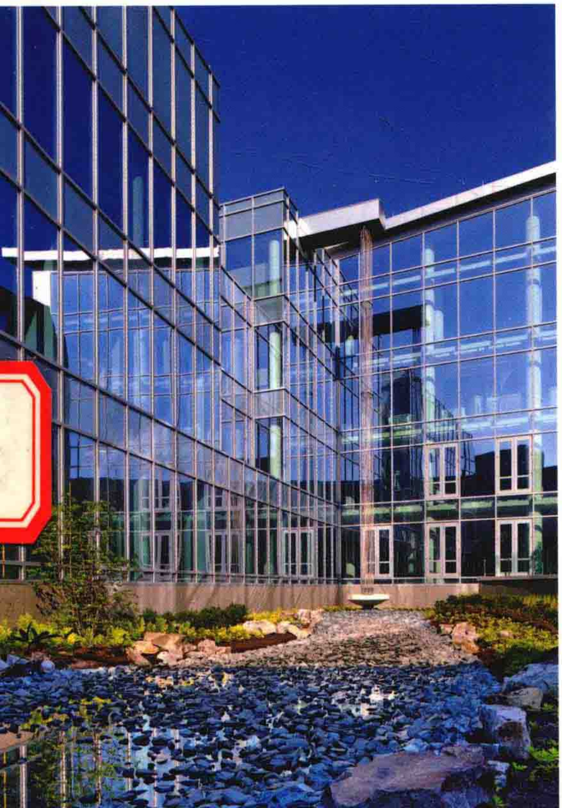


DESIGNING **RAINWATER HARVESTING** SYSTEMS

Integrating Rainwater into Building Systems



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Cover Design: Michael Rutkowski
Cover Photography: Top left: Lake|Flato Architects; Top middle: Vivian Van Giesen;
Top right: KMD ARCHITECTS + PLA, a Joint Venture; Bottom: Alan Karchmer, Courtesy of HOK

This book is printed on acid-free paper.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey
Published simultaneously in Canada

Library of Congress Cataloging-in-Publication Data:

Novak, Celeste Allen.
Designing rainwater harvesting systems: integrating rainwater into building systems / Celeste Allen Novak, FAIA, LEED AP, Eddie Van Giesen, ARCSA AP, Kathy M. DeBusk, PhD.
pages cm
Includes index.
ISBN 978-1-118-41047-9 (hardback); 978-1-118-42188-8 (ebk); 978-1-118-41786-7 (ebk)
1. Water harvesting. 2. Sustainable buildings—Design and construction. 3. Cisterns—Design and construction. 4. Sustainable architecture. I. Van Giesen, Eddie. II. DeBusk, Kathy M. III. Title.
TD418.N68 2014
628.1'42—dc23

2013038062

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

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Preface

G. EDWARD (EDDIE) VAN GIESEN

August 2013

After receiving my Masters in Landscape Architecture from the University of Georgia in 1995, I worked as a self-employed design/build landscape and general contractor and home-builder in Athens, Georgia. I always incorporated green building practices, and received local sustainable building awards, but I knew that I could do more.

In 2007, we were all on the edge of the deepest economic recession that any of us could remember. I had an eerie suspicion that the housing boom was resting on a foundation of loose sand. By the end of the summer, homebuilding, as I knew it, was over. The profession that I had enjoyed for ten-plus years was not there anymore. I was forty-six years old and suddenly out of business.

At the same time, along with the economic recession, Georgia and much of the Southeastern United States was in the grip of an extreme drought. Due to the State's increasing population, the effects of this drought were significantly amplified. Either we were all going to have to find other sources of water for the region or we would be increasingly vulnerable to water scarcity.

I did a lot of soul-searching in those months. I reflected on a trip made to Northern California in 2001, and a workshop I attended on rainwater harvesting. I read a few books on the subject, but little did I know that in only six years I would embark on the greatest adventure of my life.

I discovered that rainwater harvesting could be an answer to our water woes. It was a no-brainer. Rain falls on the roof; it is collected and utilized. Simple, easy, and sensible. Shortly thereafter, I stumbled upon the American Rainwater Catchment Systems Association (ARCSA). Through ARCSA I came to know people who had experience and generously shared their knowledge. I did not need to reinvent the wheel.

I began to install systems on a small scale and eventually worked with a company in North Carolina. By 2010, that company was bought by Watts and I joined them as the public policy director. Later I became the National Sales Manager and through my travels, I have had the opportunity to see the bigger picture. There is an enormous potential yet to be realized. Two things became abundantly clear: (1) education is essential for all the parties involved in these systems, and (2) plumbing codes need to be developed so that the industry can have a foundation upon which to build.

The opportunity to educate the design community through this book resonated with me when I was approached to be a co-author.

It was a chance to establish and reinforce the fundamental principles of rainwater collection, as well as illuminate the connections between water policies, codes/regulations, and new and existing technologies.

Everyone involved—architects, engineers, landscape architects, mechanical contractors, manufacturers, suppliers, policy makers, code officials, and others—needs to see the importance of their respective roles as part of the practice of wise use of rainwater. It is my sincere hope that this collaborative effort will contribute to an increase in awareness and implementation of successful rainwater harvesting systems.

KATHY DEBUSK

August 2013

It was during a canoe trip along the James River near Richmond, Virginia, that I discovered my true calling in life: stormwater management. While paddling past the heart of downtown Richmond one summer, my father and I were caught in a surprise thunderstorm. The short, yet intense, storm resulted in the discharge of urban runoff into the river just upstream of where we were floating. Not only did this water have a foul odor, but it was filled with a tremendous amount of trash and debris. Then and there, I decided that I wanted to become a part of the effort to decrease the impact of urban runoff on valuable water resources such as the James River.

It wasn't until many years later, after a bachelor's and master's degree in engineering at Virginia Tech, that I was exposed to rainwater harvesting. One of my first design projects as an Extension Associate at North Carolina State University was a rainwater harvesting system for an animal shelter in Craven County. It was love at first sight. I continued to design and research rainwater harvesting systems throughout my stay at NCSU, and even made rainwater harvesting the focus of my doctoral research.

Rainwater harvesting is a unique creature, unlike any other. From a water supply perspective, it challenges our country's largely centralized approach to water supply and use. This brings about many uncertainties and unknowns, which leads to a widespread hesitancy regarding the implementation and use of these systems. From a stormwater management perspective, rainwater harvesting systems are the only best management practices (BMPs) that serve an important supplementary goal—that of water supply. Moreover, rainwater harvesting systems contain more moving parts than any other stormwater BMP currently used. Together, these factors greatly increase the design complexity of these systems, the number of project stakeholders, and the necessary maintenance requirements, thus generating hesitancy within the stormwater industry to exploit the full potential of these systems. The result? Inconsistency, confusion, and a profound lack of knowledge regarding the potential benefits of these systems.

Consequently, it seems predestined that someone would recognize the need for a compilation of current knowledge regarding these practices to serve as an all-inclusive source for any person dealing with rainwater harvesting. Celeste and Eddie recognized that need and had the courage and passion to embrace such a daunting task. My hat goes off to them, and I thank them for including me. I couldn't be more honored and delighted to have been part of this effort, and I sincerely hope that the result is a valuable resource for design professionals. I learned countless lessons the hard way when designing, installing, and utilizing these systems, and if my experiences can help one person avoid the same mistakes, then it was worth every sleepless night.

CELESTE ALLEN NOVAK

August 2013

Water surrounds Michigan and our State motto *Si quaeris peninsulam amoenam circumspice* translates to "If you seek a pleasant peninsula, look around you." It is true; we are surrounded by three of the five Great Lakes. With at least one-quarter of the world's freshwater supply, there are enough rivers, inland lakes, rain, and snow to fill our aquifers and water my garden. So, why am I, a native of Michigan, so concerned about water use and rainwater harvesting?

It is the storage and treatment of waste and stormwater control that drives many of the systems described in this book, not necessarily the lack of freshwater. However, as an architect and advocate for the environment, I know that a growing population largely removed from natural cycles threatens water resources across the world. The notion that we can find new ways to live within the means of the world's environmental envelope appeals to me as a common-sense solution to a growing problem. I also know that there is a gap between policy and practice that restricts professionals from tapping into (pardon the pun) rainwater as a natural resource.

As one of my students asked after being given the simple calculations for schematic planning for rainwater harvesting: "If rainwater design is this easy, how come architects are not doing this on every project?" It's a good question and one that will be addressed in this book on planning for rainwater harvesting in building systems. As also will be discussed, not every project in every community can include rainwater harvesting. Some solutions will require new policy and code changes, some will require new types of community or neighborhood water collection and treatment. Most solutions will require the construction and maintenance of a self-sufficient decentralized water system for part of a building water supply. In some countries, rainwater collection is a strategy that can provide water as part of a disaster assistance program. In the future, it may be possible to design schools, stores, and community centers to collect, store, and treat water in order to provide a resilient water resource in times of drought. It is my belief that future buildings will be designed to collect rainwater and designers will create a new hydrologic system that restores water as it flows through the environment.

Acknowledgments

The authors draw from strong backgrounds on the subject. Celeste Allen Novak, AIA, is an architect, writer, and adjunct professor at Lawrence Technological University who specializes in sustainable design. G. Edward Van Giesen, MLA, National Sales Manager at BRAE/WATTS Water Technologies, has extensive experience in the design and implementation of rainwater systems. He has been instrumental in developing new rainwater codes and standards nationwide. Dr. Kathy DeBusk, PhD, PE, and Assistant Professor of Environmental Science at Longwood University in Farmville, Virginia, has just completed a thorough examination of rainwater quality and treatment, providing one of the first published international overviews of this global resource in communities. Contributing authors include Viviane Van Giesen, Graphic Designer, who along with Dr. Jim Novak, PhD, has offered countless hours of editing, design, and support. Fred Smotherman, BLA, has drawn from his perspective and knowledge of the construction of rainwater systems to provide information on components and maintenance. Many thanks to Cedric, Ian, and Isabella Van Giesen for their patience and hours of work transcribing interviews.

Finally, special contributions by Dr. Diana Glawe, PhD, PE, LEED AP, Associate Professor at Trinity University in San Antonio, Texas, provided the most recent information on the use of condensate; and Nicole Holmes, PE, LEED AP, provided an excerpt describing the factors involved in cistern sizing. In addition, a special thanks to researchers Azubeke Ononye, a graduate student from Lawrence Technological University, and Jacquie McDermott-Kelty, currently at the University of Michigan. Others who were significant in the development of this book include the following: Robert Goo, Office of Water, USEPA, who provided contacts for this book; Dolly Patel and Preeta John, both young architects who provided information and contacts from India. To these and to all of the architects and professionals who provided images, interviews, case study data, and constructive criticism, the authors give thanks.

CHAPTER 1

The Importance of Rainwater Harvesting

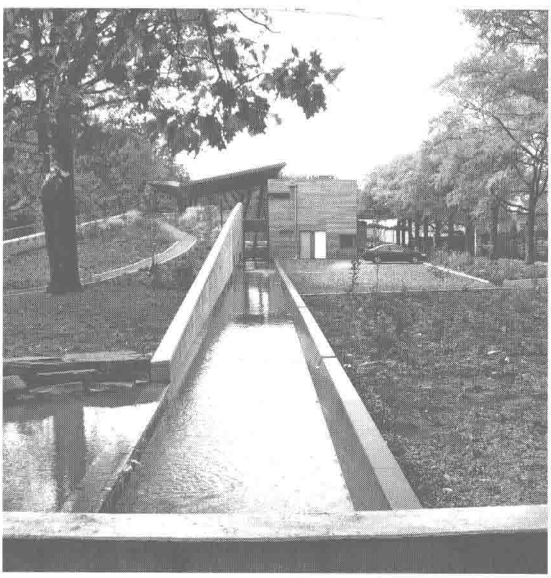

Figure 1.1 Queens Botanical Garden Visitor and Administration Center is an example of integrated rainwater harvesting system design.

Rain water harvesting and conservation aims at optimum utilization of the natural resource that is Rain Water, which is the first form of water that we know in the hydrological cycle and hence is a **primary source** of water for us. The Rivers, Lakes, and Ground Water are the secondary sources of water. In present times, in absence of Rain Water harvesting and conservation, we depend entirely on such secondary sources of water. In the process it is forgotten that rain is the ultimate source that feeds to these secondary sources. The value of this important primary source of water must not be lost. **Rain water harvesting and conservation means to understand the value of rain and to make optimum use of Rain Water at the place where it falls.**

—India: Rain Water Harvesting and Conservation Manual[1]

WATER CAPITAL

Water is the only commodity on Earth for which there is no economic substitute. Seventy-five percent of the Earth's surface is covered in water, yet only 2.5 percent of it is suitable for human consumption. Of that 2.5 percent, most is locked in polar ice caps or hidden beyond the reach of commercial technologies.[2] All life forms on the planet depend on water to survive. Simply stated, water is the basis for all life on Earth.

The more technologically advanced humans become, the more water is consumed on a per capita basis. Electricity use within a typical home requires 250 gallons (almost 1,000 L) of water per day per person; the manufacturing processes of computer chips, televisions, and cell phones require water, and the production of a half-gallon (roughly 2L) bottle of soda can take over 1.3 gallons (5 L) of pure water.[3] Even the production of food requires tremendous amounts of water, as producing 1 pound (0.5 kg) of chicken and 1 pound (0.5 kg) of beef requires over 1,600 gallons (6,000 L) of water![4] Historically, an abundance of water, as well as water scarcity, has affected both the growth and decline of every civilization. History teaches that finite water resources need to be managed with the utmost care.

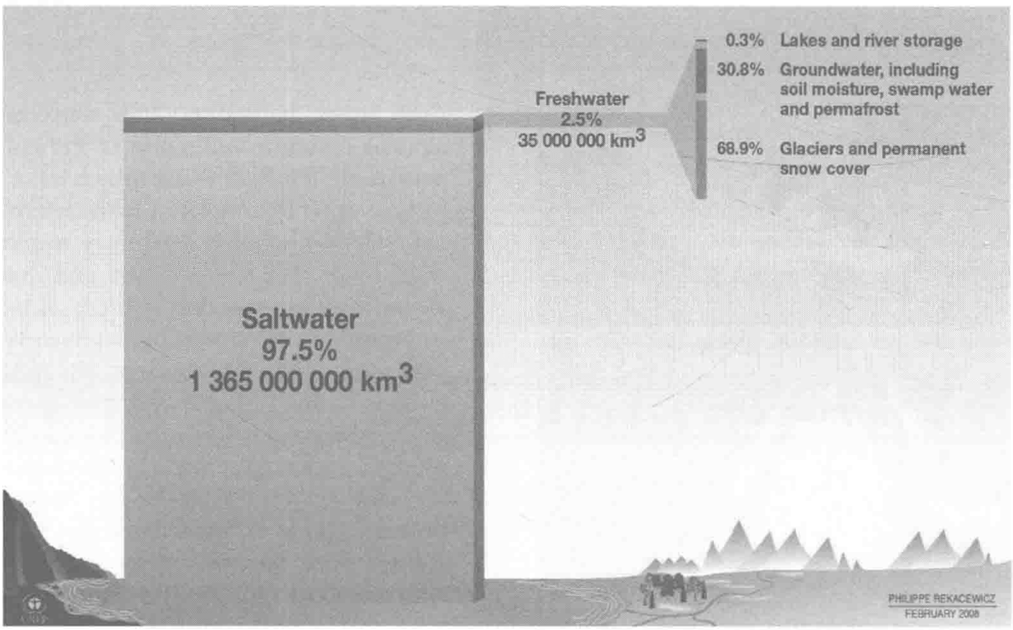

Figure 1.2 EARTH A Graphic Look at the state of the world[5] (*Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999. Image courtesy of UNEP.*)

As profound as our dependence on water is, there is an equally profound lack of knowledge concerning where water comes from and how it is best and most efficiently used as a public and private resource. According to the Environmental Protection Agency (EPA), the following statistics underscore the challenges faced by architects, engineers, and public policy makers as they face looming freshwater shortages:

- The average American directly uses 80 to 100 gallons of water each day, but supporting the average American lifestyle requires over 1,400 gallons of water each day.
- Agriculture is the largest consumer of freshwater: worldwide, about 70 percent of all withdrawals go to irrigated agriculture.
- Only 1 percent of the world's freshwater is accessible to humans.
- Forty percent of America's rivers and 46 percent of its lakes are too polluted to support fishing, swimming, or aquatic life.
- Power plants in the United States use 136 billion gallons of water per day, more than three times the water used for residential, commercial, and all other industrial purposes.[6]

In addition, scientists and researchers are describing a "peak water" crisis for water use throughout the world. As a response to these issues, professionals are developing new strategies to conserve and effectively use water resources.

Peak Water

The planet is getting thirstier as a growing worldwide population is using fresh water resources. Dr. Peter Gleick, president of the Pacific Institute, has coined "peak water" as a description for the world's water crisis. This concept describes the lack of sustainably managed water throughout the world, just as "peak oil" refers to the lack of oil reserves globally. According to Dr. Gleick, there are three major definitions for peak water. These are:

- *Peak Renewable Water:* The limit reached when humans extract the entire renewable flow of a river or stream for use.
- *Peak Non-Renewable Water:* Groundwater aquifers that are pumped out faster than nature recharges them—exactly like the concept of "peak oil." Over time, groundwater becomes depleted, more expensive to tap, or effectively exhausted.
- *Peak Ecological Water:* The point where any additional human uses cause more harm (economic, ecological, or social) than benefit. For many watersheds around the world, we are reaching, or exceeding, the point of "peak ecological water."[7]

The design challenge is to reverse the direction of peak water so that it is not a linear loss of water, but a regenerating system that allows humans to participate in the continuation of the hydrologic system.

One response to the water supply challenges is the re-creation of one of the world's oldest water supply systems: *rainwater collection*. Rainwater collection, or rainwater harvesting, involves the capture of water from roofs and/or impervious/pervious surfaces. The roofs of buildings, schools, offices, large data distribution centers, and agricultural buildings can serve as the contributing drainage area for a given system. Once captured within the rainwater harvesting system, the quality of the runoff water may be improved via physical and biological processes including filtration, disinfection, and other treatment strategies. New approaches in plumbing design are using site-collected rainwater/stormwater to provide all or part of a building's and its site-related water needs. This results in a reduction of stormwater runoff volumes leaving a site, while at the same time providing a new source of water to reduce the burden on potable water supplies.

Water conservation and stormwater management are two of the most effective sustainable design practices available to architects and engineers. Rainwater collection conforms to the goals and objectives of low-impact development, which aims to mimic the predevelopment site hydrology by using site design techniques that store, infiltrate, evaporate, and detain runoff.[8] Reducing the runoff from storm events via rainwater harvesting strategies provides benefits to property owners, including lower municipal fees and larger developable site area, and contributes to the big-picture goal of reducing the impact of urbanization on receiving water bodies.

Rainwater collection is becoming one of the many tools used by sustainable design professionals. Sustainable building rating methods and performance guidelines are influencing the development of rainwater harvesting systems. Projects throughout the world are demonstrating that rainwater collection systems can solve some of our water-related problems. Rainwater systems are meeting the challenges of water conservation while demonstrating the effectiveness of alternative nontraditional water supplies. There are numerous benefits to this approach for the conservation of the world's most valuable natural resource.

Figure 1.3 At the Queens Botanical Garden, rainwater is a valuable resource. (*James Wasley/ Atelier Dreiseitl*)

Low Impact Development

Until the 1960s, the philosophy of stormwater management was to dispose of the water as quickly as possible from urban areas to the nearest receiving water.[9] Extensive underground piping networks were used to convey runoff from parking lots, roadways, and buildings and discharge it into the closest stream or river. As the negative impacts of discharging stormwater runoff and wastewater into surface waters became apparent, the focus shifted to encompass water quality concerns as well, initiating what is now considered traditional stormwater management.[10] The major components of a traditional stormwater system are concrete curbs and gutters, drop inlets (catch basins), underground pipe networks, and detention/retention basins. The majority of modern developments, both residential and commercial, utilize curb and gutters to convey stormwater runoff from impervious surfaces (such as parking lots and roadways) to drop inlets, which are connected to extensive networks of underground pipes that carry the water to large detention or retention basins.

The use of retention and detention basins addresses some water quality and quantity concerns; however, there are detriments associated with their implementation. While retention ponds can reduce peak flows to some extent, recent research has shown that the outflow is often released at rates exceeding that, which can be absorbed by receiving streams, resulting in erosion of the streambed and banks.[11] Furthermore, basins are designed to release outflow longer than the duration of the storm event, thereby causing a prolonged state of erosion within the stream.[12] Detention and retention basins can also increase the temperature of captured stormwater due to exposure to sunlight and the shallow pool depth. The introduction of this warm water to cold-water streams can be detrimental to biota, especially trout.

The optimal approach to minimizing hydrologic impacts from an urbanizing watershed (as opposed to traditional stormwater management) is through the implementation of low-impact development (LID) principles and practices during the planning and construction phases of development. The overall goal of LID is to "mimic the predevelopment site hydrology by using site design techniques that store, infiltrate, evaporate, and detain runoff.[13]" Unlike the traditional stormwater management paradigm, the LID approach encompasses all aspects of watershed hydrology, including runoff peak flows and volume as well as the temporal and spatial distribution of runoff events.[14]

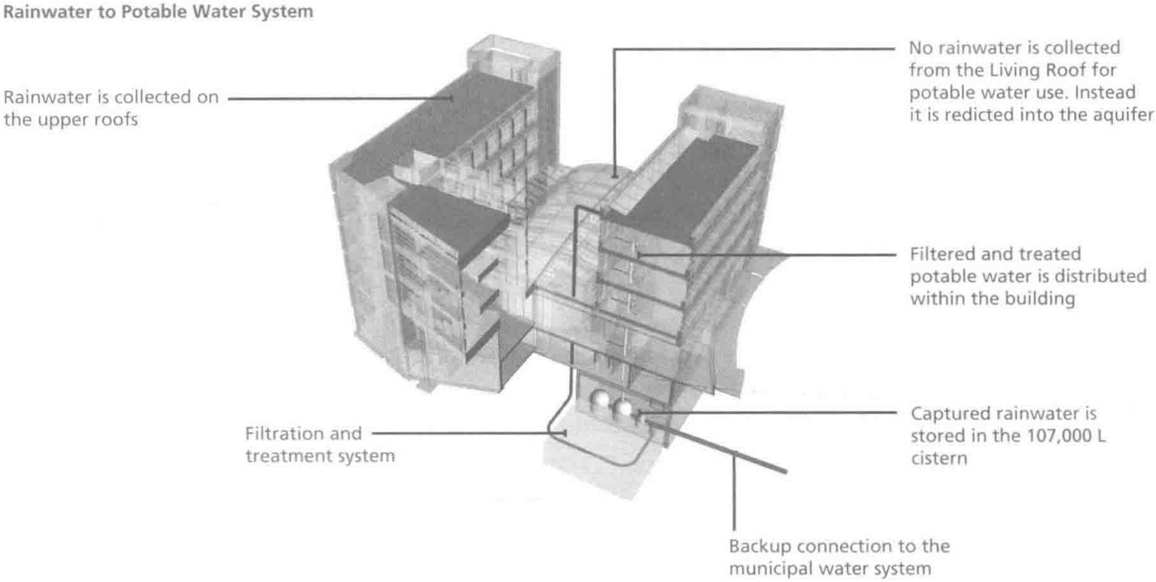

Figure 1.4 Designed by Perkins+Will, the Centre for Interactive Research on Sustainability integrates rainwater collection, graywater reuse, and water treatment for building potable water to meet the Living Building Challenge™. (*Diagram Courtesy of Perkins+Will*)

A BRIEF HISTORY OF CENTRALIZED WATER SYSTEMS

Most conventional water sources include groundwater from shallow or deep wells, rivers, and lakes (natural and manmade). Humans depend on these sources and their replenishment via the hydrologic cycle. Through the input of energy from the Sun, water moves from the Earth's surface to clouds and back to the Earth's surface again. Water is in constant motion in the hydrologic cycle.

Populations have always grown where there is adequate water. In addition to gathering water from surface sources and wells, the use of cisterns has been documented in many cultures. As far back as 3000 BC, stone structures for capturing rainwater have been found in India.[15] Large cisterns and canals carved in rock for transporting roof-collected rainwater are found in Petra, Italy, dating from roman times.[16] Aqueducts constructed by the Romans were also early efforts at providing centralized water systems to concentrated populations. Other examples are found worldwide, including irrigation strategies for agriculture.

Over the centuries, small and large communities have faced continual successes and failures in securing adequate sources of clean freshwater for daily activities. Problems in securing these sources include:

- Overuse, as populations and uses increase;
- Contaminants from human waste as well as commercial/ industrial/agricultural activities.

The effect of poor sanitation, lack of control over purification systems, and major health

Figure 1.5 Tang Dynasty leader Li Jing (571–649 AD) praised this cistern as being a "Smart Spring." It was "full of water when drought came and it was dry when the flood came."[17] (*Celeste Allen Novak, Architect*)

crises of waterborne diseases in the 19th century, particularly in urban environments, led to the current centralized water systems. Along with the need to provide water for the increased demand associated with the industrial boom, population growth demanded even more water for human needs.

In the early 1900s, the development of successful chlorination methods for disinfection of water led to further expansion of controlled water supply in the United States.[18] Centralized systems in use today throughout the developed world provide a standard level of safe, treated drinking water through a continuous loop that extracts water from lakes, rivers, and aquifers and then treats and distributes the water to the end users.

As described in a recent publication on climate change, "Urban water systems have evolved into large highly engineered systems in which water is imported from surrounding catchments and aquifers, distributed through extensive pipeline networks and used just once. Most of the used water is then collected in large sewerage systems, treated to remove contaminants and nutrients and discharged back to rivers and oceans."[19]

Once in place, that water infrastructure is largely taken for granted by the public and policy makers alike. Over the decades, the focus has been primarily on expanding the infrastructure to accommodate growth at the expense of maintaining the aging original infrastructure. According to the EPA, the aging water infrastructure is one of the United States' top water priorities.[20] The impacts of delayed maintenance, budget cuts, and disinvestment in aging infrastructure have become a 21st century political, economic, and social crisis.

The original water infrastructure in many urban centers (in the United States and worldwide) is more than 100 years old. Lisa Jackson, former EPA administrator, highlights the current state of deterioration of this infrastructure. In "Water Infrastructure" (October 2010), she writes: "An issue we face is deferred maintenance in our [water] infrastructure, which in too many communities is over-worked and

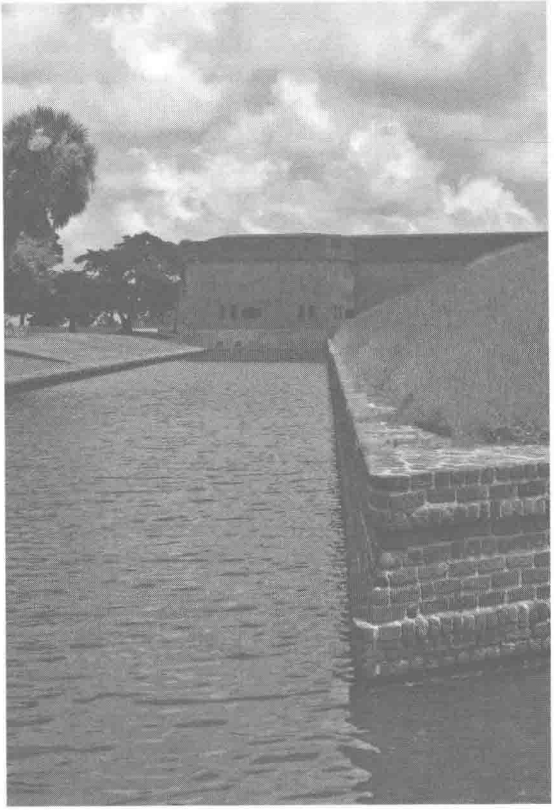

Figure 1.6 Fort Pulaski National Monument in Georgia provides an example of a historic rainwater collection system. Ten brick subterranean cisterns incorporated into the structure of the fort were capable of storing 200,000 gallons of fresh water. After the capture of the Fort, in 1862, Union soldiers supplemented the natural supply with a steam condenser which converted the moat's saltwater into freshwater. (*Eddie Van Giesen*)

under-budgeted. Our system is deeply stressed, our financial and our natural resources are limited and our needs are not negotiable."[21] This report defines one of our current national problems: We are facing costly upgrades and repairs to an aging water infrastructure that includes drinking water and wastewater treatment facilities.

In the last 100 years, with the exponential increase of manmade impervious surfaces, the hydrologic cycle has been interrupted and impacted by industrialization, mechanization, and population growth. The result is an alarming increase in stormwater discharge velocities and volumes, causing a paradoxical shortage of freshwater resources. This shortage is caused not by a reduction of the amount of water, but rather contamination and pollution of the available water due to floods, erosion, and sewage overflows.

Some alarming statistics in the EPA report include an estimated 240,000 water main breaks per year and up to 75,000 sanitary sewer overflows per year in the United States, resulting in the discharge of 3 to 10 billion gallons of untreated wastewater into our waterways.[22] Each leak wastes water and increases the costs associated with treatment and distribution. Sanitary sewer overflows discharge polluted water downstream, causing environmental damage. At the same time, pollution compromises downstream community water supplies.

Nevertheless, new regulations and policies that promote centralized water distribution are still being encouraged to the exclusion of all other decentralized approaches in many parts of the world. One of the barometers of the economic health of a country is the degree to which centralized drinking water and sewer systems are present. Countries that lack functioning centralized water distribution systems continue to look to the developed world as a source for inspiration and technical knowledge. Inadvertently, the developed world is leading their technological disciples toward their own water shortages. However, some countries, like India, Singapore, Australia, and New Zealand, are rethinking their policies toward centralized water systems and developing new approaches to water use and reuse.

New Approach to Centralization—Decentralized Rainwater Systems

U.S. cities with hundred-year-old utilities are beginning to address the creation of new municipal water systems. For example, the City of Chicago has slated over $1.4 billion in investment into fixing the leaks in aging water mains and eroding sewer systems. Chicago's improvements include the replacement of 900 miles (1,450 km) of century-old water pipes, repairing 750 miles (1,200 km) of sewer lines, reconstructing 160,000 catchbasins, and modernizing Chicago's water filtration plants. The upgrades could save an estimated 170 billion gallons (645 million m^3) of water by 2020, or close to all the water that Chicago households consume in two years, according to Chicago's Mayor Rahm Emanuel.[23]

A recent vision for a new Chicago water system was provided by UrbanLab, the winner of the City of the Future Competition in 2011. UrbanLab described a city that could become a "holistic living system that would multiply and intensify Chicago's 'Emerald Necklace' of parks, boulevards and waterways; and saving, recycling and 'growing' 100 percent of its own water."[24] Water infrastructure (drinking and waste) is being viewed as part of a living system.

Eco-Boulevard by Martin Felsen, AIA

Chicago, Illinois

Chicagoans discard over 1 billion gallons of Great Lakes water per day. This "wastewater" never replenishes one of the world's most vital resources. As a remedy, this project re-conceives the Chicago street-grid as a holistic Bio-System that captures, cleans, and returns wastewater and storm-water to the Lakes via "Eco-Boulevards."

The Eco-Boulevard transforms existing roadways, sidewalks, and parks (the "public-way"), which comprise more than a third of the land in a city such as Chicago, into a holistic, distributed, passive bio-system for recycling Chicago's water. Treated water is returned to the Great Lakes, closing Chicago's water loop.

Eco-Boulevards are ecological treatment systems that make use of natural bioremediation processes to remove contaminants from storm-water and wastewater sources. In the proposal, two types of bio-systems are at work: Type A and Type B. Type A is a hydroponic bio-machine that uses aquatic and wetland ecological processes to treat wastewater naturally. These processes are carried out in reactor tanks in enclosed greenhouses. Type B is a wetland bio-system that uses constructed wetlands and prairie landscapes that use low energy processes to biologically filter storm-water naturally.

Re-designing Chicago's non-sustainable water infrastructure will have a profound impact because the Great Lakes are a global resource holding 21% of the world's, and 84% of North America's, fresh surface water. Water availability is becoming a key global issue as water scarcity/pollution and climate change bear down on the planet. Even in the comparatively water-rich Great Lakes region, global warming could ultimately create urban flooding, frequent droughts and a scramble for water. Implementing blue/green infrastructure that safeguards ecosystem health