their composting toilet.

Images: Eco-Sense

CASE STUDY

C.K. CHOI BUILDING FOR THE INSTITUTE OF ASIAN RESEARCH



Location:	Vancouver, British Columbia
Designer:	Matsuzaki Wright Architects, Inc.
Owner:	University of British Columbia
Engineer:	Keen Engineering
Scale:	Campus

The C.K. Choi Building is a 35,000-sf state-of-the-art research facility at the University of British Columbia, known for its pioneering accomplishments in sustainable design. Completed in 1996, the building was the first of its size to install composting toilets in North America, eliminating the need to connect to the campus sewer system and reducing potable water demands by over 375,000 liters (99,000 gallons) per year.

The three-story building has ten composting toilets and three trapless ventilated urinals that require no water. The fixtures are connected to five Clivus Multrum Model M28 composting units located on the ground floor. The composting unit's 5-tray system allows maintenance staff to add wood chips and red wiggle worms that facilitate the process of turning solid waste into a humus-like topsoil rich in

nitrogen and other useful elements. The units are well ventilated, eliminating potential odors.

The combination of aerobic composting with the addition of worms reduces the overall volume of waste by 90 percent. The resulting compost is then applied to planting beds to improve depleted soil conditions. Greywater from sinks and effluent "tea" from the composting units is directed to a narrow, vegetated gravel filtration trench that runs along the front of the building. The trench functions like a subsurface biological marsh where microorganisms on the roots of the marsh plants naturally purify the water before it enters an 8,000-gallon underground cistern. The cistern, which also collects rainwater from the roof, stores water for landscape irrigation during the dry summer months.

One of the project challenges was convincing the Vancouver Health Department that the composting toilet and greywater system would work properly and safely. At the time, Vancouver's plumbing code did not address a process for regulatory approvals, and there were no North American precedents to illustrate how the system would perform. The design team spent hundreds of hours researching and presenting their case, finally gaining regulatory approval for the alternative wastewater system.

Testing performed by the Vancouver Health Department to this day has found that the fecal coliform of the water is well below acceptable levels.

Images: Clivus Multrum, Inc.

CONSTRUCTED WETLANDS

Constructed wetlands treat wastewater by mimicking the biological, chemical and physical processes that occur in natural wetlands. Some systems can require little or no operating energy and can provide ancillary benefits as site amenities.

Constructed wetlands can stand alone as treatment systems or be utilized as a polishing step for improving effluent quality within a larger system. Surface flow wetlands are characterized by shallow, above-ground flooding which produces an anoxic environment to treat wastes. In these systems, the water surface is exposed to the atmosphere and carries the risk of odors, mosquitoes and potential human contact with wastewater. By contrast, subsurface flow wetlands are designed as a bed or channel filled with media such as coarse sand or gravel. The water surface is maintained below the top of this medium, eliminating some of the risks associated with surface flow wetlands and increasing the treatment efficiency of the system.

The following section highlights components and technologies associated with subsurface flow systems.

SYSTEM COMPONENTS

PRIMARY CLARIFICATION TANK

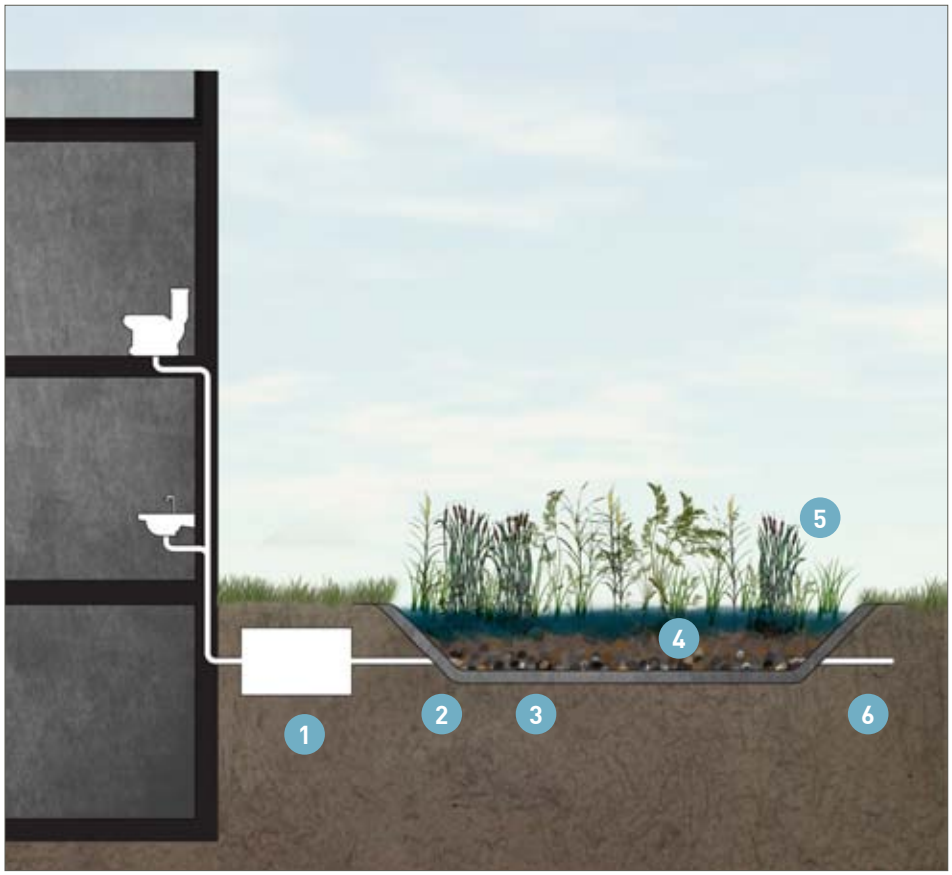
Constructed wetlands are generally preceded by a primary clarification tank for the settling of solids. Depending on the geography of the site, primary clarified tank effluent is either pumped or gravity-fed into the constructed wetland.

PLANTING MEDIUM

Constructed wetlands consist of a shallow bed filled with porous packing material that supports wetland vegetation. Gravel and coarse sand is most often used as the planting medium, ranging in size from fine gravel (less than 0.25 inches) to crushed rock (typically less than 1 inch). The depth of the planting medium ranges from 1-3 feet deep.

Water level is controlled by the outlet structure. It is typically maintained between 4 inches - 2 feet below the top of the planting medium. While the top of this porous material is typically at that same level as the surrounding terrain, the top of the material is kept dry to control odor, insects and the potential for human contact with the water during the treatment process.

FIGURE W-2: CONSTRUCTED WETLAND



SYSTEM COMPONENTS

1. Primary Clarification Tank
2. Inlet
3. Impermeable Liner
4. Planting Medium
5. Wetland Vegetation
6. Outlet

WETLAND VEGETATION

The bed is established with vegetation specifically selected to survive in fluctuating wet and dry conditions, and should ideally be native to the region and specific to the watershed, climate and altitude. While the planting medium provides the primary substrate for microbial growth, the vegetation provides additional surface area and supplies oxygen to the root zone.

In addition, the vegetation stabilizes the planting bed, provides a thermal barrier against freezing in cold climates and improves the wetland aesthetic.[78] Constructed wetlands are typically planted with a variety of species to provide a resilient and effective treatment process.

Typical species include bulrush and reeds. Cattails, while often found in wetlands, are sometimes labeled as a noxious weed because they crowd out more desirable species.

78 California State Water Resources Control Board. Review of Technologies for the Onsite Treatment of Wastewater in California. 2002.

In addition, they do not have a favorable root structure for oxygen transfer or ideal root surface area for microbial growth.

INLET/OUTLET DEVICES

Inlet and outlet devices and earth berms are used to control water depth in the wetland. These controls ensure uniform horizontal and vertical flow patterns through the planting medium, and maintain the water level below the surface.

IMPERMEABLE LINER

An impermeable liner provides a separation between the wastewater treated in the bed of the wetlands and the surrounding area. The liner prevents leakage and contamination of groundwater. The impermeable layer may consist of an on-site or imported clay layer. In areas with permeable soils, a synthetic membrane or concrete liner is used.

DISINFECTION

Constructed wetlands are adept at nutrient removal and suspended solids reduction. Like any treatment technology, the effluent from these systems should not be considered disinfected. Depending on the intended reuse application, additional disinfection by ozone, ultra-violet light or chlorine may follow constructed wetlands as a final stage in the treatment process.

TECHNOLOGY

Constructed wetlands are designed to filter and treat contaminated water in much the same way as natural wetlands. As wastewater enters into the constructed wetland, it is treated both aerobically and anaerobically. The submerged plant roots combined with the surfaces of the gravel particles or other planting medium provide a substrate for the microbial processes necessary for treatment. The level and rate of treatment is proportional to the size of microbe populations and the contact time within the system.

The combination of aerobic and anaerobic environments within a constructed wetland provides comprehensive treatment of wastewater, including removal of nitrogen and biological oxygen demand (BOD). These systems are typically designed to handle fluctuating flows and variable conditions without significant adverse effects on effluent water quality. Systems can be upgraded through the use of mechanical filters and ultraviolet disinfection to allow for water reuse applications.

Design variations for constructed wetlands include how the water flows through the system, either horizontally or vertically, and how the water is introduced, such as in a tidal flow or recirculating manner.

In a tidal flow wetland, the planting media in which the vegetation grows is completely flooded from below and then allowed to drain, maximizing the treatment capacity per unit volume. Whereas horizontal flow tidal wetlands are typically restricted to a depth approximating the root depth of the vegetation (typically about 3 feet), vertical flow tidal wetlands can be deeper and therefore require less land area than conventional systems.

In a recirculating flow constructed wetland, a pump is used to periodically recirculate effluent back into the wetland inlet for additional treatment. As the treated effluent accumulates in the basin, another wetland recirculation cycle begins. Recirculating vertical flow constructed wetlands can remove up to 99 percent of the fecal bacteria (E. coli) and over 80 percent of other wastewater constituents prior to discharge.[79]

FIT

Constructed wetlands are appropriate for projects at various scales and within a variety of climates. According to the U.S. EPA, constructed wetlands are best suited for upland locations and outside of floodplains to avoid damage to natural wetlands.[80] However, designers of these systems believe they are logical solutions in wetland areas when effluent is treated to high levels and used to recharge these ecosystems.

While space constraints can limit the application of constructed wetlands, subsurface flow systems are specifically engineered to maximize the amount of treatment capacity in a minimum amount of space — an essential component for utilizing them in more urban applications. Wetlands can also be constructed in multiple cells to allow for site constraints.

Research shows that these systems operate well even in cold climate conditions, though cold climate systems may require larger surface areas. Flexibility in their design allows constructed wetlands to be modified to meet specific site conditions or target specific pollutant loads. Research has shown that wetlands are also known to sequester metals and

79 Garcia-Perez, Alfredo, Don Jones, William Grant, and Mark Harrison. "Recirculating Vertical Flow Constructed Wetlands for Treating Residential Wastewater." Rural Wastewater. 8 Sep 2010.

80 US EPA. Wastewater Technology Fact Sheet. Wetlands: Subsurface Flow. 2000.

are an effective means of removing pharmaceutical compounds, making them an interesting option for hospitals and other sites where these substances are most prevalent. [81]

EFFICIENCY

Constructed wetlands are often less expensive to build than other wastewater treatment options because they are primarily passive systems. In addition, they also have lower operating and maintenance costs. Total expenses for subsurface systems can range from $10,000-$15,000 for an individual home. This cost can be lowered when coupled with composting toilets as the volume of wastewater generated is reduced by roughly 50 percent, thereby shrinking the required area of the constructed wetland. Costs often differ based on soil conditions, system loading and regulatory requirements.[82] Larger community-scale systems can realize lower costs based on economies of scale such as the residential cluster system installed at Lake Elmo, Minnesota, which costs approximately $5,700 per home.

Because it has no or few moving parts, constructed wetlands can be more durable than other mechanized systems used to treat wastewater, allowing for longer lifecycles and larger lifecycle cost benefits.

ADDITIONAL DESIGN CONSIDERATIONS

SIZING

Subsurface constructed wetlands can range in size from small on-site units to treat waste from individual homes or commercial buildings, to large community-scale systems serving entire neighborhoods. There are more than 100 such systems in the U.S. that treat municipal wastewater, the majority of which treat less than one million gallons per day.[83] Smaller-scale systems typically treat anywhere from several hundred up to 40,000 gallons per day. A typical residential single-family household system is roughly 300-400 feet^2 in size.

81 California State Water Resources Control Board. Review of Technologies for the Onsite Treatment of Wastewater in California. 2002.

82 Ibid.

83 US EPA. Wastewater Technology Fact Sheet. Wetlands: Subsurface Flow. 2000.

SYSTEM LOCATION

Depending on the size of the system, constructed wetlands can be located on a building site or in a centralized location serving multiple buildings. Where elevation allows, they can be located for gravity flow. Otherwise, pumps are required to convey effluent to wetland cells.

In cold climates, constructed wetlands may sometimes be enclosed in a greenhouse; however, it is not a requirement with properly designed systems such as those utilizing plants that fit the local climate. In fact, outdoor systems exist at altitudes of 10,000-ft in locations which receive no direct sunlight in winter and with temperatures routinely dropping to 40 degrees below zero for multiple days in a row.[84]

SYSTEM INTEGRATION

Constructed wetlands have the advantage of being a potential amenity on a project site by integrating the treatment system into the surrounding landscape design. Constructed wetlands can also be used to treat on-site stormwater runoff, improving water quality and protecting downstream receiving water bodies.

Images: Natural Systems International

A terraced, subsurface flow constructed wetland designed into the site landscape at Sidwell Friends School.

84 Communication with Whole Water Systems, LLC. www.wholewatersystems.com. October 2010.

CASE STUDY

EVA-LAXMEER HOUSING DEVELOPMENT

Location:	Culemborg, The Netherlands
Designers:	Atelier 2T Architects, Hospitality Concepts, V&L Consultants
Owner:	Ecological Centre for Education, Information and Advice (EVA)
Scale:	Neighborhood

The EVA-Lanxmeer project is a mixed-use housing development that includes 250 residential units, 40,000-m^2 of commercial office space, an urban farm and other community amenities such as restaurants and a hotel. Completed in 2009, the project is an international example of sustainable community planning. The project's design approach was strongly based on permaculture principles, demonstrating decentralized technologies for energy and water management and emphasizing resource recovery.

The community's integrated water management approach involves harvesting and storing rainwater and treating water and organic waste on-site for reuse. Rainwater is used for toilet flushing and washing machines to offset potable water demand. Household wastewater from kitchens and

laundry is routed through a series of on-site reed beds (helophytes) and purified through natural, biological processes. Human waste from toilets is dewatered and the solids are harvested for biogas production on-site.

The on-site biogas plant provides a source of energy and eliminates the development's need for a connection to the public sewage system. To increase the amount of solid substance in the fermenter, it was decided to combine green waste from the kitchen and sometimes from the garden with the solids. The output from the fermentation process is biogas, effluent and sludge. The sludge can be used immediately in the garden as compost. The effluent is further cleansed in the reed beds, then combined with greywater and stormwater and routed through extensive bioswales and infiltration ditches that provide open space and habitat on the site. The water is withdrawn for crop and landscape irrigation, and all water eventually returns to the city aquifer.

Occupants residing in the development are responsible for maintaining the health and performance of the integrated water management system. Regular meetings and information exchanges for residents are held to provide education on the system and the types of household products that can harm its biological balance. The system relies on a high level of commitment from residents for ongoing maintenance and long-term success.

CASE STUDY

SIDWELL FRIENDS SCHOOL

Location:	Washington, D.C., USA
Architect:	Kieran Timberlake Associates, LLP
Engineer:	Natural Systems International
Landscape Architect: Andropogon Associates	
Owner:	Sidwell Friends School
Scale:	Commercial

The Sidwell Friends School, located in the historic Tenleytown section of northwest Washington, D.C., was the first certified LEED-Platinum K-12 school in the United States. Completed in 2006, the project included a 39,000-sf addition and partial renovation of the existing school building. The school is committed to fostering an ethic of social and environmental responsibility in all students and demonstrating a thoughtful relationship between the built environment and the natural world.

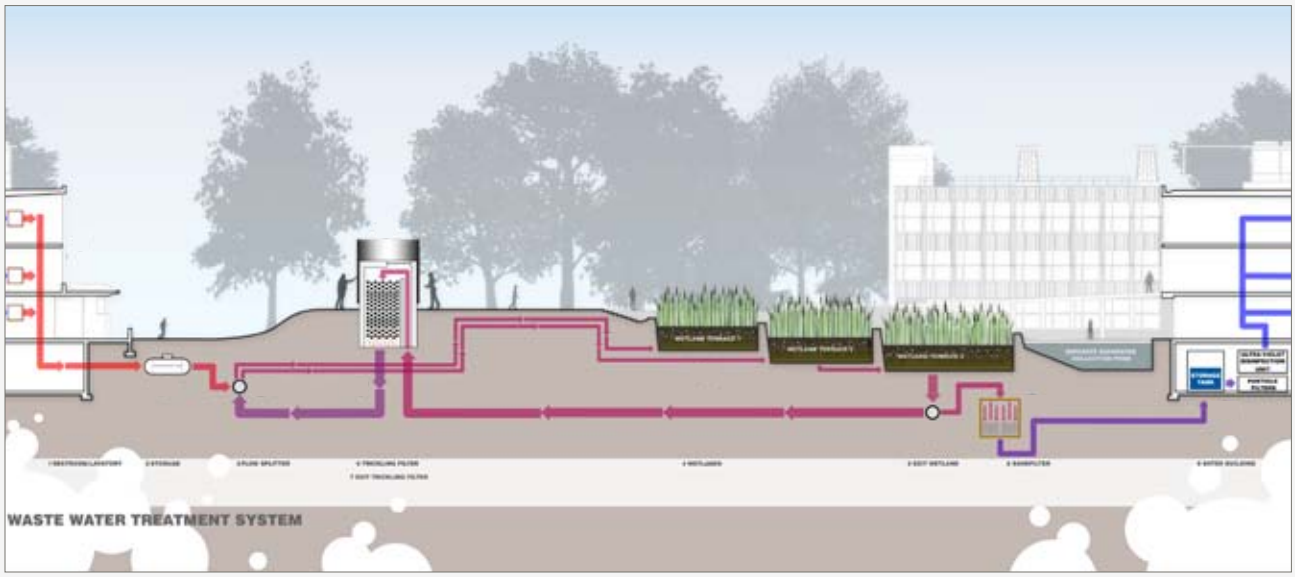
Rainwater falling on the site is collected and channeled through a constructed wetland where

Images: Andropogon Associates

waterfalls aerate the rainwater before it enters the biology pond. Overflow from the biology pond spills into a rain garden where the water is infiltrated to allow ground water recharge.

In addition, 100 percent of the wastewater from the building is routed through a terraced, subsurface-flow constructed wetland designed into the site landscape. The system includes a primary treatment tank for anaerobic breakdown of solids, a trickling filter and a series of tiered, gravity-fed constructed wetland cells where microorganisms and wetland plants help break down contaminants in the water. It then re-enters the building and is disinfected using ultraviolet light prior to reuse. Water from cisterns is used to replenish water levels in the wetland during dry spells to ensure optimal performance.

It takes approximately four days for the wastewater to navigate through the constructed wetland before entering an underground storage tank. The naturally-treated water is then reused on-site for toilet flushing and in cooling towers, reducing the building's use of potable water by 93 percent. Local authorities require regular water quality monitoring of the wastewater system and less frequent groundwater testing to ensure that the system is functioning as planned. Sidwell's students and faculty conduct most of the monitoring and testing, hiring consultants as needed.



RECIRCULATING BIOFILTERS

Biofilters are among the oldest technologies used for the biological treatment of wastewater.[85] These systems consist of chambers packed with highly porous materials such as plastics or rock. The media in the chamber provides growth surfaces for an active microbial community to treat the water. Biofilters are sometimes referred to as intermittent filters, packed bed filters, attached growth or fixed film processes.

SYSTEM COMPONENTS

CONTAINER

A container is used to house the support medium necessary for the attached growth treatment process. These containers are typically made from concrete, plastics or fiberglass.

SUPPORT MEDIUM

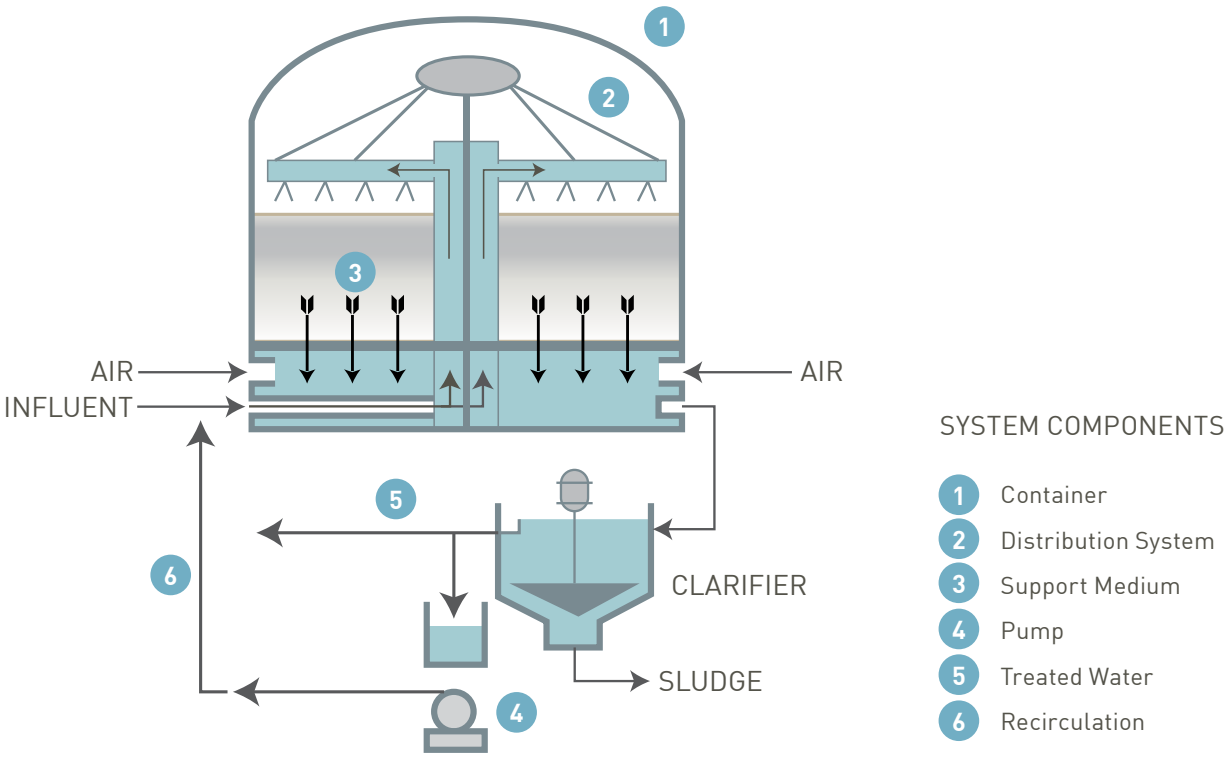
The support medium housed in the container defines the biofilter type. A variety of organic, granular or synthetic materials can be used, such as sand, gravel, crushed glass, expanded aggregates, slag, peat moss, wood chips, rubber, fabric or open-celled foam. The type of materials utilized in biofilters are typically chosen for their surface area, porosity or infiltration capacity characteristics. The medium supports the microbial community within the treatment system.

DISTRIBUTION SYSTEM

A distribution system is used to apply wastewater to the biofilter in such a way to support optimal performance of the system. Several distribution methods can be used, such as orifice systems, spray systems and gravity or pressure-driven dosing systems. The distribution method is dependent on the infiltration capacity of the support medium. For pressure-driven distribution, pumps or dosing syphons may be used. Control systems can be designed to dose the biofilter either on a timed or an on-demand basis as wastewater is generated.

85 California State Water Resources Control Board. Review of Technologies for the Onsite Treatment of Wastewater in California. 2002.

FIGURE W-3: RECIRCULATING BIOFILTER



COLLECTION SYSTEM

The collection system harvests the treated water and either recirculates it back into the biofilter for further treatment or carries it to separate mixing tanks or soil adsorption areas. The collection system can be a simple effluent drain located under the active biofilter medium. In some cases it is separated from the active medium by a coarse layer of gravel or rock to limit migration of the biofilter material.

TECHNOLOGY

Biofilters utilize an attached growth microbial aerobic process to treat wastewater. In these systems, post-primary settled water is sprayed over the top of the biofilter chamber and the wastewater percolates through the media. This simple process effectively oxidizes and reduces harmful chemical wastewater constituents. Oxidative reactions generally take place near the top of the open-air filter chamber. Oxygen concentrations are consumed by

aerobic bacteria and gradually decrease with filter depth. Anaerobic conditions near the base of the chamber provide effective reductive conditions.

An older type of biofilter technology is known as an intermittent sand filter. These systems utilize an open-air tank filled with sand. Without the use of chemicals, they can produce high-quality effluent that can then be used for drip irrigation. Energy requirements for these systems are generally low and their modular designs make system expansion or retrofitting feasible. Additionally, they can be integrated into the surrounding landscape. Disadvantages include the land area required and the potential for odor from the open-air tanks.[86] Intermittent sand filters have come under scrutiny due to an inability to service a system after an upset or overload and extensive maintenance requirements. In response, proprietary systems have been developed to minimize plugging tendencies and simplify maintenance efforts.

Biofilters can be single pass systems or recirculating (multi-pass) systems. In a single pass system, the wastewater is applied only once before being collected and conveyed to other treatment tanks or dispersal systems. Recirculating systems are designed to repeat application of the wastewater across the biofilter before it is released. In these systems, the return flow is combined with untreated wastewater from the septic tank or primary settling tank, diluting the influent introduced into the system. Recirculating systems can be smaller in size as compared to single pass systems due to the increased hydraulic loading rate. They also require more energy for pumping and controls, whereas single pass systems can use little or no energy (gravity flow systems).

Recirculating biofilters are an extremely robust method of waste treatment. Long-term performance testing has shown they can handle overloading conditions (up to double design capacity) for several months before water quality begins to degrade. These systems are typically controlled remotely by telephone/internet, making remote monitoring and adjustment possible. They are capable of attaining an advanced secondary and tertiary wastewater standard that is upgradable to a water reuse standard by the addition of a tertiary filter and ultraviolet light disinfection. In addition, effluent odors are eliminated and dissolved oxygen concentration is enhanced in the recirculation process.

FIT

Biofilter technology can be applied to individual residential projects up to the community scale. Proprietary models are engineered for commercial and industrial applications. Due

86 US EPA. Wastewater Technology Fact Sheet: Intermittent Sand Filters. 1999.

to their reduced footprint size and ability to provide a reliable and high level of treatment, recirculating biofilters have often been used in areas not conducive to the traditional drainfield applications, such as places with poor permeability, high groundwater, shallow soils and limited drainfield area.

EFFICIENCY

Recirculating biofilters can range in cost from $3,000-$10,000 for the biofilter alone, with septic settling tank and dispersal systems adding additional costs.[87] Pumps and electrical components can be assumed to have at least a 10-year life span. Ongoing maintenance of the system is required to keep filters clean and functioning properly, though the level of effort required varies greatly across systems.

ADDITIONAL DESIGN CONSIDERATIONS

SIZING

Sizing and space constraints can be a limiting factor for biofilter technologies. Recirculating systems have a typical surface area footprint of 100 square feet for an individual home, while proprietary models such as the Advantex system can be as small as 3 feet x 7.5 feet.[88] Larger systems require approximately one square foot of land for every 25 gallons treated per day, making them more compact in size than passive subsurface flow constructed wetlands but less compact than packaged membrane bioreactors.

SYSTEM LOCATION

Placement of biofilters is dependent on the type of system. They can be installed above ground, partially buried or fully buried. High groundwater, setbacks for open-air tanks and the size of the system will generally dictate where a biofilter is located on a project site or within a community. Self-contained units can also be located within the building envelope.

SYSTEM INTEGRATION

Biofilters located above ground can be hidden from view but offer few opportunities for being truly integrated into landscape features.

87 California State Water Resources Control Board. Review of Technologies for the Onsite Treatment of Wastewater in California. 2002.

88 Ibid.

CASE STUDY

ROCKY BAY

Location:	San Juan Island, WA
Engineer:	Orcas Sewage Design
Owner:	Homes for Islanders
Scale:	Residential

Residents of Rocky Bay, an affordable housing project in Friday Harbor on San Juan Island, moved in after spending more than a year contributing sweat equity to build their homes in 2007. Eight homes are thoughtfully clustered on this 4.87-acre property. They share a well for potable water and a compact, on-site wastewater system accommodates the inevitable fluctuations that occur with a varying number of users. The recirculating biofilter they selected requires system users to be thoughtful about what they contribute to the system. No toxics of any sort are to be dumped down the drain.

The AdvanTex®-AX20 recirculating biofilter system was sized for a 26-bedroom development with 120 gpd flow per bedroom. These systems are typically designed at reduced flows with safety factors built in to more accurately model real use. Grossly over-sized systems are typically less efficient.

Orcas Sewage Design Company designed a waste treatment system for Rocky Bay that processes 3,120 gpd peak flow. The AdvanTex®-AX20 Treatment System selected is known for its ability to handle excessive loads for short durations, making it a good choice for a cluster-housing development. The potential for occasional increased loads did require an additional 48-LF of laterals in the drainfield.

Household wastewater is sent to eight septic collection tanks located just outside each home. The two four-bedroom homes were outfitted with 1,500-gallon tanks and the six three-bedroom homes received 1,000-gallon tanks. The effluent pumping system discharges primary treated effluence through a common main to the recirculating biofilter. The collected solids are broken down by micro-organisms in the tank substantially reducing volume. The system operator annually monitors the accumulated solids

and has them pumped as needed, about once every 8-10 years.

The AdvanTex®-AX20 system is a secondary treatment process using aeration and filtration, similar to municipal treatment levels. At Rocky Bay the effluence is pumped to the 4,000-gallon recirculation tank which is calibrated to pass the influent through the six pods and about 4 times before pumping the effluent to the dosing tank which discharges to a drainfield with 12 lateral trenches 54-ft. long by 3-ft. wide.

Vericomm, a web-based monitoring system, tracks each home in Rocky Bay and watches for inconsistencies in system function and flow to enable an early response if necessary. If influent waste strengths were to exceed those listed in the plan, efforts would need to be made to reduce the input strength or expand the system to increase capacity.

Images: Rick Petro, Orcas Sewage Design

MEMBRANE BIOREACTORS

The suspension of wastewater and the organisms used to treat the water in an aerated tank is referred to as an activated sludge process. Membrane bioreactors (MBRs) are packaged activated sludge systems in which the secondary clarifier has been replaced with an ultra-filtration membrane with pores small enough to filter out bacteria, micro-organisms and other insoluble solids. The result is a high-quality effluent without the need for further downstream tertiary treatment systems.

SYSTEM COMPONENTS

PRETREATMENT AND AERATION CONTAINERS

Processing tank containers typically include a primary separation chamber for pretreatment/settling and an aeration chamber. Aeration chambers are sized to provide sufficient volume for contact with the microbial biomass. Some small- to medium-sized systems do not require a separate pretreatment tank. Fine screens, typically 1-3mm, are located in the containers after primary settling and before the membranes to prevent clogging.

MEMBRANE

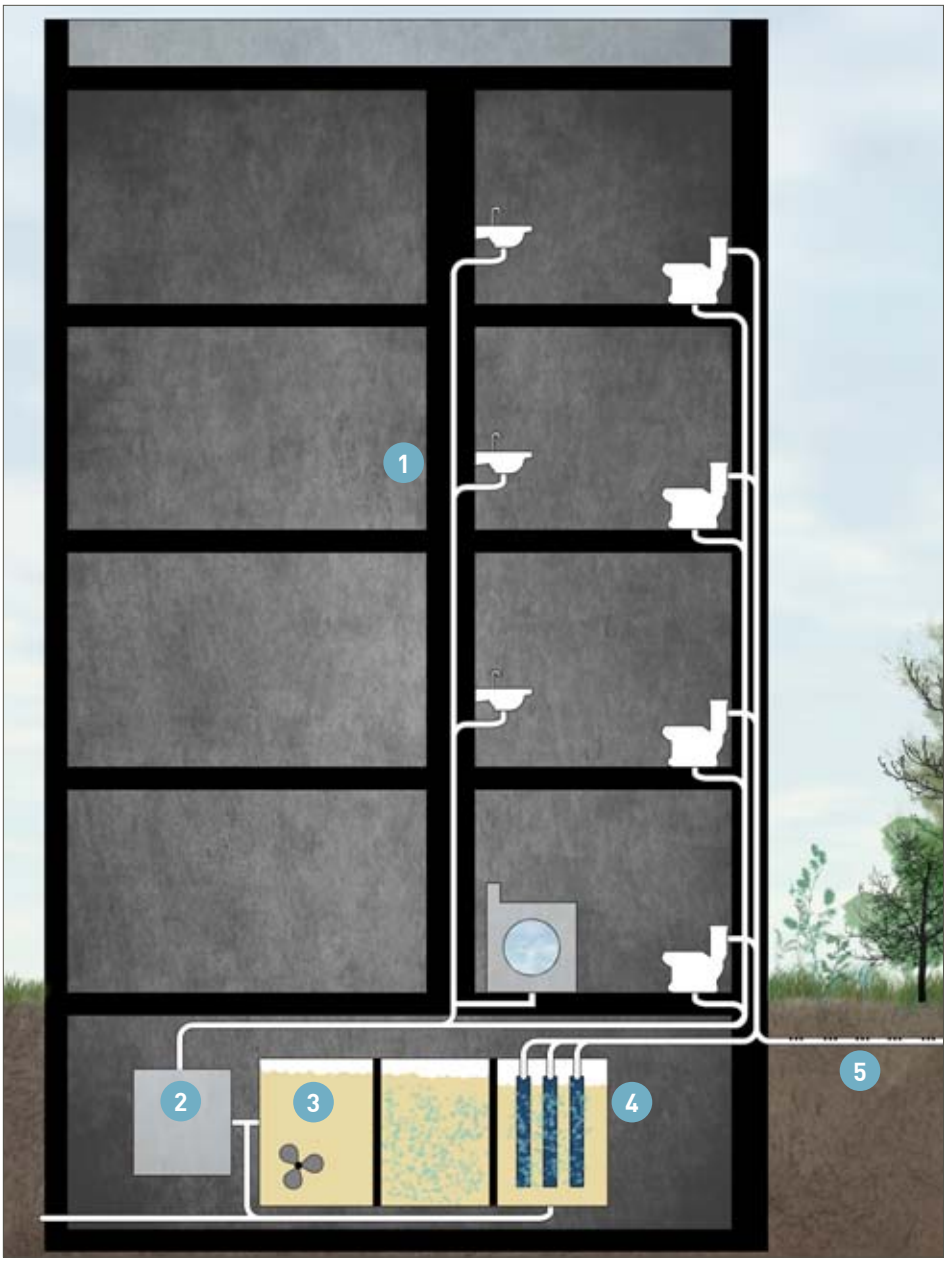
MBR membranes are porous and typically consist of cellulose or other polymer materials. Membranes are configured as hollow fibers grouped in bundles or as flat plates and designed to be easily removed for servicing and replacement. Pumps are used to force wastewater through the membrane.

TECHNOLOGY

MBRs are activated sludge systems with fine filters to prevent solids release, allowing these systems to maintain a higher concentration of bacteria compared to conventional activated sludge systems. MBRs are capable of producing high-quality effluent similar to secondary clarification and microfiltration. The ability to eliminate secondary clarification has a number of benefits, such as shorter hydraulic retention times, less sludge production, simultaneous nitrification and denitrification, low effluent concentrations and comparatively smaller footprint then other conventional treatment technologies.

The process consists of a conventional extended aeration activated sludge process in which the secondary clarifier has been replaced by an ultra-filtration membrane. The membrane

FIGURE W-4: MEMBRANE BIOREACTOR



SYSTEM COMPONENTS

1. Collection System
2. Pretreatment
3. Aeration
4. Membrane
5. Distribution System

pores are typically 0.1 to 0.5 microns in size to inhibit bacteria, micro-orgasms and other insoluble solids from passing through. This eliminates the need for downstream clarification and filtration. However, the pore size is not a complete barrier to viruses, so disinfection is still required.

Advantages of MBRs include high effluent quality, small space requirements and ease of automation. The primary disadvantages of MBR processes are the high cost of membranes, high energy demand, solids management, and the potential for membrane

fouling. Membrane manufacturers use several techniques to prevent fouling, including coarse air scrubbing and chemical treatment.

FIT

MBRs have a small footprint in comparison with other distributed technologies, making them an alternative for both building and campus-scale treatment systems. Because MBRs produce a high-quality effluent, they can be suitable for applications where the treated water will be reused on-site. However, projects pursuing high performance energy use reductions may find that MBRs are not a feasible strategy.

EFFICIENCY

Initial capital costs as well as ongoing operations and maintenance costs for MBR systems are typically much higher than for other wastewater treatment options. Installed costs can range from $7 - $20 per gallon treated.[89] The expected life of a membrane is typically only 7

The Convention Center in downtown Vancouver, British Columbia, houses a membrane bioreactor designed to treat 20,000 gallons of wastewater generated by the facility each day. All of the building's treated wastewater is recycled onsite for flush fixtures and to irrigate a six-acre green roof.

89 US EPA. Wastewater Management Fact Sheet. Membrane Bioreactors. 2007.

to 8 years, and may be considerably shorter depending on the propensity of the wastewater to produce fouling conditions.

MBRs require greater operator attention as compared with other distributed treatment options, and have considerably higher energy costs. Where these systems are used to treat water for reuse applications within buildings or at the community scale, their lifecycle costs may be offset by the reduction in potable water.

ADDITIONAL DESIGN CONSIDERATIONS

SYSTEM LOCATION

Due to their small footprint, MBRs have the most flexibility in where they can be located on a project site. Their need for frequent inspection and maintenance requires that they be located for easy access.

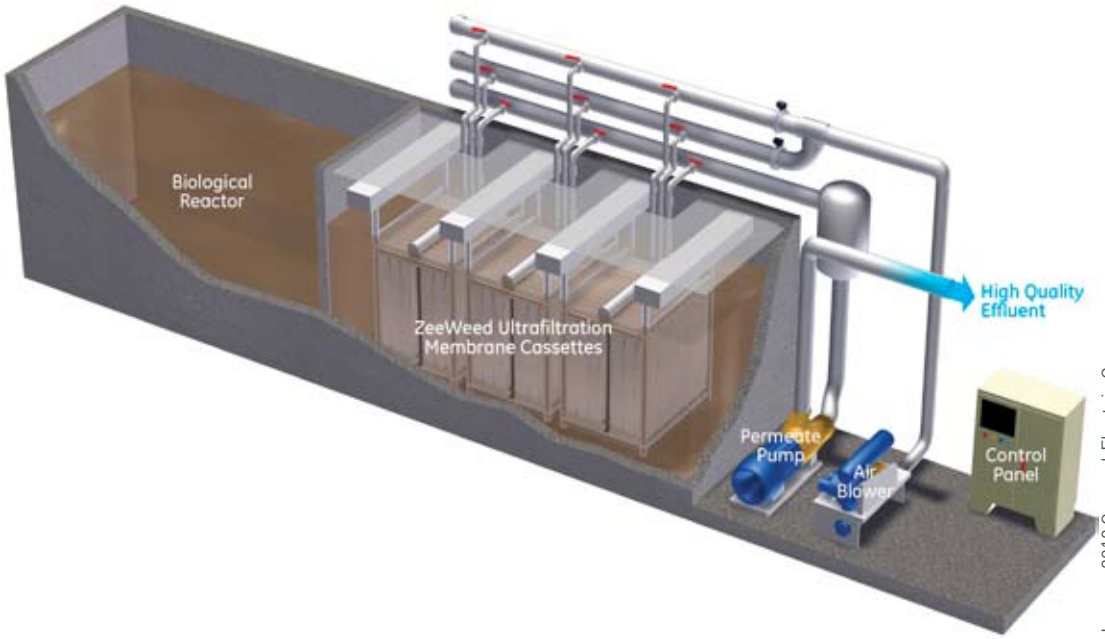


Image: 2010 General Electric Company

The GE ZeeWeed membrane bioreactor treats wastewater to high quality standards for reuse.

CASE STUDY

COUNCIL HOUSE TWO

Location:	Melbourne, Australia
Designer:	Design Inc., City of Melbourne
Scale:	Commercial

Completed in 2006, Council House Two (CH2) is a 10-story, 12,500-m^2 office building housing City of Melbourne staff. The building features high-performance energy and water-efficient design strategies through a variety of integrated systems, and demonstrates innovative ways in which buildings can achieve the City's goals set forth by their Total Watermark Policy. This policy calls for aggressive targets for water conservation, alternative water supplies and wastewater reductions to reduce the community's potable water use by 40 percent per capita by 2020.

CH2 is designed to offset potable water use by more than 70 percent through high-efficiency fixtures and the use of recycled water. Additionally, a total of 25 percent of the overall potable water demand is provided by capturing, storing and reusing clean discharge water from the building's fire sprinkler pumps. This water, traditionally sent to the sewer, is instead reused at sinks and showers.

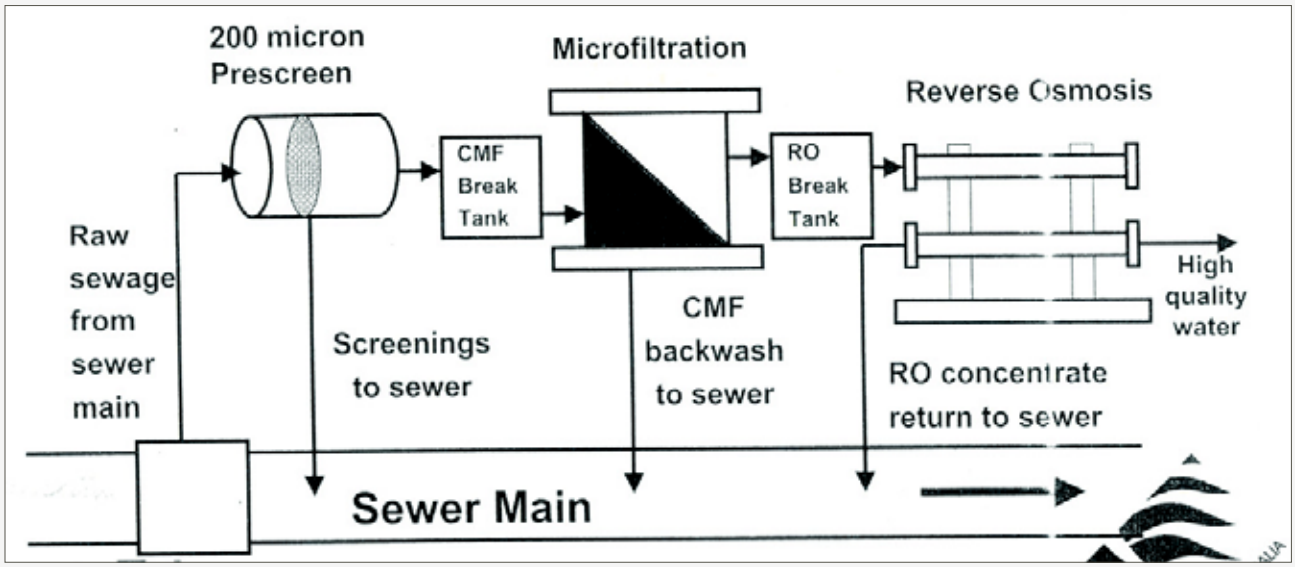
Wastewater from the building is treated for reuse on-site in a Multi-Water Treatment Plant, owned and operated by the City of Melbourne and located in the building's basement. The system treats both greywater and blackwater generated by the building's sinks, showers and toilets, in addition to sewerage that is mined from a municipal sewer adjacent to the CH2 site. Sewerage is typically made up of 95 percent water. By capturing and treating this water, CH2 is demonstrating that

municipal sewers can be a valuable source of nonpotable water.

The Multi-Water Treatment Plant includes three stages of filtration. First, wastewater is pushed through a micron-sized screen and the solids are sent to the city's sewer system. The remaining effluent is passed through a ceramic ultra-filtration screen and finally through a reverse osmosis process. The cleansed water is dosed with chlorine in the final stage to create Class-A reclaimed water. The recycled water is used for toilet flushing, roof garden irrigation and cooling towers.

The treatment system has the capacity to process 100,000 liters per day. CH2 uses approximately 45 percent of the on-site treated water, while the remainder is used by Council House 1 for street cleaning and landscape irrigation. The system has been designed to be flexible enough to alter the amount extracted and processed to meet fluctuating water demands of the building. The system payback is estimated at 15-20 years.

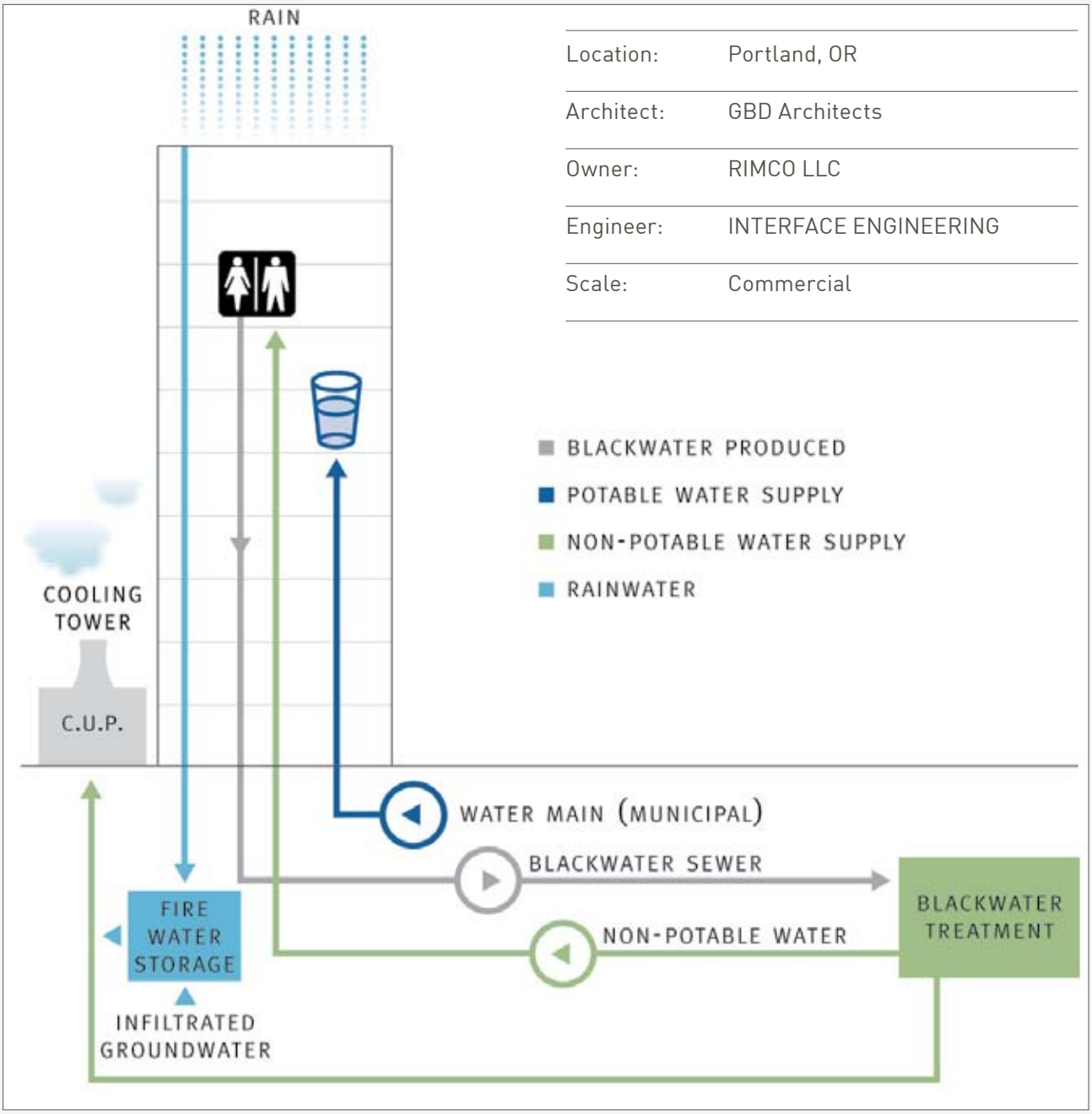
Rainwater is harvested from the roof and stored in a 15-kiloliter (approx. 4,000-gallon) cistern, also located in the basement. The rainwater is used in conjunction with the treated wastewater for irrigating green roof and living walls.



CASE STUDY

OREGON HEALTH AND SCIENCE UNIVERSITY
CENTER FOR HEALTH AND HEALING

Image: Walker Macy



Location:	Portland, OR
Architect:	GBD Architects
Owner:	RIMCO LLC
Engineer:	INTERFACE ENGINEERING
Scale:	Commercial

Image: INTERFACE ENGINEERING

The Center for Health and Healing was developed as a "spec med science facility" and was one of the largest LEED NC-Platinum projects in the nation in 2006. The 398,000-sf facility covers 20 blocks of Portland's South Waterfront neighborhood. The structure hosts a wide range of uses, from specialized offices to laboratories that tend to use a lot of water.

This OHSU building reduces, reuses and recycles all water on-site. Low-flow fixtures were installed in sinks, toilets/urinals and showers throughout the building. A 22,000-gallon cistern below the building also doubles as a source for fire suppression. Nearly one-half million gallons of rainwater are collected from the roof annually. Recovered groundwater due to a high water table provides radiant cooling in certain portions of the building. Greenroofs and the on-site membrane bioreactor process all water that moves through the site.

The Enviroquip, Inc MBR, located on the ground floor of the parking structure, treats wastewater to nearly Class 4 (drinking water) standards. This mini sewage treatment plant provides both anaerobic and aerobic treatment of wastes, before final filtering through Kubota flat-plate membranes and ultraviolet disinfection. The system is connected to the local sanitary sewer for emergency discharge purposes only. Sewage solids are sent to the city sewage system as needed through a batch release system. Membranes should be cleaned out about twice a year. The system can handle 35,000 gpd or an average of 1,600 daily users.

Treated water is combined with rainwater for use in flushing the building's core toilets/urinals, cooling tower makeup water or irrigation. Excess treated water is discharged through a bioswale that drains to the Willamette River. The complex water system reduces potable water use by more than 49 percent — a savings of roughly 5.5 million gallons annually and a cost savings of $27,000 per year compared to a similarly sized conventional building. OHSU estimates the system will pay back its initial costs in about 10 years.

OHSU contracts Vision Engineering to operate the plant. i.Water Services, Inc. was hired to obtain, hold and maintain the State DEQ permit plus a Federal NPDS permit for discharging 15,000 gpd to a federal waterway.

Image: Kimberly Mathis

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FUTURE RESEARCH

During the process of researching and compiling this report, the Cascadia Green Building Council uncovered extraordinary amounts of useful information and sources of data on topics related to best practices for water systems in buildings and neighborhoods. Much of the groundbreaking research comes from countries such as Australia, where diminishing water resources has been at the forefront of political and cultural conversations.

The concept of net zero water buildings requires a major shift in the mindset of how buildings are conceived, designed, built, regulated and operated. Despite the wealth of existing research, it is evident that much more information and on-the-ground demonstrations are needed to help shift conventional practices toward a more sustainable future with respect to our water resources. Additionally, the research needs to be credible and accessible to project design teams, regulatory agencies and policy makers to support and empower the next generation of innovate water projects.

Additional research is needed in the following areas.

PUBLIC HEALTH AND SAFETY

Current codes and regulations exist to safeguard human health and welfare and to ensure access and availability of clean water supply and wastewater treatment to all people. Alternative strategies to conventional supply and treatment — specifically those not currently supported by regulations — lack the same level of institutional consideration for their impact on safety and welfare. Opportunities exist for regulatory agencies at all levels to evaluate risks to public health and safety beyond what is currently mandated by codes, including risks associated with climate change, resource depletion, diminishing water quality and pollution prevention. Additional research is needed to evaluate public health and safety risks so that agencies can assess smaller-scale, distributed water systems

as they relate to improved resiliency and economic sustainability of existing centralized systems.

LIFECYCLE ASSESSMENT

Lifecycle assessment investigates the environmental impacts of a product or system throughout its life, including those associated with raw material extraction, manufacturing, transportation, construction, operations, maintenance and repair, and ultimately end-of-life disposal. Lifecycle assessments can provide valuable data when applied to net zero water systems. Environmental impacts associated with supplying fresh water to a building or development and conveying and treating wastewater offsite are rarely quantified, likely because the process of doing so is complex and time consuming for project teams. As a result, the design and building industry often lacks a comprehensive understanding of water supply and treatment systems of the community in which they are building. Accessible data on lifecycle impacts would help project teams make more informed decisions when determining the most appropriate water systems for the project.

Cascadia is currently working on a lifecycle assessment of centralized wastewater treatment and its associated conveyance requirements versus various small-scale, distributed treatment technologies. This research will provide valuable missing data on how decentralized and centralized systems compare to each other when considering the environmental impacts of the manufacturing, construction and operations phase of each system. Research results are anticipated to be published in April 2011, and will ultimately be used to develop a guidance document for policy makers and water utilities making decisions about infrastructure.

CHLORINE DISINFECTION

Research has shown links between chlorine disinfection byproducts and cancer, particularly bladder cancer. Currently, water regulations place greater emphasis on the public health risks associated with microbial presence in our drinking water than the risks associated with chlorine and the harmful byproducts it produces when it reacts with organic matter found in water.

While it is understood that chlorine disinfection plays an important role in our current centralized water supply paradigm, net zero water projects seeks to source their water supply from on-site sources through captured precipitation, groundwater or on-site reclaimed water. As such, residual chlorine necessary for conveyance in centralized systems can be replaced by alternative disinfection methods. Best practices for disinfection of on-site water sources, such as ozone and ultraviolet radiation, may be more appropriate and less harmful to people than chlorine. However, federal regulations currently do not

allow these. Further research is needed on evaluating the health risks associated with chlorine disinfection within the context of on-site water supply.

CLIMATE CHANGE AND RESILIENCY OF WATER SUPPLY

According to the International Panel on Climate Change (IPCC), all regions of the world show an overall net negative impact of climate change on water resources and freshwater ecosystems.[90] Awareness around the risks associated with climate change and the uncertainty it poses to the resiliency of future water resources is growing. Yet water consumption in the United States remains at unsustainable levels, regulations impede innovative water reuse strategies in buildings and the market has been slow to introduce new technologies aimed at aggressive conservation.

Further information and education is needed to better understand the impacts of climate change on our water resources. A better understanding of how net zero water design strategies help address resiliency and passive survivability will likely result in more support for these types of systems from a regulatory standpoint.

BEHAVIORAL WATER USE

Per capita water use in the United States is extraordinarily high compared to use in other countries in the world. Our wasteful habits reflect cultural norms related to water use and a lack of education related to global water issues. Accessible information and greater awareness on the amount of water needed for our everyday needs, such as energy or food production, will likely influence our behaviors around water use.

Net zero water projects are designed based on assumptions about how building occupants will use water. Changes in building occupancy, temporary or long term, or adaptive reuse of existing buildings could influence the ability of the project to stay within its intended water budget. Because of this, regulatory agencies tend to caution against the variability associated with on-site water capture to meet 100 percent of a building's water and waste treatment needs, and backup or redundancy of these systems is typically required. Further research and understanding of occupant water use behaviors in net zero water buildings can help shed light on how to best address design and regulatory considerations related to fluctuating use.

90 Intergovernmental Panel on Climate Change, 2007

WATER QUALITY

Current regulatory and cultural barriers to widespread acceptance of smaller-scale, distributed water and wastewater systems stem from the perception that these systems have inferior capabilities for meeting water quality standards. The perception is that control of water and waste systems by centralized utilities reduces public health risks and that oversight of decentralized systems, when left to homeowners or building maintenance staff, will inevitably fail. Poorly designed, operated and maintained septic systems are largely to blame. However, there is rising concern about public and environmental health risks associated with aging centralized infrastructure, leaky pipes, combined sewer overflows and the detection of pharmaceuticals, hormones, caffeine and other chemicals showing up in our water.

Increasingly and throughout the country, the media report on drugs such as antidepressants, hormones and other chemicals found in local drinking water supplies downstream of wastewater treatment facilities. Research has both highlighted the potential dangers of these chemicals in our water supply on humans and wildlife, and disregarded them as significant risks to public health based on their low concentrations. Credible research is critical to understanding how these chemicals impact water quality and health. Research data on the effectiveness of small-scale, distributed wastewater systems in handling pharmaceuticals, hormones and other chemicals should be increased and made available to policy-makers and water utilities around the country.

URBAN AGRICULTURE

Roughly 40 percent of the U.S. fresh water supply is used for agriculture. Traditionally, the availability of fresh water sources piped in for irrigation has provided a means to support large-scale agricultural production in areas with low rainfall. For multiple sustainability reasons, there has been a recent shift toward smaller-scale, local agricultural practices and weaving agriculture into urban planning. As a result, the need for agricultural irrigation changes in several ways: how it is supplied, from what sources and in what quantity.

As project design teams consider urban agriculture at the building, campus or neighborhood scales, balancing available water sources and water demand budgets become increasingly important. Additional research is needed to fully understand the impacts of water use and opportunities for water reuse in urban agriculture settings.

GLOSSARY

Biophilic is used to describe human preferences toward the natural world.

Blackwater is water containing solid and liquid wastes from toilets and urinals.

Closed-loop water systems are systems in which all water used on a project is captured, treated, used/reused and released within the boundaries of the project site.

Coliform is a commonly-used bacterial indicator of sanitary quality of water.

Decentralized or distributed water systems are on-site or neighborhood-scale systems used to collect, treat, and disperse or reclaim water from a small service area.

Disinfection byproducts are formed when disinfectants used in water treatment plants react with bromide and/or natural organic matter (e.g. decaying vegetation) present in the source water. Different disinfectants produce different types or amounts of disinfection byproducts. Disinfection byproducts for which regulations have been established have been identified in drinking water, including trihalomethanes, haloacetic acids, bromate and chlorite.

Effluent is the outflowing of water from a treatment process discharged into a receiving water body.

Evapotranspiration is the process by which water evaporates into the atmosphere from plants and ground surfaces.

Full cost pricing of water is reflected in utility pricing that recovers the costs of building, operating and maintaining a water system.

Greywater is wastewater discharged from sinks, showers, laundry, drinking fountains, etc., but not including toilets and urinals. Light Greywater is water from bathroom sinks, shower, bathtub, laundry, drinking fountains and equipment condensate. Dark Greywater is water from kitchen sinks and dishwashers.

Groundwater is a fresh water supply that is located beneath the surface of the ground and is suitable quality for all types of uses.

Infiltration is the process by which precipitation or irrigation water infiltrates naturally into the ground in landscape areas, recharging groundwater sources.

Potable water meets the U.S. EPA's drinking water quality standards and is approved by state and local authorities as fit for human consumption.

Rainwater is precipitation harvested from roof areas that is collected and stored on-site. With appropriate levels of treatment, rainwater can be reused for a variety of nonpotable and potable purposes including drinking, irrigation, washing, and flushing toilets and urinals.

Reclaimed water is wastewater that has been treated to a standard at which it can be safely reused for a specific beneficial purpose such as irrigation or toilet flushing.

Stormwater is precipitation that falls on the ground surfaces of a property. Stormwater runoff flows over the surface of the site and into sewer systems or receiving water bodies.

Water balance is a numerical account of how much water enters and leaves the boundaries of a project. Water balance seeks equality between supply volume and building demand, and is a key aspect in designing a net zero water project.

Wastewater is water that has been tainted by human activities during residential, commercial or industrial uses.

Wastewater treatment is the process of removing or reducing hazards in water and typically includes some of all of the following steps:

> ***Primary treatment*** – physical treatment process, with or without chemical assistance; some heavy metals removed
>
> ***Secondary treatment*** – a process that removes dissolved and suspended solids by biological treatment and sedimentation; biodegradable organics, volatile organics, some nitrogen and phosphorus removed
>
> ***Tertiary treatment*** – such as filtration, membrane filtration, and detention in lagoons or wetlands; usually combined with coagulation, sedimentation, filtration and disinfection; more removal of nitrogen and phosphorus, dissolved solids and heavy metals.

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