Capturing Rainwater from Rooftops: An Efficient Water Resource Management Strategy that Increases Supply and Reduces Pollution

NOVEMBER 2011

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ACKNOWLEDGEMENTS

NRDC would like to acknowledge and thank: Environment Now, the Sidney E. Frank Foundation, the Pisces Foundation, the Resources Legacy Fund, and the TOSA Foundation for their generous support of our work.

This report received substantial input and review from a number of individuals. Their participation contributed greatly to the quality of the report and its conclusions and recommendations. We acknowledge that they may not necessarily endorse all of the report's recommendations. In particular, the authors wish to thank our peer reviewers: Abby Hall, U.S. Environmental Protection Agency; Dr. Robert C. Wilkinson, Donald Bren School of Environmental Science and Management, University of California at Santa Barbara; and Katherine Baer, American Rivers.

The authors would like to thank Alexandra Kennaugh for managing the production of the report, Jon Prinsky and Sue Rossi for the design and production. The authors would also like to thank the Low Impact Development Center, Inc., and their colleagues Barry Nelson, Ed Osann, Karen Hobbs, and Larry Levine for their expertise and guidance.

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EXECUTIVE SUMMARY

Many communities in the United States face serious threats to a safe, steady supply of water. These include a longstanding reliance on centralized water delivery systems that results in urban areas and agencies largely overlooking opportunities to integrate alternate local sources of water to meet their water supply needs; the unnecessary use of potable water for non-potable uses, such as outdoor landscape irrigation and indoor toilet flushing; climate change; and continually increasing areas of impervious surfaces in our landscape that result in stormwater runoff carrying pollution to our rivers, lakes, and beaches. Although the problems of water supply and water pollution can be complex, practical solutions for both are available now, such as capturing and using rainwater from rooftops.

Rooftop rainwater capture is a simple, cost-effective approach for supplying water that promotes sustainable water management. By using rainwater rather than allowing it to run off of paved surfaces to pick up pollutants and carry them to nearby surface waters. The practice provides numerous benefits:

- Inexpensive, on-site supply of water that can be used for outdoor non-potable uses with little, if any, treatment, or for a variety of additional uses including potable supply with appropriately higher levels of treatment
- Reduced (or no) energy and economic costs associated with treating and delivering potable water to end users because capture systems often use low-volume, non-pressurized, gravity fed systems or require only the use of a low power pump for supply
- Reduced strain on existing water supply sources
- Reduced runoff that would otherwise contribute to stormwater flows, a leading cause of surface water pollution and urban flooding

Water quality and its potential impact on human health is a consideration when using rooftop rainwater capture. While rooftop runoff may contain pollutants, these pollutants are generally found in significantly lower concentrations and without many of the toxic contaminants that may be picked up by the rooftop runoff *after* it mobilizes off-site and flows over other impervious surfaces such as streets and parking lots. Overall, limiting rainwater use to non-potable applications such as toilet or urinal flushing, or hose bibs (or wall spigots) for irrigation water "presents little human health risk," according to the U.S. Environmental Protection Agency.[1] With proper care, rooftop rainwater capture can be a useful part of a holistic 21st Century water policy.

Rooftop runoff, often referred to as 'clean runoff' may contain pollutants, but "generally in lower concentrations and absent many of the toxics present in runoff from other impervious surfaces." – U.S. EPA Municipal Handbook on Rainwater Harvesting Policies

NRDC analyzed the total volume of rooftop rainwater potentially available for capture and use in eight U.S. cities, as well as the volume of water potentially available for use under various capture, storage and usage scenarios. The analyses shows that the volume of rainfall falling on rooftops, if captured in its entirety, would be enough to meet the annual water supply needs of between 21 percent and 75 percent of each city's population. Even under conservative assumptions, the study demonstrates that each city modeled can capture hundreds of millions to billions of gallons of rainwater each year, equivalent to the total annual water use of tens to hundreds of thousands of residents.

NRDC's study shows that a substantial opportunity exists to use rooftop rainwater capture as an efficient, effective water resource management approach.

Several institutional barriers need to be addressed for rooftop rainwater capture to provide maximum benefit. In many locations, the use of rainwater is prohibited or is limited to outdoor non-potable uses, such as residential irrigation, for which it is generally accepted that little or no treatment of the rainwater is required. However, with proper treatment, the use of rainwater for indoor non-potable uses, such as toilet flushing, represents a substantial opportunity for the more efficient use of water resources. Yet few municipalities have defined standards and criteria for using rainwater for non-potable indoor applications, and overlapping or contradictory regulations and requirements of multiple agencies can make the use of rainwater overly complicated. NRDC recommends several policy options and incentives to promote rooftop rainwater capture and lower the barriers for the practice:

- Adopt stormwater pollution control standards that require on-site volume retention and allow rainwater harvesting and reuse, with appropriate health and safety standards, to be used to meet that requirement, thereby creating an incentive for on-site capture
- Adopt standards that require or promote rainwater harvesting and/or water efficiency
- Review building, health, and plumbing codes for barriers to capturing or reusing rainwater
- Provide incentives for decreasing stormwater runoff and promoting water conservation
- Require use of rainwater harvesting and reuse on all public properties

A SAFE, SUFFICIENT WATER SUPPLY IS THREATENED BY OUTDATED WATER MANAGEMENT PRACTICES, WASTEFUL USE & PRICING; CLIMATE CHANGE; AND POLLUTION FROM STORMWATER RUNOFF

Monumental public works projects and groundwater extraction in arid areas of the United States, and substantial rainfall in other areas have provided a generally available water supply. This leads to the view that water is an abundant resource—and, perhaps, to its unnecessary waste. But the limited availability of water is becoming increasingly clear. The longstanding reliance on centralized water delivery systems means opportunities to integrate alternate local sources of water to meet local water demand are often overlooked. Distorted water pricing can lead to unnecessary waste, for example using potable water for non-potable uses such as outdoor landscape irrigation and indoor toilet flushing. Climate change will compound water resource challenges at the same time that increasing population will add demand to existing water supplies, and the increase in impervious surfaces from development accompanying population growth will result in even more stormwater runoff carrying pollution to our rivers, lakes, and beaches. These emerging water challenges only increase the stress on critical water supplies and demand a re-examination of current water management practices. Rooftop Rainwater Capture is a sustainable practice that can help address these challenges.

High Rates of Water Consumption Strain Diminishing Water Supply

Each day in the Unites States, 44 billion gallons of freshwater are drawn from surface and groundwater sources and delivered by public water systems to residential, commercial, and industrial users (see Figure 1: Uses of Daily Freshwater Withdrawals in the United States).

In fact, water demand in the United States is among the highest in the world, averaging 100 to 165 gallons per person per day—or as much as 4 times more than in some European countries (see Figure 2: Comparison of Daily Domestic Demand in North American and European Countries).[2,3]

Figure 1: Uses of Daily Freshwater Withdrawals in the United States

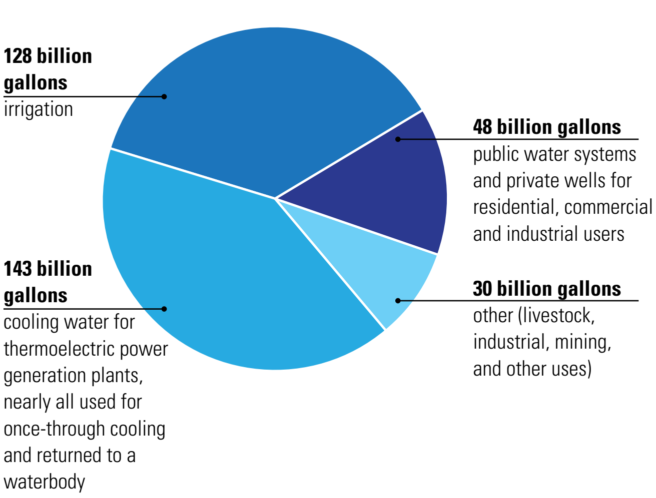
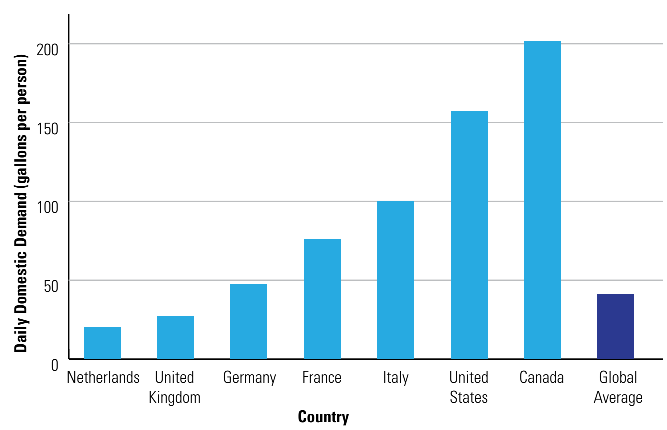


Figure 2: Comparison of Daily Domestic Demand in North American and European Countries



Source: A.Y. Hoekstra and A.K. Chapagain, *Water Footprints of Nations: Water Use by People as a Function of Their Consumption Pattern*, Water Resources Management (2007) 21:35-48, available at http://www.waterfootprint.org/Reports/Hoekstra_and_Chapagain_2007.pdf (accessed October 2011).

Typical domestic indoor per person water use in the United States is 70 gallons per day (see Table 1: Typical Daily Water Use). However outdoor water use can constitute 30 to nearly 60 percent of overall domestic demand, increasing the average per person domestic use up to 165 gallons per day or more.[4] While potable water is used almost exclusively for domestic uses, up to 80 percent of domestic demand may not require drinkable water. Similar trends exist for commercial water use, where, because contact uses such as cooking and showering are decreased, the percentage of use suitable for non-potable supply can be even higher. Both the domestic and commercial statistics show that potable water is most often used to supply non-potable needs.

Table 1: Typical Daily Water Use		
	Domestic	Office Buildings
Use	Percent of Daily Total (Gallons per Person)	Percent of Daily Total
Potable indoor uses*		
• Showers/Baths	7.8% (12.8)	-
• Dishwashers	0.6% (1.0)	-
• Kitchen	-	3%
• Faucets	6.6% (10.9)	1%
• Other uses, leaks	6.7% (11.1)	10%
Subtotal potable	**21.7% (35.8)**	**14%**
Non-potable indoor uses		
• Clothes washers	9.1% (15.0)	-
• Toilets/urinals	11.2% (18.5)	25%
• Cooling	-	23%
Subtotal non-potable	**20.3% (33.5)**	**48%**
Outdoor uses	**58.0% (95.7)**	**38%**
Total non-potable indoor and outdoor uses	**78.3%**	**86%**

*Domestic kitchen use accounted for in dishwasher and faucet categories.

Source: American Waterworks Association Research Foundation (AWWARF), *Residential End Uses of Water, Denver*, CO, AWWARF, 1999. Pacific Institute, *Waste Not, Want Not: The Potential for Urban Water Conservation in California*, November 2003.

For example, 270 billion gallons of water are used each week—a significant portion of it potable—to water 23 million acres of lawn in the United States. This watering bill costs $40 billion annually.[5] In addition, more than 11 percent of drinking water delivered to households—an estimated 6 billion gallons of water each day or more than 2 trillion each year—and 25 percent of drinking water delivered to commercial buildings is flushed directly down the toilet,[6] and along with it the money and energy used to treat and deliver the water.

Vast Amounts of Energy Are Used to Treat, Supply, and Dispose of Water

Carbon Dioxide Emissions from Water Treatment and Distribution.

Fuel Type	CO_2 Output Rate (lbs CO_2/kWh)	Drinking Water Energy Demand (kWh/MG)	CO_2 Output per MG Drinking Water Supplied (lbs)
Coal	2.117		2,960
Petroleum	1.915	1,406	2,680
Natural gas	1.314		1,840

Source: U.S. Department of Energy and U.S. EPA, *Carbon Dioxide Emissions from the Generation of Electric Power in the United States*, July 2000. EPRI.

Approximately 75 billion kilowatt-hours (kWh) of electricity are used each year—4 percent of total annual electricity consumption in the United States—for delivering drinking water and treating wastewater. Electricity constitutes approximately 75 percent of the cost of municipal water treatment and distribution,[1] and nationally, it takes an average of 1,400 kilowatt hours (kWh) of electricity to supply 1 million gallons of drinking water.[2]

The water-energy link is particularly pronounced in drier regions of the country. In California, for instance, most of the state's residents live where the state's water isn't. Two-thirds of the State's population lives in Southern California while two-thirds of the precipitation falls in Northern California. This disparity requires Southern California to import approximately 50 percent of its water supply from the Colorado River or through the California State Water Project from the Sacramento-San Joaquin Delta in Northern California, at tremendous energy costs.[3] Transporting water several hundred miles and lifting it more than 3,000 feet over the Tehachapi Mountains requires between approximately 7,918 kWh to 9,930 kWh per 1,000,000 gallons of water or more, depending on the end delivery point. As a result, the State Water Project is the largest overall user of electricity in California;[4] the energy needed to deliver water to its end users is six to seven times the national average, and nearly 50 times the amount needed to provide water in the northern part of the state.[5,6,7] But even in a city such as Baltimore, Maryland, supplying 240 million gallons of water each day to the city's approximately 500,000 residents and its surrounding suburbs at the national average rate for energy use require the city to consume approximately 336,000 kWh per day, or enough electricity each month to power more than 9,700 households.[8,9] Nationwide, the electricity required to treat and deliver potable water creates a significant carbon footprint. The U.S. Environmental Protection Agency estimates that the water sector produces 45 million tons of CO_2 emissions annually, equivalent to the output of more than 8 million cars.[10,11] The table following provides the emissions by fossil fuel source in relation to the energy used to deliver water.

Using the percentages of power plant types used statewide in Maryland[12] as the basis of calculations, the City of Baltimore emits 80,000 tons of CO_2 each year to supply drinking water.[13] Southern California imports, on average, more than 675 *billion* gallons of water each year from the Colorado River or Northern California.[14] More than 2.5 million kWh are required to supply this water to end users. Assuming that only natural gas is used to supply the required electricity, this results in the emission of more than 3.75 million tons of CO_2 each year, just from imported water. Viewed in this context, water use has a major impact on the sustainability of a region and on the ability not only to meet water supply needs, but also to substantially reduce electricity demand and carbon emissions.

Notes:

1 U.S. Department of Energy, *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*, December 2006.

2 Electric Power Research Institute, *Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment—The Next Half Century*, EPRI, Palo Alto, CA: 2000. 1006787.

3 California Energy Commission, *California's Water—Energy Relationship*, CEC-700-2005-011-SF, November 2005.

4 California Energy Commission, *Integrated Energy Policy Report*, CEC-100-2005-007-CMF, November 2005, available at http://www.energy.ca.gov/2005publications/CEC-100-2005-007/CEC-100-2005-007-CMF.PDF.

5 Id.

6 Navigant Consulting, *Refining Estimates of Energy Use In California*, December 2006, prepared for California Energy Commission, available at http://www.energy.ca.gov/2006publications/CEC-500-2006-118/CEC-500-2006-118.PDF.

7 Robert Wilkinson, *Methodology for Analysis of the Energy Intensity of California's Water Systems and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures*, Ernest Orlando Lawrence Berkeley Laboratory & California Institute for Energy Efficiency, Agreement No. 4910110, January 2000.

8 Average monthly household electricity use in Maryland is 1,038 kWh.

9 Energy Information Administration, Electric Sales, Revenue, and Average Price 2008, January 2010, available at http://www.eia.doe.gov/cneaf/electricity/esr/esr_sum.html (accessed March 2010).

10 US EPA, Sustainable Infrastructure for Water & Wastewater—Energy and Water, 2009, available at http://www.epa.gov/waterinfrastructure/bettermanagement_energy.html#basicone (accessed August 2009).

11 Based on a "typical passenger vehicle" output of 5.5 metric tons of CO_2 per year. U.S. Environmental Protection Agency, February 2005. Emission Facts: Greenhouse Gas Emissions from a Typical Passenger Vehicle. http://www.epa.gov/OMS/climate/420f05004.pdf.

12 In Maryland, coal comprises 51%, natural gas 5%, and oil 12% of electric generating capacity. Nuclear power constitutes the remaining balance.

13 Constellation Generation Group, Generation Capacity Fact Sheet, 2007, available at http://www.bge.com/vcmfiles/Constellation/Files/factsheet_generation.pdf (accessed October 2009).

14 David S. Beckman, Noah Garrison, Robert Wilkinson, Richard Horner, *A Clear Blue Future*, NRDC, August 2009, available at http://www.nrdc.org/water/lid/.

Distorted Pricing Encourages Water Waste

Water use cannot be discussed without considering its price. Among industrialized countries, only Canada pays less for water than the United States; Canada is also the only country that uses more water per capita that the United States. The average cost of water in the United States is $3.53 per 1,000 gallons,[7] ranging from $0.94 to $8.50 per 1,000 gallons. One cent can buy anywhere from 1.2 to 10.6 gallons of tap water.[8,9] By comparison, a 20-ounce bottle of water selling for $1.50 costs the equivalent of $9,600 for 1,000 gallons—2,700 times the average cost of tap water.

A consequence of the underpricing of water is that water service as a public utility is frequently undervalued. A Government Accountability Office survey of utilities found that user fees and other funding sources do not generate enough revenue to cover the full cost of providing service in 29 percent of water utilities.[10] The EPA advocates for full cost pricing of water that recovers the total expense of the capital and operating costs of treating and delivering water and signals the increasing scarcity of water resources, as a critical component of sustainable infrastructure. However, nearly one-third of utilities fail to achieve this goal. Water pricing can be tiered in an ascending block rate structure in order to maintain the affordability of essential uses of water (essential uses or necessity uses, at a residential scale for instance, are defined by Billings and Jones to include drinking, bathing, sanitation, cooking, and clothes and dish washing). This quantity is estimated to be approximately 3,000 gallons per household per month. Unfortunately, flat or declining rate structures remain in use and serve to undercut efficiency efforts, resulting in the waste of a valuable resource.

A further consequence of the underpricing of water is that it discourages investment in practices that create alternative water supply, such as rooftop rainwater capture. At the same time, stormwater fees are often assessed at a flat rate rather than based on actual site discharges, giving property owners no incentive to reduce runoff through harvesting rainwater for on-site reuse. Pricing water to reflect its true cost will encourage efficient use, conservation, and the use of practices that create alternative water supply, such as rainwater harvesting. Rational pricing encourages rational use.

> ***As a result of climate change, it is projected that "the Sierra snowpack will experience a 25 to 40 percent reduction from its historic average by 2050."[11]***
> – California Department of Water Resources, Managing an Uncertain Future

Climate Change Will Compound Diminishing Water Supplies

Climate change is predicted to compound population growth's increased water demands by further constraining water resources throughout the United States. As warming increases, changes in the timing, volume, quality, and spatial distribution of available freshwater resources are expected, making access to already limited supplies increasingly unpredictable. While the effects of climate change will be experienced in all corners of the United States, the extent of these effects will vary with geographic location. In particular, many already water vulnerable regions of the country will be made more vulnerable, as warming alters supply patterns.

The climate impacts on water resources are projected to include:[12,13,14]

- A decrease in the duration and extent of snow cover in most of North America
- An increase in the frequency of heavy precipitation events across the United States
- An increase in streamflow in the eastern United States
- A decrease in annual precipitation in the Central Rockies and Southwest
- A decrease in mountain snow water equivalent (the amount of water contained within the snowpack) in Western North America
- A decrease in runoff and streamflow in the Colorado and Columbia River basins
- A decrease in the proportion of precipitation falling as snow in the West
- An increase in number and duration of droughts in the West
- A decrease of 25 to 40 percent by 2050, and potentially 70 to 90 percent by 2100, of the Sierra snowpack, which forms California's largest freshwater surface reservoir

Western watersheds will be especially susceptible to supply constraints due to climate change because of their reliance on snowmelt as a water source. Less precipitation overall, less precipitation as snow, and earlier onset of snowmelt will reduce the flow in Western rivers and the amount of available water overall. By 2050, reductions in available snowpack in the Western mountains and earlier melting of the snowpack are very likely. In snowmelt dominated watersheds, winter and early spring flows will increase while summer flows substantially decrease, altering the expected pattern and availability of water supplies. Because western reservoirs are largely used for flood control early in the season and at that time must release water rather than store it to protect against flooding during later season storms, earlier-season snowmelt flows are unlikely to be available as a water supply in the drier summer and fall.[15] Overall, with increased warming and evaporation, Colorado basin runoff is projected to decrease 10-25 percent during the 21st century.[16] A 2011 interim report by the Bureau of Reclamation on the Colorado River Basin water supply estimated a 9 percent decrease in river flows on the Colorado River at Lee's Ferry within a 50-year time frame.[17]

California, Nevada, and five other states rely on water from the Colorado River to meet water supply needs[18] and are vulnerable not only to climate change but also to additional strain from population growth. The State of Nevada's population is projected to increase by up to 1.2 million people between 2009 and 2030.[19] During this same period California is expected to see its population increase by more than 10 million people.[20,21] At the current average per capita consumption rate of 185 gallons per day,[22] an increase of 10 million people in California would create additional demand for more than 675 billion gallons per year, and exert a substantial additional strain on already over-allocated water supply systems.

The Colorado River basin is an area with an already long history of water stress and jurisdictional conflicts over water rights. However, recent analysis has determined that the annual flow of the Colorado, upon which water allocation between the seven states, Mexico, and several Native American tribes is based, was overestimated by approximately 975 billion gallons,[23,24] equivalent to the water use of more than 6 million households.[25]

Beginning in October 1999, the southwest experienced a decade long drought, with the period from 2000—2004 witnessing the lowest 5-year period of Colorado River flow on record.[26] In October, 2010, the water level in Lake Mead reached its lowest point since the reservoir was first filled after the construction of Hoover Dam 75 years ago.[27] Unfortunately, recognition of the limits of the Colorado River has coincided with a rush of growth and development taking place in the Southwest. Because of demand, the Colorado River now flows only intermittently, if at all, all the way to its terminus in the Gulf of California.[28] With more demand on the river and other sources in the region coming each year, water scarcity presents a real and present concern.

Water supply challenges are not limited to arid or western parts of the country. In 1999 the Tampa Bay water authority authorized construction of a 25-million-gallon-per-day ocean desalination plant to supply up to 15 percent of the area's water needs.[29] The plant, which was built primarily as a hedge against population growth and uncertain continued water supplies for a metropolitan area traditionally viewed as having a wet climate, ultimately experienced a series of significant technical and cost setbacks.[30]

In 2007 Lake Lanier, the primary water source for the 5 million residents of Atlanta and its surrounding metropolitan area, came within three months of going dry.[31] The two-year drought that had created the crisis was sustained and severe, but was within historical norms. However, rapid population growth, additional agricultural irrigation, and increased water demand from power generation to meet the energy needs of the growing metropolitan region combined to create demand that outpaced supply. That this severe shortage occurred in the normally water-rich Southeast (in non-drought years the average annual precipitation in Atlanta is approximately 50 inches)[32] only highlight the consequences of unchecked growth and high rates of water consumption.[33]

Rain and Stormwater Runoff are Major Contributors to Water Pollution

The U.S. EPA views urban runoff as one of the greatest threats to water quality in the country.[34] As development has altered the landscape, the movement of water through the environment has changed. Rain that once was absorbed by vegetation and the ground is now converted to stormwater by the presence of impervious surfaces such as roads, rooftops, and parking lots that prevent infiltration of water into soil and drastically increase the volume of runoff that results from precipitation. "[M]ost stormwater runoff is the result of the man-made hydrologic modifications that normally accompany development."[35] As this runoff flows over paved surfaces, it picks up proportionally higher levels of pollutants, including animal wastes, bacteria, pathogens, metals, oils and other automobile fluids, and carries them to streams, lakes, and the ocean.[37] Degradation of waterways as a result of urban stormwater runoff is readily apparent across the country. The EPA's latest assessment of the nation's water quality finds significant impairment: 44 percent of assessed rivers and streams, 64 percent of assessed lakes, ponds, and reservoirs, and 30 percent of assessed bays and estuaries are impaired for one or more pollutant and are not supporting one of more of their intended uses, including swimming, fishing, or recreation. Stormwater runoff is identified as a leading source of pollution for each of these types of water bodies.[38]

> ***According to the U.S. EPA, "[urban runoff] is one of the most significant reasons that water quality standards are not being met nationwide."[36]***
>
> – U.S. General Accounting Office Urban Runoff Programs Report

Urban streams, located in areas with high levels of imperviousness and correspondingly higher volumes of stormwater runoff, have tended to fare worse than streams in non-urbanized areas of the country. USGS studies of urban streams find that concentrations of total phosphorus exceed the EPA's goal for nuisance growth in 70 percent of streams. Insecticides in these streams are often found at a higher concentration than in even agricultural areas and levels of fecal coliform bacteria commonly exceed recommended standards for water recreation.[39] Stormwater's impacts in urban areas are compounded by aging and often inadequate infrastructure. Similarly, combined sewer systems, which collect stormwater in the same pipes as wastewater, discharge 850 billion gallons of untreated sewage overflows to urban waters in nearly 750 municipalities each year when their pipes are overwhelmed with the influx of stormwater from heavy rainfall events.[40] In 2010, stormwater caused or contributed to 8,712 beach closing and advisory days nationwide (58 percent of the closing and advisory days for which a source was identified); and an additional 1,880 closing and advisory days were caused by sewage spills and overflows.[41]

In order to address the problems caused by stormwater runoff, the National Research Council (NRC) has found that using green infrastructure, or management measures that retain runoff on-site by harvesting, infiltrating, and evapotranspirating stormwater, are critical to reducing the volume and pollutant loading of small storms.[42] When green infrastructure practices, such as bioswales, infiltration trenches, rain gardens, and rain barrels or cisterns that harvest rainwater prevent runoff from leaving the site, they also prevent 100 percent of the pollutants in that retained volume of water from ever reaching local rivers, lakes, or beaches and the ocean. Traditional methods of addressing runoff have involved use of "structural" or engineered solutions to transport stormwater away from developed sites as quickly as possible, through systems of curbs, gutters, pipes, and centralized storm sewers that offer little or no treatment of runoff, or through combined sewer systems that may be unequal to the task of handling large volumes of stormwater.[43] Accordingly, the NRC's recommendation presents a dual benefit—use of green infrastructure both reduces pollution in stormwater runoff, while increasing potential water supplies through infiltration to recharge groundwater supplies or harvesting practices to provide an on-site source of water supply.

Photo: EPA/Abby Hall

A rain barrel used to capture residential roof runoff in Santa Monica, CA.

Photo: EPA/Abby Hall

A cistern used to capture rooftop runoff in Chicago.

ROOFTOP RAINWATER CAPTURE PROVIDES A SAFE, EFFICIENT SOLUTION THAT CAN INCREASE WATER SUPPLY AND DECREASE WATER POLLUTION

Harvested rainwater can be an ideal water source. Although collecting and storing rainwater is a simple practice employed for millennia, current systems for water supply overwhelmingly favor use of centralized infrastructure, which makes the practice challenging to incorporate. Accordingly, harvesting is an underutilized practice, but one that offers numerous benefits, including:

- Reducing strain on existing water supply sources at a time when providing adequate water supply is becoming an increasing challenge for many regions
- Reducing or eliminating energy and economic expenditures associated with treating and delivering potable water to end users
- Providing an inexpensive, on-site supply of water that can often be used for non-potable uses with little, if any, treatment, or for a variety of additional uses including potable supply with appropriately higher levels of treatment[44,45]
- Reducing runoff that would otherwise mobilize contaminants and contribute to stormwater pollution, a leading cause of surface water pollution and flooding in urban areas throughout the country[46]

As a result, harvesting and using the rain, rather than letting it run off, conserves other water resources and reduces stormwater pollution.

In harvesting systems, cisterns or rain barrels are used to collect runoff from impervious surfaces, such as roofs. Roofs often constitute a significant percentage of impervious surfaces in urban areas, up to 25 percent or more of urban land cover,[47] meaning that they generate a large amount of runoff. Downspout drains provide an easy location from which to collect runoff and therefore an optimal location from which to reduce stormwater volume. Until recently rooftop capture was most often practiced in dry climates or remote areas with limited access to water. However, as harvesting has re-emerged as a viable practice, it is increasingly being used in urban areas where reducing the volume of stormwater runoff is critical to improving water quality downstream.[48]

Water quality and the potential impacts of polluted water on human health is a fundamental concern in considering use of captured rooftop rainwater. While rooftop runoff may contain pollutants (metals or hydrocarbons from roofing materials, nutrients from atmospheric deposition, bacteria from bird droppings), these pollutants are generally found in significantly lower concentrations, and the runoff is generally free of the toxic contaminants that may be picked up after the runoff mobilizes off-site.[49] As a result, rooftop surfaces represent a preferred location for capture.

> ***"Rainwater used for residential irrigation (on the scale of rain barrel collection) does not typically require treatment. Commercial applications and non-potable indoor uses require treatment but the type of use will determine the extent of treatment [necessary]."***
>
> – U.S. EPA Municipal Handbook on Rainwater Harvesting Policies

Treatment for rooftop runoff, where necessary, may include practices such as filtration or disinfection using ultraviolet disinfection, ozonization, or treatment with chlorine or iodine. Even use of simple devices such as first flush diverters, which divert the first amount of rain (which washes away much of the surface debris or contaminants on a roof surface) away from storage tanks can result in availability of high quality water for on-site non-potable uses.[50] In all cases, when using captured rainwater it is important that appropriate consideration be given to health and environmental impacts. However, by limiting rainwater use to non-potable applications such as toilet or urinal flushing, or hose bibs for irrigation water, the use of captured rainwater "presents little human health risk."[51]

The Volume of Rooftop Rainfall Available for Capture is Significant

The sheer volume of rain falling on our rooftops is tremendous—into the billions and tens of billions of gallons per year for even small to mid-sized cities. Table 2: Total Rooftop Rainfall for eight U.S. Cities shows the total annual volume of rainwater falling on rooftops in eight U.S. cities, if captured in its entirety, would be enough to meet the water supply needs of between 21 percent and 75 percent of that city's population each year. Capturing even a portion of this water for on-site reuse would substantially increase local water supplies, while simultaneously acting to reduce stormwater pollution. As a result, like many of the stormwater management practices considered as green infrastructure, rooftop capture presents significant potential for better pollution control and urban water management.

Table 2: Total Rooftop Rainfall for Eight U.S. Cities

City	Estimated 2008 Pop.	Land Area (mi^2)	Acres of Residential Roof	Acres of Non-Res. Roof	Annual Rainfall (in.)	Annual Rooftop Rainfall (Billion Gal.)	Equivalent Number of People Supplied Annually	% of Pop.
Atlanta, GA	519,000	132	4,801	4,462	47.6	11.98	291,772	56.2%
Austin, TX	743,000	252	11,151	4,426	30.2	12.78	311,249	41.9%
Chicago, IL	2,837,000	227	17,288	12,099	39.0	31.10	757,493	26.7%
Denver, CO	588,000	153	7,252	4,260	14.5	4.54	110,548	18.8%
Fort Myers, FL	68,000	22	782	624	54.5	2.08	50,660	74.7%
Kansas City, MO	476,000	314	2,315	3,874	35.1	5.90	143,666	30.2%
Madison, WI	229,000	67	-	2,491	29.5	1.99	48,566	21.2%
Washington, DC	588,000	61	1,318	7,081	39.4	8.99	218,968	37.2%

Source: Rooftop area data provided by case study cities. Rainfall data from NOAA National Climate Data Center. Population Data from Census 2000.

To project the benefits that rooftop rainwater capture can provide on a large scale, modeling is often used. For example, a modeling analysis of Tucson, Arizona conducted by scientists at the University of Arizona that evaluated the city's land uses and total annual rainfall found that rainfall captured from roofs and used on site for landscaping could reduce residential water use by 30 to 40 percent.[52] In this paper, NRDC conducted similar analyses for eight U.S. cities: Atlanta, Austin, Chicago, Denver, Fort Myers, Kansas City, Madison, and Washington, D.C. For a description of NRDC's methodology, see Appendix A.

NRDC's analysis shows the total volume of rainwater potentially available for capture and use, as well as the volume of water likely available for use under a variety of scenarios placing conservative assumptions and constraints on the ability to either capture or to use the volume of rainfall from different storm events. The analyses of multiple scenarios demonstrate that there is substantial potential to capture and use rainwater for non-potable activities and as a result, significant opportunity to reduce potable water demand. The results vary according to each city's roof area and climate, but there is opportunity in each of the cities evaluated to capture hundreds or thousands of millions of gallons of rainwater each year, a quantity of water equivalent to the total annual water use of tens to hundreds of thousands of residents.

Scenario 1: Capturing and Using *All* of the First Inch of Rainfall from Each Storm Event

In the first scenario analyzed, we constrain the potential ability to capture rainwater by assuming that each site would have storage capacity to capture and use only the first one-inch of rainfall from each storm event. Any rainfall volume above the first one-inch of rain would not be captured and would instead bypass the storage system. We also assume that for any month in which the average temperature for a given city falls below 40 degrees Fahrenheit, rainwater systems at residential sites would be considered inoperable. However, we also assume that each site has the capacity to make use of the entire volume of captured rainwater before the next storm occurs, effectively emptying out any rain barrel or cistern completely before the next rainfall event.

Table 3: Total Annual Rooftop Rainfall Capture Assuming One-Inch Capacity shows the rooftop rainfall volume that could be captured for use in each city under these assumptions.[53] We conducted analyses of scenarios assuming that 25 percent, 50 percent, and 75 percent of each city's total available roof area would be used for capturing rainfall, presenting low, medium, and high estimates of potential rooftop capture. The substantial volumes of water that can be captured under these scenarios demonstrate the significant opportunity for increasing local water supplies through rooftop capture.

Table 3: Total Annual Rooftop Rainfall Capture Assuming One-Inch Capacity (Scenario 1)

City	Estimated 2008 Pop.	Annual Rooftop Rainfall (Million Gal.)	Annual RW Capture 25% Roof Area (Million Gal.)	Equiv. People	Annual RW Capture 50% Roof Area (Million Gal.)	Equiv. People	Annual RW Capture 75% Roof Area (Million Gal.)	Equiv. People
Atlanta, GA	519,000	11,981	1,519	36,992	3,037	73,960	4,556	110,953
Austin, TX	743,000	12,780	1,337	32,560	2,675	65,145	4,012	97,705
Chicago, IL	2,837,000	31,104	4,148	101,017	8,295	202,009	12,443	303,026
Denver, CO	588,000	4,540	677	16,487	1,355	32,998	2,032	49,486
Fort Myers, FL	68,000	2,080	294	7,160	587	14,295	881	21,455
Kansas City, MO	476,000	5,900	816	19,872	1,632	39,744	2,449	59,641
Madison, WI	229,000	1,994	340	8,280	679	16,536	1,019	24,816
Washington, DC	588,000	8,991	1,335	32,511	2,670	65,023	4,005	97,534

For example, NRDC's modeling shows that capturing and using the first one-inch of rooftop rainfall from each storm event in Atlanta, GA could supply enough water for approximately 74,000 people, or nearly 15 percent of the city's total population in even our mid-level estimate, which assumes only 50 percent of the city's rooftops are available for capture.

Scenario 2: Capturing and Using Only Some of the First Inch of Rainfall from Each Storm—and Associated Cost Savings

The second scenario analyzed demonstrates that even if rooftop capture is further constrained by a conservative assumption of the rate at which end users can make use of captured water, rooftop capture still has the potential to provide enough water for tens to hundreds of thousands of people per year in each city. In this scenario, we limit the potential capture volume by assuming that residential sites use captured rainwater only for outdoor irrigation and that non-residential sites use it only for toilet flushing, and by then limiting the rate at which a site's storage tanks can be emptied from these uses before the next storm event occurs (see Table 4: Total Annual Rooftop Rainwater Capture Assuming One-Inch Capacity and Limitations on Rate at Which Captured Water is Used for NRDC's results). Again, using our mid-level benefit analysis for Atlanta as an example (assuming that 50 percent of the city's existing rooftop area is available for capturing rainfall), even if rooftop harvesting is constrained by the rate at which the water is ultimately used before the storage tanks can refill, rooftop rainwater capture could still supply enough water for more than 48,000 people per year.

Table 4: Total Annual Rooftop Rainwater Capture Assuming One-Inch Capacity and Limitations on Rate at Which Captured Water is Used (Scenario 2)								
City	Estimated 2008 Pop.	Annual Rooftop Rainfall (Million Gal.)	Annual RW Capture 25% Roof Area (Million Gal.)	Equiv. People	Annual RW Capture 50% Roof Area (Million Gal.)	Equiv. People	Annual RW Capture 75% Roof Area (Million Gal.)	Equiv. People
Atlanta, GA	519,000	11,981	991	24,134	1,982	48,268	2,973	72,402
Austin, TX	743,000	12,780	1,077	26,228	2,155	52,481	3,232	78,709
Chicago, IL	2,837,000	31,104	2,708	65,948	5,416	131,896	8,124	197,845
Denver, CO	588,000	4,540	570	13,881	1,140	27,763	1,711	41,668
Fort Myers, FL	68,000	2,080	165	4,018	330	8,037	495	12,055
Kansas City, MO	476,000	5,900	544	13,248	1,090	26,545	1,634	39,793
Madison, WI	229,000	1,994	241	5,869	483	11,763	724	17,632
Washington, DC	588,000	8,991	875	21,309	1,751	42,642	2,627	63,976

Scenario 2's limits on assumed rate of use are further conservative in that, as discussed in the methodology attached as Appendix A, the model for Table 4 assumes that rooftop rainfall at residential properties will use captured water *only* for outdoor irrigation, even though residential properties could additionally use rooftop rainwater for toilet flushing and other non-potable applications. For non-residential properties, the analysis assumes that captured rainwater would be used *only* for toilet flushing, though water could additionally be used at non-residential properties for applications including outdoor irrigation and building cooling system make-up. Based on the variability of possible end uses and of land uses within the non-residential building category, and to provide a conservative estimate of the potential for captured rooftop water use, these water demands were not factored into the model. However, these potential uses present significant additional opportunities for rainwater use in actual application that could greatly increase the total volume of rooftop rainwater captured and used for each city.

The results also demonstrate that identifying as many non-potable uses as possible for rainwater, especially consistent, predictable uses such as toilet flushing and cooling system make-up, and removing unnecessary impediments for use of rainwater, are important for maximizing the amount of rainwater captured and potable water conserved. With regard to the latter point, while outdoor irrigation represents one ideal use for rooftop rainwater, if it is the only use considered it can limit opportunities for capture. In areas such as Southern California, rainfall may occur primarily during the winter months while outdoor irrigation may be needed more in the summer, creating a partly mismatched supply and demand. However, irrigation during the winter months is practiced in Southern California, and by making use of opportunities to use winter rainfall for consistent non-potable indoor demands, the applicability of rooftop rainwater capture can be significantly increased. In general, rainwater harvesting will have applicability in any region of the country when non-potable indoor demands are allowed to be met using rainwater as a supply. These uses constitute a significant water demand and consume a high percentage of potable water. Equally important, the substitution of rainwater for potable water provides a cost savings to consumers from the resulting lower water bills. When residential and non-residential properties use potable water for outdoor irrigation, for instance, they are not only paying for the cost of the drinking water used, but also a cost for wastewater treatment for water that does not then enter the sewer system or flow to a treatment plant.[54] NRDC's analysis estimated the aggregated annual savings from reduced potable water purchases and reduced wastewater discharges[55] for each modeled city, based on the total potential rooftop rainwater captured and used in the mid-level scenario presented in Table 4.[56] Table 5 shows the estimated cost savings for ratepayers in each of the cities from the modeled rooftop rainwater capture volumes.

City	Rainwater Captured and Used (MG/yr)	Water Rate ($/1,000 gal)	Wastewater Rate ($/1,000 gal)	Combined Rate ($/1,000 gal)	Potential Cost Savings ($)
Atlanta, GA[1]	1,982	$2.73	$10.33	$13.06	$25,885,000
Austin, TX[2]	2,155	$1.00	$3.43	$4.43	$9,545,000
Chicago, IL[3]	5,416	$2.01	$1.73	$3.74	$20,255,000
Denver, CO[4,5]	1,140	$1.91	$1.95	$3.86	$4,400,000
Fort Myers, FL[6]	330	$3.93	$9.58	$13.51	$4,460,000
Kansas City, MO[7]	1,090	$3.19	$3.05	$6.24	$6,800,000
Madison, WI[8]	483	$1.88	$1.78	$3.66	$1,770,000
Washington, DC[9]	1,751	$3.36	$4.83	$8.18	$14,325,000

Table 5: Estimated Annual Cost Savings from Reduced Potable Water Use Based on Mid-Level Scenario Assuming One-Inch Rainfall Capture Capacity and Limitations on Rate at Which Captured Water is Used

Notes:
Water and wastewater rates are based upon each municipality's identified rates for the 2010 fiscal or calendar year.
The lowest residential water rates were used for the purposes of this cost analysis.
Many municipalities use increasing block rate pricing, the first block prices were therefore used.
Atlanta, Kansas City, and Washington, D.C. provide rates per 100 cubic feet of water purchased.
Those rates were converted to the values presented.
Chicago provides its wastewater rate as a percentage of the water bill. For the 2010 calendar year,
the wastewater rate is 86 percent of the water bill. For this analysis the wastewater rate used was 86 percent of the water rate.
Rates are for water usage only and do not include connection or service fees.
Sources:
1 City of Atlanta Department of Watershed Management, FY 2007-08 and Approved FY 2008-09 through *FY 2011-12 Water and Sewer Rates*.
2 City of Austin, Texas Austin Water Utility, *Water Service Rates—Retail Customers; Wastewater Service Rates—Retail Customers: Approved Rates Effective November 1*, 2009.
3 City of Chicago, *Water Rates and Sewer Rates—Effective 1/1/10*.
4 Denver Water, *Rate Schedule No. 1—Inside City*.
5 Denver Wastewater Management Division, *Sanitary Sewer Questions—How is my Sanitary Sewer Bill Calculated*.
6 City of Fort Myers Utility Rates as of 10-01-09.
7 City of Kansas City, Missouri, *Water Rates for 2009*.
8 Madison Municipal Services, *Billing Questions*.
9 DC Water and Sewer Authority, *Understanding Rates—Current Rates Effective 10/1/2009*.

The goal of implementing rainwater harvesting practices on 50 percent of a city's existing rooftop area is one that is achievable. The pace at which development and redevelopment the United States progresses means that "[i]n 2030, about half of the buildings in which Americans live, work, and shop will have been built after 2000."[57] New development, redevelopment, and opportunities to retrofit existing structures create frequent opportunity to install and use rainwater harvesting systems. In addition to new development, existing buildings are "lost," either redeveloped or destroyed and rebuilt, at the rapid rate of 1.37 percent per year for commercial buildings, and 0.63 percent per year for residential structures nationwide.[58] For examples of how rooftop rainwater capture can be integrated into new buildings and retrofits, see the two following case studies.

Integrating Rooftop Rainwater Capture in a Retrofit: NRDC's Robert Redford Building in Santa Monica, California

NRDC's renovation of a 1920s-era structure in downtown Santa Monica achieved LEED® New Construction, Version 2 Platinum certification. The water system in the 15,000 square foot building includes a combined graywater recycling and rooftop capture system. Rainwater is collected in two 40-foot long cylindrical cisterns buried beneath outdoor planters adjacent to the building, with a total storage capacity of approximately 3,000 gallons. Collected rainwater is added to a graywater collection tank, which also receives water from the building's sinks and showers. The combination of graywater and rainwater is treated in an 800 gallon per day on-site filtration and disinfection system and used for toilet flushing and irrigation.

Photo: ©NRDC

Rainwater Cistern at NRDC's Santa Monica Office (inset photo after planter planting).

The Robert Redford Building demonstrates the potential of using several techniques to both capture and conserve water. The rooftop capture and graywater system allow water to be used multiple times for appropriate uses rather than in the typical single use fashion. High-efficiency water features such as dual-flush toilets, waterless urinals, and drought-tolerant plants reduce the building's water demand for typical uses. The water reuse and efficient features combine to reduce the building's potable water consumption by 60 percent, conserving more than 60,000 gallons of water annually and demonstrating the water savings that can be achieved with an integrated approach to water use.[1]

The Robert Redford Building also demonstrates the institutional barriers that may confront many rainwater harvesting and water efficiency projects. The local plumbing code prohibited waterless urinals, requiring a resolution that allowed the waterless urinals to be installed with water supply stubbed out behind the wall if needed for future use. This resolution made Santa Monica the first city in the country to allow the use of waterless urinals in its plumbing code,[2] but by requiring the installation of unnecessary plumbing, existing plumbing codes reduced the cost-savings that could be achieved by use of the waterless urinals. The City is now seeking a change to City Code to allow for waterless urinals to be installed without an available water supply. Similarly, California's graywater ordinance did not contain a provision for rainwater collection; an agreement was negotiated with the County Health Department after which the City's Building and Safety Division agreed to sign off on the plans.[3,4] The agreement required that the collected rainwater be fully treated with the building's graywater even though it was being used for non-potable applications.

Sources:

[1] A. Griscom, *Who's the Greenest of Them All—NRDC's New Santa Monica Building May be the Most Eco-Friendly in the U.S.*, Grist, November 25, 2003.

[2] City of Santa Monica, Office of Sustainability and the Environment, Urinals, available at http://www.smgov.net/Departments/OSE/Green_Office_Buying_Guide/Restroom/Urinals.aspx, accessed on October 31, 2011

[3] Center for the Built Environment, University of California, Berkeley, *The Natural Resources Defense Council—Robert Redford Building (NRDC Santa Monica Office)*, Mixed Mode Case Studies and Project Database, 2005.

[4] Natural Resources Defense Council, *Building Green—Case Study, NRDC's Santa Monica Office*, February 2006.

Integrating Rooftop Rainwater Capture in a New Build: The Solaire in Battery Park City, New York, New York

The Solaire demonstrates the potential water savings that can be gained by integrating water conservation features with reuse systems. The 357,000 square foot, 27 floor building contains 293 residential units and was the first high-rise residential structure in the United States to receive LEED® Gold certification. The Solaire was designed to comply with Battery Park City's stormwater standards, which require more than 2 inches of runoff to be collected and treated on site. As part of meeting compliance with this standard, rainwater from the building's roof is collected in a 10,000 gallon cistern located in the basement.

Photo: ©WERF

The cistern at the Solaire was integrated into the building during construction.

The cistern system is one component of a larger water reuse system in the building. A 25,000 gallon per day wastewater treatment plant is located in the building to treat sewage. Rainwater collected in the cistern is treated along with the wastewater treatment plant effluent in a UV/ozone unit prior to being sent to a combined water reuse tank. Overflow from the cistern is sent to the storm sewer. Combined reuse water is used for toilet flushing and building make-up water (water used to replace cooling system water that is lost to evaporation) in addition to providing irrigation water for two green roofs on the building.[1]

In conjunction with water efficient appliances installed in the building, the cistern system and blackwater reuse system decreased the building's potable water use by 48 percent and wastewater discharge by 56 percent over conventional construction.[2] Because of its innovative environmental features, the Solaire earned New York State's first-ever tax credit for sustainable construction.[3,4]

Sources:

[1]Water Environment Research Foundation, *21st Century Sustainable Water Infrastructure: Smart, Clean, and Green*, February 2009.
[2]Natural Resources Defense Council, *Case Study: The Solaire*, Building Green from Principle to Practice.
[3]D. Talend, *Model Citizens—High Rises in Manhattan's Battery Park City are ahead of the Curve in Residential Water Treatment and Reuse*, Onsite Water Treatment: The Journal for Decentralized Wastewater Treatment Solutions, September/October 2007.
[4]M. Zavoda, *NYC High-Rise Reuse Proves Decentralized System Works*, WaterWorld, February 2006.

REMAINING INSTITUTIONAL CHALLENGES AND HOW STATES ARE OVERCOMING THEM

Although still in the early stages of adoption in many urban areas, rainwater harvesting has been used successfully in a number of applications around the country to decrease stormwater runoff and reduce the demand of potable water. Despite its growing use, in many locations rooftop rainwater capture faces barriers either directly, in the form of prohibitions against the use of rainwater or the use of rainwater for specific purposes, or indirectly through contradictory regulations and requirements of multiple agencies. For example,

- In Colorado, the state recently passed a bill to allow rooftop rainwater capture, under limited circumstances, for residential properties supplied by a well (or eligible for a well permit). But the practice remains broadly prohibited in the state for commercial or other developments, or where water in the area is provided by a water district or a municipality under a prior appropriation water rights doctrine.[59]
- In California, despite the success of pilot rain barrel and rainfall harvesting programs,[60,61,62] the use of harvested rainwater for indoor applications is generally not permitted throughout the state. However, as a sign that such challenges are surmountable, in 2008 the City of San Francisco engineered a memorandum of understanding between the city's Public Utilities Commission, Department of Building Inspection, and Department of Public Health to explicitly authorize the use of captured rainwater for indoor, non-potable uses like toilet flushing, irrigation, heating and cooling, and vehicle washing, without treatment other than preliminary filtering.[63] The MOU also defines the roles of the participating agencies and establishes applicable standards, which remains an

important step for ensuring no unintentional impacts to public health or the environment occur.[64] The City of Berkeley has similarly authorized the use of captured rainwater for indoor, non-potable applications.[65] However, the Governor recently rejected legislation that would have helped authorize, with oversight of local agencies, the use of captured rooftop rainwater for indoor non-potable uses in urban areas throughout the state.[66]

In many states and municipalities barriers to rooftop capture prevent the application of captured rooftop rainwater for its full range of potential uses, but with proper evaluation and through establishing standards to ensure adequate water quality, these barriers can be overcome. In fact, several states and municipalities throughout the country have affirmatively permitted or incentivized the use of rooftop rainwater capture systems:

- The State of Georgia, in 2009, after experiencing extreme drought conditions in 2007 and 2008, amended its state plumbing codes and issued detailed rainwater harvesting guidelines to authorize the use of captured rooftop rainwater for both indoor and outdoor non-potable applications.[67]
- The State of Texas established a Rainwater Harvesting Evaluation Committee in 2005 and directed the state's Water Development Board and other agencies to formulate recommendations for minimum water quality standards for potable and non-potable indoor use and ways in which the state can further promote rainwater harvesting.[68]
- The City of Portland, Oregon allows the use of rainwater for indoor and outdoor non-potable applications, and, when properly treated, to replace potable water supply.[69]
- The City of Tuscon, Arizona, in 2010, put into effect a rainwater harvesting ordinance that requires new developments to meet 50 percent of their landscaping water requirements by harvesting rainwater.[70]
- The states of Virginia, Oregon, and Washington have all also adopted guidelines for design and use of rainwater harvesting systems,[71] and an estimated 30,000 to 60,000 people in the state of Hawaii (up to nearly 5 percent of the state's population) rely on rainwater to meet their water supply needs.[72]

In other states, permits issued under the federal Clean Water Act for the operation and discharge of stormwater from municipal storm sewer systems have increasingly required the use of green infrastructure practices that retain runoff on-site, such as capturing rooftop rainwater, to control stormwater.

- In West Virginia, a statewide permit was issued in 2009 that requires new development and redevelopment sites to retain up to one inch of rainfall on-site through use of green infrastructure practices.[73]
- In California, permits adopted in Ventura County, Orange County, the San Francisco Bay Area, and several other jurisdictions all require that new development and significant redevelopment projects retain the volume of runoff produced by the 85th percentile storm on-site (roughly ¾ of an inch of rain in coastal southern California) using green infrastructure practices, including capturing rooftop rainfall.[74] Several California cities, such as San Francisco, Los Angeles, Santa Monica, and San Diego have also enacted successful pilot programs to incentivize use and demonstrate the effectiveness of rain barrel systems for reducing the impacts of stormwater runoff and capturing rooftop rainwater during dry periods.[75,76,77,78]

Barriers preventing greater use of rooftop capture exist, but tend to be institutional rather than technological. Public health and plumbing codes designed for a centralized water approach often fail to adequately address rainwater reuse, or water is so undervalued that a financial incentive to conserve water is often lacking. While these oversights lead to missed opportunities to make use of an available source of water, they are also easily addressed, and substantial additional opportunities to make use of rainwater exist throughout the country.

POLICY RECOMMENDATIONS

The simple practice of rooftop rainwater capture offers the potential to improve the sustainability of urban areas. While it is increasingly used in the urban environment, it is also often overlooked because of institutional and regulatory constraints, or because its benefits are not widely known. Several policy options and incentives can be used to promote rainwater harvesting and lower the barriers for the practice.

Adopt stormwater pollution control standards that require on-site volume retention.

The renewed interest in rainwater harvesting is partially driven by its usefulness as a stormwater pollution management technique. On-site stormwater volume retention requirements which reduce pollution of surface waters are also effective at encouraging or even requiring the use of rainwater harvesting. Adopting stormwater standards that focus on the volume of discharges is often the first step in developing more protective water quality regulations and promoting sustainable use of water resources. The Environmental Protection Agency's planned reforms to its national stormwater rules represents the best opportunity to apply these kinds of standards across the country.

Adopt standards that require or promote rainwater harvesting and/or water efficiency.

Jurisdictions have begun requiring rainwater harvesting and better water management. Beginning in June 2010, Tucson, Arizona has required that all commercial development include a rainwater harvesting plan that includes a landscape water budget: harvested rainwater must be used to provide fifty percent of the landscape irrigation water. In addition to cisterns and rain barrels, the regulations allow berms and contoured slopes to be used to direct rainwater to trees and landscaped areas.[79]

Review building, health, and plumbing codes for barriers to reusing rainwater.

National and international guidance is currently lacking for rainwater harvesting. This has led to the exclusion of the practice in some jurisdictions or the presence of more stringent requirements than necessary for rainwater harvesting systems. Rainwater used for rain barrel-scale residential irrigation does not typically require treatment, and U.S. EPA states that rainwater presents little human health risk if properly treated when used for larger scale outdoor landscape irrigation or indoor non-potable applications such as toilet or urinal flushing, or for building cooling make up water. Local plumbing codes and public health codes should be revised to include rainwater harvesting as an accepted practice, establish acceptable end uses of rainwater, and set appropriate treatment, design, construction, and maintenance standards.

Provide incentives for decreasing stormwater runoff and promoting water conservation.

Stormwater utility fee discounts, tax incentives, and grant programs have been used successfully to promote the adoption of innovative stormwater practices. For example, stormwater utility fee discounts based upon the actual amount of stormwater discharged or the amount of impervious surface rather than a flat fee, provide an incentive for stormwater management measures, such as rainwater harvesting, that retain stormwater on site. Dedicated grant programs have been successful in promoting innovative stormwater practices and administrative incentives such as expedited green permit reviews provide an indirect financial rationale for including sustainable environmental practices. Further opportunities exist to provide funding for public agencies and private entities to incorporate green infrastructure practices such as rainwater harvesting into building retrofit projects. These incentives coupled with the ability to reduce the amount of potable water purchased can provide the financial justification for the capital investment in rainwater harvesting systems.

Require use of rainwater harvesting on all public properties.

In order to encourage the use of rainwater harvesting within their jurisdictions, local, state, and federal agencies should take a leadership role in designing new, redeveloped, and retrofitted agency owned or leased facilities to incorporate rainwater harvesting strategies.

APPENDIX A: NRDC'S METHODOLOGY

Our analysis evaluated the available daily rainfall and conservatively estimated non-potable water demands to determine reasonable projections for the amount of potable water demand that could be replaced by using rainwater for eight selected U.S. cities. To determine the available amount of rooftop rainwater that could be captured in each of the cities, GIS data were used to identify the total land area of residential and non-residential roofs. These areas represented the total space available for rainwater capture. For the purposes of this assessment, three different capture scenarios were evaluated; rainwater capture results were calculated assuming that 25, 50, and 75 percent of both the residential and non-residential total roof area for each city was utilized for rainwater collection.
In addition, daily rainfall data for time periods ranging from 27 to 60 years were obtained for each city to provide long-term estimates of available rainfall. The volume of rain that could be captured each day was determined using the following equation:[a]

V_{gal} = Square Feet of Roof x % of Total Roof Area Used[b] x Inches of Rain x 1 ft/12 in x 7.48 gal/ft^3 x 0.8 Capture Efficiency[c]

Once the available supply was determined, the potential for rooftop rainwater capture was determined under two different modeling scenarios. Scenario 1 (see Table 3) was designed to examine the potential for rainwater capture under circumstances of limited storage capacity for water. The scenario assumed that residential and non-residential locations ability to capture rooftop rainwater was constrained by the ability to store only the first one-inch of rainfall per day from any storm event—any volume of rainfall over one inch would bypass the site's storage system. However, the first scenario also assumed that each site would be able to use up to the full volume of captured rainfall from a one-inch storm prior to the next storm event occurring, meaning that a site's rain barrels and cisterns would be emptied entirely before the next rainfall event occurs. For the analysis, it was assumed that when the average monthly temperature was less than 40 degrees Fahrenheit, outdoor irrigation would not be practiced at residential locations and rainwater would not be captured or used. A summary of the model assumptions is included below.

Rainwater Harvesting Model Assumptions—Maximum One-Inch Rainfall Capture Capacity	
Residential	**Non-Residential**
• 25, 50, or 75% of roof area used for harvesting • 250 gallons of rain barrel storage per 500 square feet of roof • Up to one inch of captured rainwater used each day for non-potable uses • For months when the average monthly temperature was less than 40°F, the systems were assumed to be inoperable and rainwater was not collected or used.	• 25, 50, or 75% of roof area used for harvesting • 500 gallons of cistern storage per 1,000 square feet of roof • Up to an inch of captured rainwater used each day for non-potable uses

Scenario 2 (see Table 4) was designed to examine the potential for rooftop rainwater capture under circumstances additionally constraining the ability to capture and store rainwater based on the rate at which the captured water can be used. Specific, conservative constraints on non-potable use of the collected rainwater were assumed for both residential and non-residential buildings. For residential locations, it was assumed that for every 500 square feet of roof area, 250 gallons of rainwater storage (two, 125-gallon rain barrels) could be used to provide outdoor irrigation of 25 gallons per day; for non-residential locations it was assumed that for every 1,000 square feet of roof, a 500 gallon cistern would supply 32 gallons of water per day for toilet flushing. All other model assumptions for the second scenario were identical to the first. A summary of the model assumptions is included below.

Rainwater Harvesting Model Assumptions—Maximum One-Inch Rainfall Capture Capacity and Limitations on Rate at Which Captured Water is Used	
Residential	**Non-Residential**
• 25, 50, or 75% of roof area used for harvesting • 250 gallons of rain barrel storage per 500 square feet of roof • Captured rainwater used for outdoor irrigation at a rate of 25 gallons per day per 500 square feet of roof area • For months when the average monthly temperature was less than 40°F, the systems were assumed to be inoperable and rainwater was not collected or used.	• 25, 50, or 75% of roof area used for harvesting • 500 gallons of cistern storage per 1,000 square feet of roof • Captured rainwater used for toilet flushing at a rate of 32 gallons per day per 1,000 square feet of roof area (assumed 4 persons per 1,000 square feet x 4 flushes per day x 2 gallons per flush)

For both conditions, a spreadsheet model was then used to conduct a comparative analysis of rainwater inflow versus outflow for each day of the historical rainfall data set. Inflow into the rainwater harvesting system occurred on any day in which there was rainfall. If the rainfall was in excess of the capacity of the storage system and the daily usage rate, the excess rainfall bypassed the system and was not captured. The assumed residential and non-residential water demands were outflows from the rainwater harvesting systems each day provided there was available rainwater in the storage system. With the assumed demands and storage volumes presented in the first scenario both the rain barrels and cisterns used all of the collected rainwater each day. For the conditions presented in the second scenario, the residential rain barrels provided a 10-day supply of water and the non-residential cisterns provided a 16-day supply of water when not replenished with rainwater.

Notes:

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[b] Percent of total roof area used equaled 25, 50, or 75 percent.

[c] An 80 percent capture efficiency accounts for water loses from incidents such as intentional first flush diversions to remove pollutants or spillage from gutters. The capture efficiency standard means that for every 1 inch of rain, 0.8 inches of rainfall will be captured.

ENDNOTES

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