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Rainwater Harvesting: A Holistic Approach for Sustainable Water Management in Built Environments

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Summary: This article describes a holistic approach for planning and implementation of water infrastructure in built urban environments. The holistic approach is based on recognizing the links between all water on a site, from potable water to stormwater. The holistic approach facilitates sustainable management of water resources and water infrastructures. Rainwater harvesting system, defined as rooftop rainwater capture and use is a key component of developing a holistic approach for water management in urban environments. The topics discussed in the article include: 1) characteristics of urban runoff and potential impact of rooftop rainwater harvesting on stormwater drainage system, 2) characteristics of potable water systems and potential impacts rooftop rainwater harvesting and use on water and energy conservation, and 3) the status of groundwater systems in urban environments and potential advantages of rainwater harvesting in conjunction with groundwater recharge and storage. The article is concluded with potential impediments to implementing rainwater systems in urban environments.

Keywords: urban water infrastructure, decentralized water infrastructure, rainwater harvesting

Introduction

Urbanization dramatically alters the hydrology of a landscape. As the percentage of impervious area increases, runoff, particularly from small, high frequency storms increases, potentially causing flooding, carrying pollutants to surface waters, and decreasing groundwater infiltration (see Shuster et al 2005 for a review). These changes in the fate of precipitation have received significant attention and lead to restructured stormwater regulations geared to more closely match natural hydrology. However, these increases in runoff represent only a small fraction of the changes to the overall water balance of a site and ignore the significant volume of water that enters and leaves site as potable water and wastewater. A holistic approach to urban water management requires recognizing that all water on a site should be considered as part of the site water balance and should be actively managed to replicate the natural hydrology.

Embracing a holistic approach to water management will also require decreased reliance on centralized water infrastructure, the backbone of modern urban systems. This infrastructure depends on water treatment systems, pumps and pipelines to deliver potable water to urban areas and remove wastewater. In 2005 in the U.S., 1.6 billion m^3 of freshwater per day were withdrawn from the rivers, lakes and groundwater systems with 0.17 billion m^3/day (11 percent) attributed to public domestic water consumption (Kenny et al. 2009) and approximately 25 to 30 percent of this water lost to leakage before reaching its point of use(Kirmeyer et al., 2001). In WashingtonD.C., the D.C. Water and Sewer Authority (DCWASA) delivers 0.4 million m^3/day of potable water, while the DCWASA's Blue Plains Wastewater Treatment Facility treated 1.2 million m^3/day of sewage and stormwater (DCWASA 2010). This import and export of water represents a significant deviation from the pre-development hydrologic cycle. In addition, these two types of water are viewed as completely separate. A holistic approach to water management requires looking at all of the sources and sinks of water on a site.

This paper focuses on rainwater harvesting as a tool in a holistic approach to rainwater harvesting. Rainwater harvesting has served water supply demands since Carthaginian-Roman civilization (Crasta et al. 1982) and in recent year has gained attention as a low impact development best management practice (BMP). In the context of this paper, rainwater harvesting system is defined as rooftop rainwater capture and use for various purposes. Figure 1 shows a modern rainwater capture and use system.

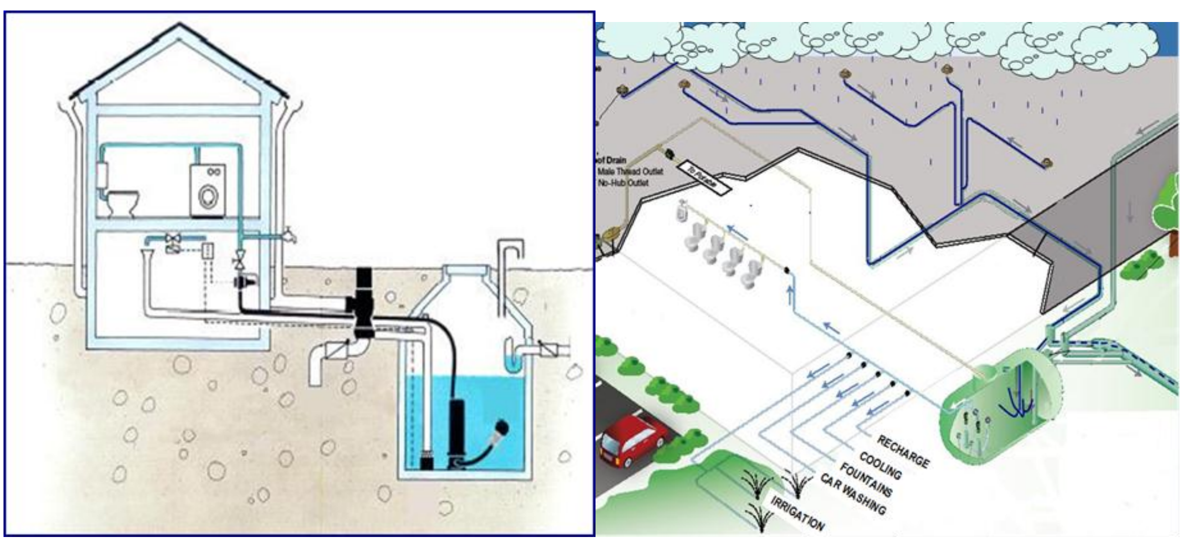

Figure 1. Modern rainwater harvesting and use (Credit: Rainwater Management Solutions, Inc.)

In the modern world, rainwater harvesting has been implemented as a water supply option in both developing and developed countries, mostly in localities where conventional water supplies are non-existent and/or cost-prohibitive (Yaziz et al. 1989, Younos et al. 1998). In recent years, in developed countries there is increased emphasis on green building design and a significant trend toward rooftop rainwater harvesting for in-building non-potable water uses, such as flushing toilets and outdoor non-potable uses such as landscape irrigation. Design procedures for rainwater harvesting are well documented (e.g., Lawson et al. 2009).

Rainwater harvesting is especially well-suited as a stormwater management practice in urban areas. Assuming a 20 percent loss due to splash and evaporation, 1cm rainfall depth on a single 1,000 m^2 rooftop area can generate about 8.0 m^3 of runoff volume to stornwater drainage system. The impact can be significant when considering the high density of building in urban setting. For example, seventeen percent of the 127 km^2 (31,400 acres) Cub Run watershed in the suburban Washington D.C. is impervious (Dougherty et al. 2004).On average, building rooftops constitute 16 to 45 percent of the impervious areas in urban environments (Akbari et al. 2003).If rooftops in Cub Run constitute 30 percent of the impervious area, 1cm of rainfall would produce 64,770 $m^3$of rooftop runoff to stormwater drainage system. Based on the average annual rainfall for the D.C. area(100 cm,www.weather.com), the rooftops in the Cub Run watershed would produce over 6 million m^3 of runoff per year. While rooftop runoff typically contains less nitrogen and phosphorus than site runoff, the increase in runoff volume is still a threat to receiving waters and several contaminants, such as metals, are associated with rooftop material and enter the stormwater drainage system(Chang 2004; Göbel et al. 2007).Limited land availability and high land values can make many low impact development practices such as bioretention areas difficult to implement, increasing the attractiveness of rainwater harvesting as a BMP. In addition, on many urban sites, the roof area constitutes a high percentage of the overall site imperviousness.

Rainwater Harvesting Systems

Rainwater Harvesting for Stormwater Management

Rainwater harvesting is emerging as a promising low-impactBMP for urban stormwater management.Several studies have documented the impact of rainwater harvesting systems on runoff volume reduction (e.g., Herrmann and Hasse, 1997; Gowland and Younos, 2008).Table 1 shows the effects of rainwater harvesting and use on stormwater runoff volume reduction for several buildings in Virginia localities studied by authors of this paper.Characteristics of rooftop runoff quality differ from other impervious surfaces such as roads and parking areas and also vary among roofs for different roof material. Metals are the most commonly noted contaminants of concern in rooftop runoff (e.g., Good 1993; Förster 1996; Chang 2004; Göbel et al. 2007).Chang (2004) noted that roofs can be a serious source of nonpoint source pollution and found that concentrations of Al, Mn, Cu, Pb, and Zn in roof runoff exceeded the national surface water quality standardsat least 5 percent of the time while Zn and Cu concentrations most often violated standards. Rainwater harvesting can be a method to reduce the input of these metals to surface waters.

Table 1. The impact of rainwater harvesting and use on stormwaterdrainage volume

Building Type & Rooftop Area (m^2)	Location & Annual Rainfall (cm/year)	Estimated Available Rainwater [(a)] (m^3/year)	Projected Rainwater Use & Use Purpose (m^3/year)	Balance to Stormwater Drainage (m^3/year)
Blacksburg[(b)] Municipal Build. (BMB) (205)	Blacksburg, VA (108.28)	753	856 Indoor use (toilets for 80 users) Outdoor use (landscape irrigation)	0[(e)]
Blacksburg[(b)] Motor Company Build. (BMC) (930)	Blacksburg, VA (108.28)	795	193 Indoor use (toilets for 25 users) Outdoor use (landscape irrigation)	602
Manassas Park[(c)] Elementary School (5,713)	Manassas Park, VA (91.95)	4991	4922[(c)] Indoor use (toilets and urinals for 1,067 users) Outdoor use (landscape irrigation)	69
Charlottesville[(d)] Area Transit Facility (2,443)	Charlottesville, VA (108.10)	18671	16057[(d)] Indoor use (toilets and urinals and bus wash facility)	2614

(a) Based on rainwater harvesting design procedures (see Lawson et al. 2009); (b) Gowland and Younos 2008; (c) The water use estimate is based on the volume of water supplied by the rainwater harvesting system design calculations not the total demand; (d)Information for the Charlottesville Area Transit Facility was obtained from engineers; (e)It's assumed that all captured rainwater is used.

A rainwater harvesting system considers this stormwater runoff a resource not a pollutant. In most rainwater harvesting systems, the volume of potable water saved is equal to the volume of runoff reduced, and both represent a decrease in imports and exports of water from the site. In this sense, rainwater harvesting as an alternative water source and as a BMP are synergistic.

Based on a study by the Pacific Institute, non-potable water uses, such as landscaping (35%), cooling (15%), laundry (2%), and toilet flushing (12% (72% of restroom water use is toilet flushing and restroom use represents 16% of overall water use) represent a significant portion of water use in the commercial, institutional and industrial sector (Gleick et al 2003). A holistic approach to water management recognizes that these end uses do not need to be supplied by the water of drinking water quality.

Even though non-potable water demands are frequently high,if a large portion of the captured rainwater cannot be used in a built environment, other means of disposal for the excess rooftop runoff must be considered. For example, for the Blacksburg Motor Company Building (BMC) shown in Table 1 there is potential for only for 193 m^3 of captured rainwater (< 25%) to be used and the balance would flow to stormwater drainage system. Possible solutions to address excess rainwater include considering an integrated approachfor stormwater management noted earlier that incorporates RWH and other BMPs such as bioretentionsystems. Under appropriate conditions, sharing of captured rooftop rainwater between adjacent/nearby buildings can be considered a feasible option. For example, excess captured rainwater from the BMC building (Table 1) can be directed to the adjacent BMB building where water demand exceeds water availability. This approach can have potential application in shopping malls where several businesses with varying water demand share the same building and potable water system. In other situations, the excess water can be used to alleviate groundwater depletion and further diminish the alterations from the natural hydrologic cycle.

RWH for Groundwater Preservation and Drought Management

Many urban areas experience chronic and significant groundwater level decline due to reduced surface infiltration caused by increased impervious areas and excessive groundwater withdrawal for public and industrial consumption. In many coastal cities, the combination of urbanization and groundwater withdrawal has resulted in saltwater intrusion in coastal aquifers. Integrating a RWH system and artificial groundwater recharge (AGR) system in built urban environments could prevent salt water intrusion into coastal aquifers (Grady and Younos 2010). In such integrated systems, the excess rooftop runoff (tank overflow after use) can be directed to a recharge well. If land is available, an infiltration trench or similar LID-BMPs can also facilitate groundwater recharge. However, implementation of a conjunctive RWH-AGR system will require better knowledge of captured rainwater quality to prevent introduction of harmful contaminants, such as heavy metal, into the groundwater system. With further research, appropriate water filtration and monitoring schemes may be developed.

Effects of RWH on Potable Water and Energy Savings

Restoring the natural hydrologic cycle through rainwater harvesting will have the additional environmental benefit of reducing energy use. Younos and Lawson (2011) illustrated potential energysavings due to a decentralized rainwater harvesting system in a case study site- planned renovation of Anacostia Senior High School in Washington D.C. – rooftops area approximately7711 m^2 where captured rainwater (5,000 m^3) will be used for flushing toilets and urinals and landscape irrigation. Using estimates of energy use by rainwater harvesting system (Grady and Younos 2008; Garrison et al. 2009) and energy use by waterwater/stormwatertreatment facilities (DDOE 2010; DCWASA 2006), theAnacostia High School rainwater harvesting system would both reduce demand on the potable distribution system and prevent stormwater from entering combined sewer system. The planned rainwater harvesting system would represent a decreased energy use of 2,370 kWh per year.

Impediments to RWH in Urban Environments

While the use of rainwater harvesting is the United States is increasing, multiple issues must be addressed for it to reach its full potential. At present, potable water in the U.S. is inexpensive and financial incentive on water savings alone is not a convincing argument to commercial land developers. There is a need to facilitate educational opportunities for developers on water sustainability and advantages of integrating RWH system in green buildings and retrofitting of old buildings. Another area of concern related to implementing rainwater harvesting system is lack of governmental guidance and regulations. At present, in most states the guidelines for rainwater harvesting are not clearly addressed by regulations and codes. States such as Texas, Virginia, Oregon, Georgia and North Carolina have made progress towards clear regulation for implementing rainwater harvesting systems. However, few states have comprehensive regulations to address both the use of harvested rainwater and design of rainwater harvesting systems as a stormwater management practice or groundwater recharge option.

Conclusion

Rainwater harvesting systems should be considered as a component of an integrated and holistic approach for sustainable management of water resources and urban water infrastructure. The implementation of rainwater harvesting systems as a low- impact development BMP can either eliminate or reduce the impact of rooftop runoff on stormwater drainage and receiving waters resulting in improved surface water quality and meeting the goal of the Clean Water Act. RWH systems can contribute to potable water and energy savings as and assist in groundwater preservation and prevention of saltwater intrusion in coastal aquifers.

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