A Guide to Types of Non Potable Water and the Potential for Reuse in Urban Systems

Sally Brown

Agriculture in urban areas in the US and much of the developed world is protected by secure and reliable sources of water for irrigation. Garden hoses have always provided safe and potable water for plants and people. However, there are multiple reasons to look towards other sources in urban areas. Centralized systems have aging infrastructure. Leaks in pipes that both bring potable water to homes as well as collect used water from homes result in significant quantities of wasted water (Ghimire et al. 2014). Treating water to potable standards requires energy and depletes fossil resources. While this is necessary for potable water, water for irrigation does not need to meet the same rigorous standards. Decentralized water collection and use was once commonplace (Van Meter et al. 2014). It is again being looked at as a more sustainable alternative to centralized systems and groundwater irrigation around the world (Van Meter et al. 2014). While much of the focus has been on agricultural systems in rural areas, there are many reasons to apply these approaches for urban agriculture as well.

In large- scale agricultural systems, water is often the most limiting factor for plant growth. Worldwide, crop irrigation accounts for 70 % of our freshwater usage. When rainwater is limiting or when aquifers dry up, our food supply is threatened.

Urban agriculture has additional sources of water that can be used for irrigation: grey water from homes (water from the home other than toilet water), reclaimed water (treated water from wastewater plants), as well as stormwater collected from roofs and streets. Use of each of these types of water has associated costs and benefits. For grey water and stormwater, there is also the potential for safety concerns. In fact, for some municipalities use of these waters is regulated or restricted. This chapter will focus on water sources for urban agriculture. Different types of water with associated risks and benefits will be discussed. Collection systems for the different

S. Brown (✉)
School of Environmental and Forest Sciences, University of Washington, Seattle, WA, USA
e-mail: slb@uw.edu

© Springer Science+Business Media Dordrecht 2016

S. Brown et al. (eds.), *Sowing Seeds in the City*,
DOI 10.1007/978-94-017-7453-6_3

waters will be described. Examples of regulations covering use of alternative water sources will be provided. Finally, the potential environmental and economic impacts of use of potable and alternative sources of water for urban agriculture will be discussed.

It is also important to remember that use of alternative sources of water for urban agriculture is new and unexplored territory. Citizens in the US typically have affordable and unlimited access to strictly regulated potable water. Only recently have we recognized that dependence on potable water for a range of uses is not sustainable. Part of that realization includes understanding that alternative sources of water including stormwater, grey water and reclaimed water are good substitutes for potable water for certain uses. There are uncertainties associated with the use of alternative sources of water. These uncertainties are likely to result in some contradictory regulations and understanding of risks and benefits. The information presented in this chapter will reflect that uncertainty.

Types of Water: Stormwater Basics

Stormwater refers to water that falls from the sky. Stormwater can be a source of irrigation water for urban agriculture from water collected from roofs as well as water collected from streets. It is relatively simple for homeowners to install water collection equipment below rainspouts. Using water collection containers can provide significant quantities of water for irrigation (Fig. 1).

It is possible to estimate how much stormwater can be captured using a collection system. No stormwater collection system is 100 % efficient. The efficiency of a system will depend on the type of surface that the water runs over before it is captured. Collecting stormwater from a metal or slate roof will yield more water, and porous roof surfaces like tiles will yield less water. Here is a tool for estimating how much water can be collected off of a surface. The equations are then used to estimate of how much water a roof system in an area with 100 cm of annual precipitation can collect in 1 year.

Annual rainfall (inches)* area of the collection surface (SF)* 144 sq inches/SF* 0.00433 gal/cubic inch*0.85 collection efficiency = water available for harvesting

Annual rainfall (cms)* area of the collection surface (Square meters)*10,000 cm^2 / m^2*0.001 liter/cm^2 * 0.85 collection efficiency = water available for harvesting

If the surface area is 100 m^2 and the annual rainfall in the area is 100 cm then:

100 cm rainfall * 100 m^2 collection area*10,000 cm^2/m^2 * 0.001 liter/cm^2* 0.85 efficiency = 85,000 liters of water per year.

Water collected from roofs is typically clean and not subject to regulations (see regulatory section for additional information). Some cities have active programs to provide rainwater collection barrels to homeowners. Obstacles to rainwater use include having sufficient storage capacity and the necessity of connecting the storage to existing irrigation systems. Cisterns could be constructed to maximize

Fig. 1 Stormwater collection barrels in Seattle, WA. The newer home was designed to include a stormwater barrel while at the older home, the owners added the barrel. Seattle Public Utilities sells and delivers rain barrels to customers (http://www.seattle.gov/util/environmentconservation/mylawngarden/rain_water_harvesting/buyrainbarrels/)

rainwater storage. However, these are costly and might require some type of municipal subsidy to gain wide spread use.

Water falling on streets could also be used for irrigation. Here collection is more problematic and there are concerns about contamination. In urban areas the focus on stormwater treatment has been to move the water away from streets as quickly as possible. Traditionally storm sewers or underground pipes were constructed to expedite water movement off streets and into existing natural water bodies. In many municipalities storm sewers and wastewater treatment piping are one and the same. For these combined systems, rainwater is directed to wastewater treatment plants where it is typically treated and released into natural water bodies. For large storm events, the quantity of precipitation entering these combined systems can overwhelm the ability of the treatment plant to effectively treat the water. When this happens, treatment plants will release excess stormwater mixed with untreated sewage. These releases are referred to as combined sewer overflows (CSO). The Washington, DC water management agency, DC Water has a description for its combined sewer system and the associated potential for overflows (http://www.dcwater.com/wastewater_collection/css/).

CSO releases are regulated under the National Pollutant Discharge Elimination System (NPDES). Municipalities are fined if they exceed a certain number of discharges per year (http://cfpub.epa.gov/npdes/home.cfm?program_id=5). As part of this regulatory framework, municipalities are currently working to reduce or eliminate CSOs. Strategies to eliminate or reduce CSOs have been developed using both grey (engineered) or green (natural) systems. For example, DC Water is currently constructing large underground storage tanks to store stormwater (http://www.dcwater.com/workzones/projects/anacostia_tunnel.cfm). This will allow the agency to treat the water gradually over time and will avoid discharges of untreated stormwater and wastewater. These types of solutions are very costly. Portland, OR has opted to integrate green stormwater infrastructure in combination with engineered systems as a way to reduce costs. The Tabor to the River project (http://www.portlandoregon.gov/bes/47591) has involved planting trees and rain gardens in addition to replacing sewer pipe. Including the green infrastructure in this effort has reduced the cost of the project from $144 million for a fully engineered solution to $63 million.

There is a potential for stormwater diverted from treatment plants to green infrastructure to be used for food production. It is easy to imagine for example, curbside or parking strip gardens receiving stormwater. However, there are concerns about contaminants in stormwater and the safety of using this water for food production. Contaminants in stormwater will originate from vehicular traffic and buildings (tires, brake pads, exhaust, and road building materials), soil and sediments and trash (Ingvertsen et al. 2011). Stormwater can also carry particles from dry deposition of particulates in urban air (Kabir et al. 2014). Pathogens from fecal material or dead animals may also be present.

Research has characterized contaminants in stormwater. Nutrients are often the primary contaminants of concern in stormwater due to their negative impacts on receiving fresh water bodies (Kabir et al. 2014). Both nitrogen and phosphorus are typically elevated in stormwater suggesting that use of green infrastructure for stormwater treatment will provide plants with a portion of their required nutrients. Stormwater will typically contain very low levels of metals, some organic contaminants, pathogens and dissolved organic matter (Kabir et al. 2014; McElmurry et al. 2014). The metals most commonly detected in stormwater are copper and zinc, both of which are necessary plant nutrients (Ingvertsen et al. 2011). Other metals including lead, cadmium, and chromium may also be detected, typically at low parts per billion concentrations (Kabir et al. 2014). Organic contaminants in stormwater are likely to consist of petroleum hydrocarbons, herbicide or pesticides and dissolved or suspended organic matter from soils (LeFevre et al. 2012). One study showed that dissolved organic matter in urban stormwater is similar in characteristics to suburban stormwater and water collected from parking lots (McElmurry et al. 2014). Although a study noted increased concentrations of hormones and wastewater micropollutants in CSOs, the observed increase was due to the release of untreated wastewater rather than elevated concentrations of these compounds in stormwater (Phillips et al. 2012).

There are currently no studies about the feasibility of using urban stormwater collected from streets for food production. There are also no regulations on use of these waters. As green infrastructure becomes more common in urban areas, there will likely be some evaluation of the potential for these waters to be used for some type of agricultural production. In the absence of regulations and based on information characterizing the contaminants in stormwater, it would seem advisable to limit use of street stormwater to irrigate crops that have no direct contact with soils. While previous work has suggested low availability of metal and organic contaminants from urban soils, the potential for pathogen transfer is likely the most significant concern with beneficial use of this water source (Attanayake et al. 2014). Tree fruits or bushes for example, could be grown using stormwater with minimal risk of pathogen transfer. Crops like carrots or potatoes would have a much higher risk due to the direct contact of the edible portion with the soil.

Reclaimed Water Basics

In urban areas, all wastewater flows through a centralized system of pipes to wastewater treatment plants. These plants have been designed to remove wastes (primarily dissolved carbon, nutrients, and pathogens) from the water through a combination of biological and chemical processes (Metcalf and Eddy 2003). The solids from these processes are typically treated to stabilize the organic matter and further reduce pathogens. These treated solids, termed biosolids, can then be used as a soil conditioner and fertilizer. Use of biosolids for urban agriculture is discussed in an upcoming chapter. The treated water from these facilities is typically discharged into a natural water body such as a river or lake. Most plants were constructed at low points in the topography so that water flow to the plants would be assisted by gravity. They are also typically located near water to facilitate discharge of the treated effluent. Most of the wastewater treatment plants in the US were constructed or last upgraded after passage of the Clean Water Act when concerns about water availability were much less pronounced then they are today. As a result, very few of these plants were constructed with the necessary infrastructure to divert the treated water from discharge into water bodies to beneficial use sites. Retrofitting these systems to facilitate beneficial use of the treated water involves constructing the necessary underground piping and pumping to deliver the treated water to end use points. Because of the expense associated with this type of capital project, it has typically only been done in areas where fresh water resources are scarce or when new plants and infrastructure are being constructed (http://www.kingcounty.gov/environment/wastewater/ResourceRecovery/ReWater.aspx).

Currently, California, Florida, Texas and Arizona are the states with the most developed reclaimed water use infrastructure. End users are typically large-scale sites such as golf courses or commercial farms (US EPA 2012). Because of the high infrastructure costs, large-scale use of reclaimed water for urban agriculture may be limited. However, there is a potential for use in farms on the perimeter of cities or for larger farms in urban areas (Fig. 2).

Grey water basics are covered in a following chapter.

Fig. 2 A reclaimed water and biosolids compost demonstration garden at the South Treatment Plant operated by the King County Wastewater Treatment Division. The garden includes both edible and ornamental crops and is used as a way to educate potential customers and the general public about the benefits and safety of reclaimed water use. Picture Jo Sullivan

Regulations on Potable Water Alternatives

Rainwater

There are currently no regulations concerning use of rainwater for growing food crops. Summaries of rainwater regulations and guidance on a state by state basis can be found at the following websites: American Rainwater Catchment Systems Association (www.arcsa.org) and the National Conference of State Legislatures (http://www.ncsl.org/research/environment-and-natural-resources/rainwater-harvesting.aspx).

Many states have guidance on how to collect rainwater, likely quantities of rainwater that can be collected, how to store rainwater and how to filter and treat the collected water for different end uses. For example, Texas has a rainwater harvesting manual that includes a wealth of information on multiple aspects of rainwater harvesting (http://www.ecy.wa.gov/programs/wr/hq/pdf/texas_rw_harvestmanual_3rdedition.pdf). The manual includes information on types of collection systems, expected efficiencies of different systems, water quality and treatment, water balance and system sizing, best management practices, costs and available incentives for both individuals and municipal structures. According to the manual, it is important to consider the roofing material to determine both if a rainwater collection system is recommended and the expected efficiencies of different systems. For example, roofs made of clay or concrete tile are porous. While these materials will not impact water quality, they will reduce efficiency as a result of loss from texture, slower flow and increased evaporation. Roofs made from composite or asphalt are likely to leach toxins and so should not be used for collection of potable water but can be used for collection of irrigation water.

Multiple sources recommend that the 'first flush' of water, the first water collected after a dry spell, will likely have higher concentrations of particulates and contaminants than water collected from a primed surface. There is also information provided on how to filter particulates from collection systems and how to remove contaminants or pathogens from these systems. Most of these manuals were written with multiple uses of collected water as a focus. Specific consideration of use of the water for food crop irrigation is absent, however guidelines can be interpreted with this in mind.

Grey Water

Reuse of grey water is more heavily regulated than use of stormwater. In some cases reuse of grey water is prohibited while in others regulations governing reuse are in place or being established. The Washington State Department of Health recently codified regulations on grey water reuse for subsurface irrigation (http://www.thegreywaterguide.com/washington-state.html). These regulations separate grey water into two categories: light grey water and dark grey water. Light grey water originates from bathroom sinks, showers, and clothes washing machines. Dark grey water originates from kitchen sinks and dishwaters, non-laundry utility sinks, and any other water used in the home that has not come into contact with black water (water from toilets or urinals). There are specific regulations based both on the type of grey water and on the quantity of grey water that is generated (Table 1). This tiered system was put into place to require increasing levels of treatment and certain use restrictions based on the expected concentrations of hazardous materials

Table 1 Regulations on greywater use based on source of water and on size of system developed by the Washington State Department of Health and codified in Chapter 246–247 WAC

Project type	Source of greywater	Storage	Quantity	Treatment and distribution
Tier one	Light greywater	None	Less than 60 gal per day per irrigation system- limit 2 per building	No treatment- gravity (exception: treatment is required when used in a public location such as a playground, school, church or park)
Tier two		Less than 24 h per day	Less than 3500 gal per day	No treatment- even distribution (typically by pressure)
Tier three	Dark greywater	No limit	Less than 3500 gal per day	Treatment required- even distribution (typically by pressure)

The regulations were put into place in July, 2011 in the grey water. For example, the Tier three system is required to treat dark grey water, light grey water stored for more than 24 h (time for pathogen and algal growth), or any water type to be used in a green roof or public environment (http://www.doh.wa.gov/Portals/1/Documents/Pubs/337-063.pdf).

Arizona has similar but somewhat less restrictive regulations (http://www.azdeq.gov/environ/water/permits/download/graybro.pdf). While greywater may only be used for irrigation, both flood and subsurface irrigation are allowed. Reuse of greywater by homeowners is allowed without any permitting with the provision that homeowners follow recommended best management practices. In contrast, regulations in California are more complex and include a consideration of soil type in determining how much water a system can absorb. Permits are required for systems that reuse any water in addition to water generated by clothes washing machines (http://www.hcd.ca.gov/codes/shl/2007CPC_Graywater_Complete_2-2-10.pdf). Other states currently ban or severely restrict the use of greywater. In Florida, use of greywater is limited to flushing toilets and water must be treated before it can be used (http://edis.ifas.ufl.edu/ae453). However, this is likely to change as the environmental and economic benefits of greywater reuse are appreciated and the risks associated with use are better understood. For example, although greywater use is currently banned in most states, it is easy to find isolated examples of reuse for various purposes (http://blog.chicagolandh2o.org/2012/11/08/how-soon-is-now-the--future-of-water-reuse-becomes-reality-at-an-oak-park-home/). These examples are likely the first steps to more universal acceptance of greywater use including use for irrigating food crops.

Laundry to Landscape- Greywater Use in Northern California

Daily Acts is a nonprofit located in Petaluma, CA (http://dailyacts.org/dao-home). It was founded in 2002 by Trathen Heckman with the goal of demonstrating how daily acts by families and individuals could both nurture community and have a positive environmental impact. Daily Acts is one of about 150 similar nonprofits in the US focused on building personal and community resilience (http://www.transitionus.org/). Daily Acts is currently working with a number of municipalities in Northern California to facilitate adoption of grey water diversion from wastewater to home lawns and gardens in a program that Heckman refers to as ‘Laundry to Landscape’.

Although grey water use in California had been legal, it had not been widely adopted due to a very cumbersome permitting process along with high costs for system installation and restrictions on water end use. The push for broader acceptance of grey water reuse in California began as an environmental movement rather than as a municipal cost savings or water conservation initiative. For example, Greywater Action (http://greywateraction.org/) and the Greywater Guerrillas (http://www.nytimes.com/2007/05/31/garden/31greywater.html?pagewanted=all) were two groups pushing for a regulatory structure

(continued)

that would promote grey water reuse. This has evolved and continues to evolve in Northern CA over time. A series of workgroups, combining a broad range of stakeholders has helped to engender confidence in the safety of less restrictive grey water use, which in turn has enabled broader adoption of Laundry to Landscape.

In 2008 the California State Senate Bill 1258 directed the Department of Housing and Community Development to develop revised standards for indoor and outdoor uses for residential grey water systems. An initial group was put together prior to the grey water bill revisions that took place in 2008. Heckman was invited to participate in the process in preparation for the rewriting of the regulations. The group included a broad range of stakeholders who, through an iterative process, developed a white paper that provided the background for the revisions. A civil engineer was involved in the process and provided engineering approval to the suggested revisions. This was critical to public and regulatory acceptance of the more liberal rule that was developed. Also critical was a simple system, where a branched drain was used to divert water from home washing machines into yards. The system had been approved by the City of Berkeley. Having a model system to include in the discussion was also an effective tool to facilitate regulatory change.

It is now possible to install a greywater system in homes in a growing number of municipalities in Northern California without a permit. In some cases, the municipality will also provide subsidies for purchasing greywater systems and training for instillation and use. It is not permitted to use the greywater to grow crops that come into direct contact with soil. However, use of the water to irrigate fruit trees and other edibles that do not contact the soil is encouraged. Daily Acts held a first training workshop in Petaluma in 2010 with 5 systems installed. A neighboring town, Santa Rosa was also interested and so held a shorter weekend training, again led by Daily Acts with a total of 12 systems installed. In 2012 Daily Acts had a 100 Greywater Systems Challenge in partnership with four municipalities. A free workshop in Petaluma attracted 80 participants. For each family of four who does this conversion, 5000–8000 gal of water are diverted from centralized treatment facilities to soils.

Heckman considers himself to be a permaculture- ecological designer using a holistic perspective to apply the principles and functions of natural systems to homes and municipalities. Reuse of greywater fits directly into this vision. Conserving and catching water is one of the core elements of permaculture. He says that ‘we can change the world in a garden’. A greywater system as part of a natural garden landscape with medicinal plants, edible plants, bees and chickens is a means to educate people. Heckman has seen that reconnecting people to the hydrological cycle through greywater diversion in their homes is a very powerful tool with broader implications. While Daily Acts did not set out to be greywater experts, he now recognizes that greywater is a perfect entry point into ecological design and a sustainable world (Fig. 3).

(continued)

Fig. 3 A greywater workshop hosted by Daily Acts. The pictures show an indoor demonstration of the plumbing retrofit required, changing the plumbing on a washing machine, and installing the irrigation system outside a home (Photos Daily Acts)

Fig. 3 (continued)

Reclaimed Water

Reclaimed water is effluent from municipal wastewater treatment plants that has been treated to a high enough standard to be suitable for different end uses. This water is very easy to regulate and very difficult to distribute. The water is generated by public facilities that are already subject to a range of regulatory requirements and oversight.

Table 2 EPA guidelines for reclaimed water use for urban and agricultural uses

	Treatment	Reclaimed water quality	Reclaimed water monitoring	Setback distances
Urban reuse	Secondary	pH = 6.0–9.0	pH- weekly	50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media
	Filtration	≤10 mg/l BOD	BOD- weekly	
	Disinfection	≤ 2 NTU	Turbidity- continuous	
		No detectable fecal coliform/100 ml	Fecal coliform- daily	
		1 mg/l Cl_2 residual (min.)	Cl_2 residual- continuous	
Agricultural reuse	Secondary	pH = 6.0–9.0	pH- weekly	50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media
	Filtration	≤ 10 mg/l BOD	BOD- weekly	
	Disinfection	≤ 2 NTU	Turbidity- continuous	
		No detectable fecal coliform/100 ml	Fecal coliform- daily	
		1 mg/l Cl_2 residual (min.)	Cl_2 residual- continuous	

The analysis conducted to meet these requirements is similar to what is required to test water to determine if it is acceptable for beneficial reuse. The US EPA has established guidelines for water reuse (Table 2). The guidelines, last issued in 2012, include recommendations for water quality standards for different types of reuse, a discussion of technical and legal issues associated with reuse along with examples (http://water.epa.gov/infrastructure/sustain/availability_wp.cfm).

Urban use is typically considered to be limited to landscape and golf course irrigation with no specific provisions for urban agriculture. The EPA recommended guidelines for unrestricted use of reclaimed water for urban irrigation and irrigation for food crops that may be eaten raw are shown in Table 2. Guidelines for both end uses are identical, suggesting that if reclaimed water meets standards for unrestricted landscape irrigation it would also be suitable for edible crop irrigation. EPA also has additional recommendations for water quality for crop irrigation. These recommendations are designed to protect the plants that are being irrigated rather than the people that would eat the plants. A portion of these are shown in Table 3. These guidelines focus on the potential for reclaimed water to increase soil salinity and the availability of certain inorganic ions to hinder plant growth.

Table 3 Recommendations for reclaimed water characteristics to protect plant health from US EPA

Potential problem		Units	None	Slight to moderate	Severe	
Salinity						
	Electrical conductivity (EC)	dS/m	<0.7	0.7–3.0	>3.0	
	Total dissolved solids (TDS)	mg/L	<450	450–2000	>2000	
Infiltration						
Sodium adsoprtion ratio (SAR)						
	0–3			>0.7	0.7–0.2	<0.2
	3–6		And EC=	>1.2	1.2–0.3	<0.3
	6–12			>1.9	1.9–0.5	<0.5
	12–20			>2.9	2.9–1.3	<1.3
	20–40			>5.0	5.0–2.9	<2.9
Specific ion toxicity						
	Sodium (Na)					
	Surface irrigation	SAR	<3	3–9	>9	
	Sprinkler irrigation	meq/l	<3	>3		
	Chloride (Cl)					
	Surface irrigation	meq/l	<4	4–10	>10	
	Sprinkler irrigation	meq/l	<3	>3		
	Boron (B)		mg/L	<0.7	0.7–3.0	>3

For both cases, concentrations are defined that will be acceptable for plants that are watered primarily using reclaimed water.

When reclaimed water meets required standards, use for food crop or landscape irrigation is generally broadly supported. In general, use of reclaimed water is increasing across the country. Different states have different regulations governing water quality for unrestricted irrigation of food crops as well as for urban use. Currently 32 States have water quality guidelines for urban irrigation water quality and 27 have guidelines for agricultural irrigation of food crops. As of 2011, 29 % of the reclaimed water that was beneficially used was used for agricultural irrigation with 18 % used for landscape or golf course irrigation. This is expected to increase rapidly (US EPA 2012).

Environmental Benefits

Watering a garden using a hose connected to the home's water supply uses water that has been treated to drinking water standards to grow food. With grey water or stormwater, water that would otherwise have required treatment is being used, while at the same time potable water is being conserved. Use of reclaimed water is using treated water, but also conserving potable water. There are multiple environmental benefits associated with using alternative water sources to irrigate a garden, but the primary benefits are linked to reducing the amount of water that requires treatment on either end of the pipeline. While these benefits will vary based on the source of the water that is used and the nature of the drinking water and wastewater infrastructure in a particular area, in general the practices prevent water from entering the stormwater or wastewater treatment systems and also reduces the quantity of water that needs to be treated to meet potable water standards.

Alternative water sources save both energy and money. The energy savings from diverting water from centralized treatment as well as the monetary savings from reduced infrastructure requirements and the associated capital costs for constructing that infrastructure can be estimated (Center for Neighborhood Technology 2010; Ghimire et al. 2014). A recent study quantified the benefits of domestic stormwater harvesting using life cycle assessment. The collected water was directed towards toilet flushing but benefits would likely be similar if the water was used for irrigation (Ghimire et al. 2014). The authors found that use of harvested rainwater conserved energy, and reduced fossil fuel use, eutrophication potential, and potable water use. Human health benefits (including cancer, non cancer, and health criteria air pollutants) also benefitted from domestic rainwater harvesting.

In a midsized city, the local wastewater utility uses about 343 kWh to treat 1000 m^3 of water. It is possible to calculate the fossil fuel use associated with that by using the specific CO_2 equivalent for electricity in that region. Using the US EPA calculator, this amount of energy (343 kWh) is similar to that released by burning 27 gal of gasoline. There is also an economic cost for stormwater treatment. For example, the City of Chicago spends $0.025 for every cubic meter of stormwater it treats. For each 100 m^2 roof in that city that installs a rainwater collection system (about the size of a single family home), the city saves about $2.09 in treatment costs annually. If a new subdivision were constructed where all homes had stormwater collection, the city would also be able to reduce the size of the treatment facility. The City of Portland has estimated that the cost of grey or engineered infrastructure for each square meter of impervious surface is about $29.00. If citizens harvest rainwater from the roof of their homes and used it to water their gardens, these emissions and dollar costs are avoided. If greywater is diverted from treatment and this is done on a large enough scale, similar savings are achieved.

References

American Rainwater Catchment Systems Association (www.arcsa.org)

Arizona Department of Environmental Quality. http://www.azdeq.gov/environ/water/permits/download/graybro.pdf

Attanayake CP, Hettiarachchi GM, Harms A, Presley D, Martin S, Pierzynski GM (2014) Field evaluations on soil plant transfer of lead from urban garden soil. J Environ Qual 43:475–487

California http://www.hcd.ca.gov/codes/shl/2007CPC_Graywater_Complete_2-2-10.pdf

Center for Neighborhood Technology (2010) The value of green infrastructure a guide to recognizing its economic, environmental and social benefits. www.cnt.org/…/gi-values-guide.pdf
Florida http://edis.ifas.ufl.edu/ae453
Ghimire SR, Johnston JM, Ingwersen WW, Hawkins TR (2014) Life cycle assessment of domestic and agricultural rainwater harvesting systems. Environ Sci Tech 48:4069–4077
Ingvertsen ST, Bergen Jensen M, Magid J (2011) A minimum data set of water quality parameters to assess and compare treatment efficiency of stormwater facilities. J Environ Qual 40:1488–1502
Kabir MI, Daly E, Maggi F (2014) A review of ion and metal pollutants in urban greenwater infrastructures. Sci Tot Environ 470–471:695–706
LeFevre GH, Novak PJ, Hozalski RM (2012) Fate of naphthalene in laboratory- scale bioretention cells: implications for sustainable stormwater management. Environ Sci Tech 46:995–1002
McElmurry SP, Long DT, Voice TC (2014) Stormwater dissolved organic matter: influence of land cover and environmental factors. Environ Sci Tech 48:45–53
Metcalf & Eddy (2003) Wastewater engineering: treatment and reuse, 4th edn. Metcalf & Eddy/McGraw-Hill, New York
National Conference of State Legislatures http://www.ncsl.org/research/environment-and-natural-resources/rainwater-harvesting.aspx
Phillips PJ, Chalmers AT, Gray JL, Kolpin DW, Foreman WT, Wall GR (2012) Combined sewer overflows: an environmental source of hormones and wastewater micropollutants. Environ Sci Tech 46:5336–5343
Texas Rainwater Harvest Manual http://www.ecy.wa.gov/programs/wr/hq/pdf/texas_rw_harvestmanual_3rdedition.pdf
US EPA (2012) Guidelines for Water Reuse. EPA/600/R-12/618. http://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf
Van Meter KJ, Basu NB, Tate E, Wyckoff J (2014) Monsoon harvests: the living legacies of rainwater harvesting systems in South India. Environ Sci Technol 48:4217–4225
Washington State Department of Health http://www.thegreywaterguide.com/washington-state.html