Green Roof Performance Measures

A Review of Stormwater Management Data and Research

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Peter A. Johnson
Chesapeake Bay Foundation – Anacostia River Initiative

Introduction

Green roof technology is used in many urban settings to improve storm water management by reducing total quantities of rooftop runoff and peak flow rates during high-intensity rains. The water quantity retention performance of green roofs has been measured and documented for a range of conditions and design parameters. In contrast to water quantity data, however, water quality measurements from green roof systems are much less available. As green roofs become standard acceptable technologies for managing stormwater, their water quality performance may need more verification.

This paper reviews recent green roof water quality and quantity research data as well as the process for evaluating BMPs in general and green roof technology in particular that has been proposed as a method for stormwater management.

The green roof as an acceptable technique for storm water management

Most major urban regions have developed laws and regulations for storm water management that apply to commercial property owners. Typical regulations require owners to install and maintain systems that will prevent or reduce the pollutants that are carried by rainwater when it washes off buildings, sidewalks and parking lots into storm sewers. These regulations usually specify the size and performance of storm water management technologies that are acceptable for a specific site based on calculations of runoff volumes and possible pollutant discharges. The District of Columbia has adopted regulations and a supplementary stormwater management guide that follow a practice similar to most other major urban areas in the United States.

Typical stormwater management guidebooks, including the one for DC, refer to systems termed “BMPs” (best management practices) that are designed to capture and retain certain quantities of stormwater and also filter it to remove pollutants before discharging the water into storm sewers. The design and selection process for these BMPs are described in the guidebook and an owner or developer can select the one that is best for a specific site. While green roofs are equivalent to many BMPs in their ability to manage stormwater, guidebooks do not usually reference them as acceptable techniques that meet regulatory requirements. Reasons for this may be the lack of water quality test data for the performance of green roofs or the lack of clear performance standards to justify a design to reduce certain levels of pollutants in stormwater discharges. As green roofs become a more standard practice, more specific design standards should be used.

Water quality data for green roofs

A few US researchers have collected data measuring water quality from green roof experiments. Three of the sets of measurements reported recently are from experiments by the City of Portland, Oregon; by North Carolina State University; and by Pennsylvania State University. While these and other data suggest that green roofs can be designed to filter some pollutants from rainwater, none are comprehensive enough to validate long-term performance of specific green roof designs. In addition to this work in the US, some longer-term studies have been done in Germany that provide data to help design green roofs that will remove certain pollutants.

Some green roof practitioners have noted that up to 30 percent of nitrogen and phosphorus contained in runoff from urban areas originates in the dust that accumulates on rooftops and other surfaces. Green roofs have the potential to filter this kind of contamination (Miller, 2003).

Experiments in Portland Oregon in 2002 reported by Tom Liptan (City of Portland Bureau of Environmental Services) provide some data on phosphorus concentrations in runoff. The measurements show higher concentrations in green roof runoff than in the rainwater but several experimental problems were noted.

A paper published in August 2004 discusses green roof research and water quality data from experiments by Dr. Bill Hunt and others at the Water Resources Research Institute, N. C. State University. Samples of green roof rainfall runoff were collected over a six-month period during 2003 and compared with that of a control roof and rainwater. Concentrations of total nitrogen and total phosphorus were measured. Results showed that nitrogen concentrations from the green roof were the same as the control roof and phosphorus concentrations were higher. The authors postulated that total nitrogen might decrease over a longer time experiment but probably, for this green roof, both N and P were leaching from the soil media.

The Penn State Center for Green Roof Research, has conducted a series of experiments measuring water quality from test green roofs over several years period beginning in 2000. Some of the parameters measured were nitrates, particulate matter and pH. The results of these experiments have not yet been published but results posted on their web page show that the runoff from their green roofs contains fewer nitrates, particulate matter and has a higher pH.

Studies conducted by Dr. Manfred Kohler and Dr. Marco Schmidt at the Technical University of Berlin add longer-term data on green roof water quality performance. Their work reported in 2004 show that green roofs retain and bind contaminants from air dust or rain but nutrients can leach out of the substrate as well. However, the leaching of nutrients can be reduced over time as shown by experiments over four years. These studies also show that, with the appropriate choice of substrate, mature green roofs can be designed to reduce total pollutants discharged in the runoff.

One monitoring experiment was conducted on a Washington DC green roof during 2006-2007. Water quality and quantity data were collected from the American Society of Landscape Architects (ASLA) headquarters building 3,000 sq ft green roof at 636 Eye Street NW. The ASLA green roof retained approximately 75% of the total rainfall volume that fell on it over the ten month period that data were collected. Nitrogen concentrations were similar to the values measured in the rainwater indicating that, when combined with the measured volume reduction, a significant overall reduction of nitrogen in stormwater runoff from a green roof can be expected.

While these and other experiments show that certain pollutant removal from rainwater is possible with green roofs, more research is needed to confidently predict the performance of specific designs.

Water Quantity Control data for green roofs

Green roofs will retain significant quantities of stormwater during low to moderate rainfalls and, during extreme events, will delay and reduce peak flows. A number of researchers have conducted controlled experiments and published replicable data on the performance of green roofs in reducing the quantity of stormwater runoff.

The most common practice for extensive green roofs incorporate approximately 3" to 4" of growing medium vegetated with a mixture of sedum plants plus a commercial drainage mat, a root barrier and standard waterproofing. These systems have been shown to reduce storm-water runoff by 50-100% during most rains resulting in an average of about 50% - 75% total water retention from rainfall over a typical year. This water retention, in effect, means that over half of the annual rainfall on a typical green roof stays on the roof until it is evaporated back into the air, thus never entering the stormwater system. Over an average year of typical Washington DC rainfall, such a green roof would retain about 15 gallons of stormwater per square foot of coverage.

In very heavy rains green roofs will not retain all of the water but they usually delay runoff and reduce peak flow rates. The effectiveness of green roofs as stormwater detention systems will vary depending on the system design, depth of substrate and climate. All green roofs have a limited retention capacity that can be described by a "threshold storm" (defined by volume, rate and duration). In designing green roofs it is important to define the size and type of storms it is intended to address.

The reduction in flow rates from storms that green roofs provide can serve to reduce overflows of combined sewer systems and other retention facilities. The data on water quantity control performance are available from several sources. One key source is the Center for Green Roof Research at Penn State which has collected recent data from their test roofs that can be readily applied to local US east coast conditions such as

Washington DC.[1] Another source is a Federal Technology Alert recently published by the US Department of Energy [*Green Roofs – 2004*].[2] This report contains data on rainwater runoff and retention capacity for different green roof soil depths. It concludes that a green roof with 3-4 inches of soil can retain about one inch of rainfall. One inch of rain is equivalent to about 0.6 gallons of water per square foot of green roof area. This report concludes that a typical green roof will absorb, filter, retain and store up to 75% of the annual precipitation that falls on it under conditions prevalent in most areas of the United States.

In other research work, the City of Portland Bureau of Environmental Services found that a typical green roof captures and evaporates between 10 and 100 percent of the rainfall depending on both the roof design and the characteristics of the rain event. (BES, 2004) The nature of the growing media such as size and texture of soil particles as well as the soil depth have a large influence on water retention capacity (NebGuide, 1996). Because most extensive roofs have growing media specifically engineered to be lightweight and thin, their design has great influence on retention capacity. Some additional data collected by the firm "Roofscapes, Inc." show that about three inches of growing media will reduce average annual rainfall by more than 50 percent (Roofscapes Inc. 2002).

Using a combination of the above data for guidance, the following table provides some rough estimates of the water retention capacity for a typical extensive green roof under the conditions prevalent in the Washington DC area. These numbers can be used for making first estimates of performance but each roof design will have its own performance measures and they can be determined through the application of available test data for specific systems.

Stormwater retention capability of typical extensive green roof in Washington DC

	Gals per sq ft of green roof	Gals per acre of green roofs
Green roof water retention max for single rain event	0.6	25,000
Green roof water retention total for average year of rain	15	630,000

<u>Performance Standards for acceptable BMPs</u>

Most stormwater management guides that are used to determine the use of acceptable BMP systems, list those that have been tested to demonstrate their ability to perform on a roughly equal level. That is – the acceptable BMPs will all remove about the same amounts of stormwater pollutants if properly designed, sized and maintained. The process usually used to select a proper BMP is to evaluate which system will best meet site, safety and space requirements and then to design it to the required size to handle

[1] For more data see: (http://hortweb.cas.psu.edu/research/greenroofcenter/)

[2] US Department of Energy, Energy Efficiency and Renewable Energy, Federal Energy Management Program. "Green Roofs", DOE/EE-0298, 2004. (www.eere.energy.gov/femp/).

calculated stormwater quantities. Therefore most guides have assumed that all BMPs are equal with regard to removing pollutants.

The BMPs listed in most guides are categorized as “treatment BMPs”, that is they are designed to treat the stormwater runoff after it is collected from rooftops, sidewalks, parking lots, etc. Some guides (for example, Maryland) cite green roofs as a new technology that offers stormwater management benefits. The Maryland guide states that green roof technology should be evaluated on a case-by-case basis if proposed by a building owner. In at least one guide (California) BMPs are divided into two categories: one designated as “Source Control BMPs”, and the other as “Treatment Control BMPs”. Within these designations, green roofs could be considered as source control systems because they perform best by retaining large amounts of stormwater and related pollutants on rooftops and preventing it from becoming runoff. Under these conditions, treatment is not necessary.

The Washington DC stormwater management guidelines require BMPs to be sized to contain a certain quantity of water equivalent to a one-half inch rainfall on all impervious surfaces. Since a typical green roof will retain about one inch of rainfall, if the green roof coverage is at least 50% of a building rooftop area, it will satisfy the BMP size requirement. This reasoning has been used to evaluate proposed green roofs for buildings in DC and approve the designs as acceptable for stormwater management purposes. To date the coverage of green roofs in DC has been small but more are scheduled to be built over the next years. The following table shows all of the rooftop acreage in DC – some portion of which may be suitable to install green roofs in the future.

Total Acreage of Washington DC Rooftops
Within different regions

	Within CSO	Outside CSO	Total
Anacostia WS	1,500	1,500	3,000
Rock Creek	1,100	1,200	2,300
Potomac	400	500	900
TOTAL	3,000	3,200	6,200

Note: The following is a rough breakdown of this acreage by building type:

Houses & Rowhouses = 45%
Commercial / Institutional = 40%
Federal = 10%
Apartments = 5%

Note:

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