Benefit Measurement and Valuation

1. WATER

STEP 1 - QUANTIFICATION OF BENEFIT: REDUCED STORMWATER RUNOFF

The first step in valuing the water benefits from green infrastructure is to determine the volume of rainfall (in gallons) retained on site; this volume becomes the resource unit for all water benefits. When working through the calculations, keep in mind that some of the ranges given are based on the compilation of multiple cases studies and there may be more site-specific numbers to plug into the given equations. Where possible, the guide will suggest strategies for determining site-specific information.

Practices that provide water benefits include green roofs, permeable pavement, bioretention and infiltration, trees and water harvesting.

GREEN ROOFS

To quantify the stormwater runoff retained from green roofs, it is necessary to know the following information:

- Average annual precipitation data (in inches) for the site
- Square footage of the green infrastructure feature
- Percentage of precipitation that the feature can retain

The highly site-specific variables influencing the percentage of annual rainfall that a green roof is capable of retaining, listed below, are important considerations:

- The most important variable influencing the runoff reduction performance of the green roof is the depth of the growing media. The deeper the roof, the more water retained in the media.
- The growing media's antecedent moisture content will influence stormwater retention for any given storm event. This means that irrigation practices and storm frequency affect overall performance.
- Local climate variables also influence stormwater retention performance. For example, hotter, less humid climates lead to less antecedent moisture and more stormwater retention capacity.
- All else being equal, flat roofs retain more stormwater than sloped roofs.
- Size and distribution of storm events affect total stormwater retention. For example, holding the retention rate and annual precipitation constant, a green roof in a place with many small storms retains a greater percentage of the total rainfall than a green roof in a place with fewer, larger storms.

The following equation relies on two conversion factors. The 144 sq inches/square foot (SF) will convert the precipitation over a given area into cubic inches. Then, the factor of 0.00433 gal/cubic inch (i.e. the number of gallons per cubic inch) will convert that volume of precipitation into gallons, which is needed to quantify the amount of runoff reduced.

[annual precipitation (inches) * GI area (SF) * % retained] * 144 sq inches/SF * 0.00433 gal/cubic inch = total runoff reduction (gal)

Empirical studies of green roof stormwater retention performance have found that green roofs can retain anywhere from 40 to 80 percent of annual precipitation. The calculation in Example 1.1

uses the average of this range, or a 60 percent retention rate, to demonstrate a mid-range performance number:

Example 1.1:
A green roof with an area of 5,000 SF, using a 60% retention rate, will reduce annual runoff in Chicago, Ill. as follows:

[38.01 inches annual precipitation * 5,000 SF area * 0.60 retention rate] * 144 sq inches/SF * 0.00433 gal/cubic inch = 71,100 gallons of runoff reduced annually

TREE PLANTING

Water interception estimates, determined on a per tree basis, are needed to calculate the amount of stormwater runoff reduced from a given project. Therefore, it is necessary to know the number of trees being planted and their size and type. For example, the larger leaf surface area on one kind of tree will intercept more rainfall than will a smaller tree or leaf. In addition, the rate at which trees intercept rainfall is significantly impacted by a site's climate zone, precipitation levels and seasonal variability, which affects evapotranspiration rates.

The Center for Urban Forest Research of the US Forest Services, utilizing its STRATUM model, has compiled a set of *Tree Guides* that take into account many of these factors and estimate the level of benefits provided by trees:
http://www.fs.fed.us/psw/programs/cufr/tree_guides.php

These guides are organized by STRATUM climate zone which can be determined from the map provided at:
http://www.fs.fed.us/psw/programs/cufr/images/ncz_map.jpg

Table 1.1
Annual Rainfall Interception in Gallons from 1 tree, 40-year average, Midwest Region

	Small tree: Crabapple (22 ft tall, 21 ft spread)	**Medium tree: Red Oak** (40 ft tall, 27 ft spread)	**Large tree: Hackberry** (47 ft tall, 37 ft spread)
Rainfall Interception	292 gallons	1,129 gallons	2,162 gallons

Source: McPherson, E. et al. (2006).

Once the climate zone is determined, the tables in the tree guides' appendices are structured according to size of tree, with an example tree type provided. Average annual volume of rainfall interception can then be estimated based on these factors on a per tree basis. Table 1.1 provides an example of this information.

Using these values, the following equation provides an estimate for the volume of runoff intercepted on site:

number of trees *
average annual interception per tree (gal/tree)
= total runoff reduction (gal)

Example 1.2:
This example demonstrates the annual reduction in runoff yielded from planting 100 medium red oaks in the Midwest Region.

100 medium trees * 1,129 gal/tree = 112,900 gallons of runoff reduced annually

BIORETENTION AND INFILTRATION

Well-designed bioretention and infiltration features capture all or nearly all of the precipitation which falls on the feature and its related drainage area. However, in an urban context, the percentage of rainfall that these features can accommodate depends on available square footage and locally determined maximum ponding times. Determining a more site-specific performance measure requires complex hydrological modeling. The equation for determining the capacity of a bioretention feature requires the following information:

- Area and depth of the bioretention feature
- Relevant drainage area contributing runoff to the infiltration area
- Average annual precipitation data (in inches)
- Expected percentage of retention

These variables also affect the feature's retention percentage:

- Rainfall amount and distribution
- Site irrigation practices
- Temperatures and humidity
- Soil infiltration rate (based on soil type)

The following equation provides a simplified estimate of the potential volume of runoff captured using bioretention and infiltration practices:

[annual precipitation (inches) * (feature area (SF) + drainage area (SF)] * % of rainfall captured] * 144 sq inches/SF * 0.00433 gal/cubic inch = total runoff reduction (gal)

Example 1.3:

A site in Chicago, Ill. that retains 80% of stormwater runoff, with an infiltration area of 2,000 square feet and a drainage area of 4,000 square feet, reduces the volume of runoff as follows:

[38.01 inches annual precipitation * (2,000 SF + 4,000 SF) * 0.80 retention rate] * 144 sq inches/SF * 0.00433 gallons/cubic inch = 113,760 gallons of runoff reduced annually

PERMEABLE PAVEMENT

To quantify the water retained from permeable pavement, it is necessary to know the following information:

- Average annual precipitation data (in inches) for the site
- Square footage of the green infrastructure feature
- Percentage of precipitation that the feature is capable of retaining

Depending on the intensity of the precipitation event, studies have shown that pervious pavement can infiltrate as much as 80 to 100% of the rain that falls on a site (Booth et al 1996; Bean et al 2005; MMSD 2007; USEPA and LID Center 2000). Example 1.2 uses the lower end of this range, or an 80% retention rate. To find a more site-specific percentage, the following factors must be considered:

- Slope of the pavement – flat surfaces typically infiltrate more water
- Soil content & aggregate depth below pavement
- Size and distribution of storm events
- Infiltration rate
- Frequency of surface cleaning

The following equation quantifies the total amount of runoff that a given permeable pavement installation can reduce annually. As with the bioretention and infiltration calculations, the percentage of rainfall that these features can accommodate depends on available square footage and locally determined maximum ponding times:

[annual precipitation (inches) * GI area (SF) * % retained] * 144 sq inches/SF * 0.00433 gal/cubic inch = total runoff reduction (gal)

Example 1.4:
A permeable pavement feature with an area of 5,000 SF, using an 80% retention rate, will reduce annual runoff in Chicago, Ill. as follows:

[38.01 inches annual precipitation * 5,000 SF area * 0.80 retention rate] * 144 sq inches/SF * 0.00433 gal/cubic inch = 94,800 gallons of runoff reduced annually

WATER HARVESTING

Benefits from water harvesting are based on the volume in gallons of stormwater runoff stored onsite. To determine this volume, the following information is necessary:

- Average annual precipitation data (in inches)
- Rainfall intensity
- Size of the water-collecting surface (in square feet)
- Capacity for temporary water storage and release
- Frequency of harvested water use for building needs, irrigation or evaporative cooling (e.g. whether the captured rainwater is used before a subsequent rain event)

For every square foot of roof collection area, it is possible to collect up to 0.62 gallons of runoff per inch of rain with perfect efficiency. However, an efficiency factor of 0.75–0.9 is included in the equation to account for water loss due to evaporation, inefficient gutter systems and other factors (Texas Water Development Board 2005).

Applying the following formula provides a basic understanding of how much rainwater could be captured by this practice, both for site specific measurement as well as a cumulative calculation across a community or region.

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

Example 1.5:
The following equation illustrates how to determine the capacity of a water harvesting practice using annual rainfall data for Chicago, Ill.:

38.01 inches annual rainfall * 1,000 SF of surface * 144 sq inches/SF * 0.00433 gal/cubic inch * 0.85 collection efficiency = 20,145 gallons captured annually

After estimating the gallons of stormwater a particular site and practice can retain (i.e. the total resource units), this information should be used in Step 2.

STEP 2 - VALUATION OF QUANTIFIED BENEFITS: REDUCED STORMWATER RUNOFF

The valuation process in the "Water" section is divided into the following four subsections and outlines each separately:

- Reduced Water Treatment Needs
- Reduced Grey Infrastructure Needs
- Improved Water Quality
- Reduced Flooding

Methods for valuation will only be provided in the "Reduced Water Treatment Needs" and "Reduced Grey Infrastructure Needs" subsections. The other two sections discuss benefits and current research, but they do not present a formal valuation method, given the amount of varying factors required to value these benefits.

Reduced Water Treatment Needs

For cities with combined sewer systems (CSS), stormwater runoff entering the system combines with wastewater and flows to a facility for treatment. One approach to value the reduction in stormwater runoff for these cities is an avoided cost approach. Runoff reduction is at least as valuable as the amount that would be spent by the local stormwater utility to treat that runoff. In this case, the valuation equation is simply:

runoff reduced (gal) * avoided cost per gallon ($/gal) = avoided stormwater treatment costs ($)

Example 1.6:

The Metropolitan Water Reclamation District of Greater Chicago has a marginal cost of treating its wastewater and stormwater of $0.0000919 per gallon (CNT 2009). Using Example 1.1, in which the 5,000 SF green roof provided a runoff reduction of 71,100 gallons, the annual avoided cost for water treatment associated with this site becomes:

71,100 gallons * $0.0000919/gallon = $6.53 in annual avoided treatment costs

Keep in mind, the figure from this example is a single unit that can be aggregated to a larger scale, demonstrating the cumulative benefit that can be achieved within a neighborhood or region. Additionally, avoided cost approaches inevitably underestimate the full value of an ecosystem service. As such, this figure should be considered a lower bound for the monetary value of reduced stormwater runoff. More locally specific treatment costs are available from local water treatment utilities.

Reduced Grey Infrastructure Needs

Green infrastructure practices can reduce the volume of water needing treatment as well as the level of treatment necessary. Therefore, utilizing these practices can reduce the need for traditional or grey infrastructure controls for stormwater and combined sewer overflow (CSO) conveyance and treatment systems, including piping, storage and treatment devices. Similar to the approach taken in other sections of this guide, the value of reducing grey infrastructure derives from the benefits transfer method of avoided costs resulting from the use of green infrastructure. While the case studies below give examples of how these costs can be compared, it is beyond the scope of this guide to determine exact cost savings. This is due to the many site-specific variables that effect the monetary values involved, such as soil types, rainfall distribution patterns, peak flow rates and local materials costs.

One method of assessing avoided grey infrastructure costs when using green infrastructure practices is demonstrated by a case study in Portland, Oregon. In this study, the Bureau of Environmental Services estimated that it costs the city $2.71/SF in infrastructure costs to manage the stormwater generated from impervious areas (Evans 2008). The city uses the following equations to estimate the resulting avoided cost savings:

conventional cost of structure ($/SF) * total area of structure (SF) = total expenditure for conventional approach ($)

total expenditure for conventional approach ($) * % retained = avoided cost savings ($)

Please note, while the typical resource unit used within this "Water" section is *gallons* of stormwater retained, this particular benefit instead considers *percent* of stormwater retained.

Example 1.7:

Using Portland, Ore. as an example, a 5,000 SF conventional roof would have a one-time expenditure of $13,550. However, by utilizing a green roof, which in this particular study has been shown to retain 56 percent of runoff, Portland can expect an avoided cost savings of $7,588:

$2.71/SF * 5,000SF = $13,550 in total conventional expenditure

$13,550 * 56% = $7,588 avoided cost savings

Groundwater Recharge

Green infrastructure practices that enable rainwater infiltration contribute to the recharge of both deep aquifers and subsurface groundwater. When rain falls on a permeable surface, some runs off, some returns to the atmosphere through evapotranspiration and the remainder is infiltrated into the ground. This infiltrated water either recharges aquifers or joins subsurface flows, which end up in local streams. Both aquifer recharge and subsurface flow are important components of a functional water cycle that sustains the ecosystem services on which human activity depends.

Aquifers provide water for drinking and irrigation. Aquifer levels are essentially a function of the relationship between discharge (withdrawal by humans, evaporation, interaction with surface waters) and recharge (primarily infiltrated precipitation). Over time, withdrawing more from an aquifer than is recharged through precipitation can cause declining aquifer levels, resulting in higher pumping costs, reduced water availability and even land subsidence that can result in sink holes.

Green infrastructure affects groundwater recharge in highly site-specific ways. Some infiltrated rainfall may discharge back into surface waters after a few days; in other cases, generations may pass before infiltrated water again becomes available for human use. For this reason, this work does not define specific guidelines for quantifying and valuing the groundwater recharge benefit of green infrastructure. Nonetheless, it is important for the future health of watersheds to monitor aquifer levels and stream flows and consider the benefits of restoring infiltration.

Another study, in the Blackberry Creek watershed near Chicago, Illinois, estimated the benefits attributable to green infrastructure practices resulting from avoided costs of infrastructure that would have been needed to control reduced peak discharges (Johnston, Braden and Price 2006). The study found that, based on Federal Highway Department pipe sizing requirements, reduced peak discharges within their low impact development scenario resulted in a downstream benefit of $340 per developed acre. This is an initial cost savings; performing a life-cycle cost analysis would better demonstrate long-term monetary benefits. The calculations for this method are dependent on access to the following variables and results are best determined through the use of hydrologic modeling:

- Peak flow rates
- Allowable ponding time
- Pipe size requirements

In the case of Seattle's Street Edge Alternatives (SEA) project, which utilizes bioswales to capture and treat stormwater runoff, Seattle Public Utilities found that bioretention combined with narrowing the roadway, eliminating the traditional curb and gutter, and placing sidewalks on only one side of the street garners a cost savings for the city of 15–25 percent, or $100,000–$235,000 per block, as compared to conventional stormwater control design (SPU). Additionally, Seattle Public Utilities has identified cost savings in terms of the life span of the project; SEA streets are designed to improve performance as plantings mature, whereas traditional systems tend to degrade over time (Wong and Stewart 2008).

Improved Water Quality

Using green infrastructure for stormwater management can improve the health of local waterways by reducing erosion and sedimentation and reducing the pollutant concentrations in rivers, lakes and streams. These effects, in turn, lead to improved overall riparian health and aesthetics—indicators of improved water quality and channel stabilization.

The impacts of green infrastructure on water quality, while well documented, are too place-specific to provide general guidelines for measurement and valuation. The water quality improvements associated with green infrastructure, furthermore, are not of sufficient magnitude to be meaningful at the site scale. This benefit, therefore, is best evaluated in the context of watershed-scale green infrastructure implementation, accompanied by hydrologic modeling, to estimate changes in sedimentation and pollutant loads resulting from a green infrastructure program.

Regulators measure water quality in a variety of ways. Damaging pollutants carried by stormwater runoff typically include nitrogen, phosphorous and particulate matter. Water quality monitors can measure concentrations of dissolved nitrogen and phosphorous, as well as total suspended solids (TSS), usually in milligrams per liter. In economic valuations, water *clarity* is often used as a proxy measure for water *quality*. While only an approximate measure, water clarity strongly correlates with the presence of phosphorous, nitrogen and TSS pollution. Suspended particulates directly decrease water clarity, while high concentrations of nitrogen and phosphorous lead to eutrophication—a process whereby increased nutrients in waterways lead to algae blooms which cloud the water and decrease dissolved oxygen. In extreme cases, eutrophication can lead to hypoxic conditions, characterized by the absence of sufficient oxygen to support any animal life. Water clarity is typically measured using the Secchi disk test, in which a black and white patterned disk is lowered into the water until no longer visible; this depth is considered the water clarity depth.

Previous research has applied a benefits transfer approach to quantify the expected improvement in water clarity resulting from a green infrastructure program. Several hedonic pricing studies estimated the impact of water clarity changes on lakefront property values. Studies in Maine and New Hampshire have estimated implicit marginal prices for a one meter change in water clarity ranging from $1,100 to $12,938 per lakefront property (Gibbs et al 2002; Boyle et al 1999; Michael et al 1996). A hedonic pricing study of the St. Mary's River Watershed in the Chesapeake Bay estimated home price impacts of water quality changes not merely for waterfront properties but for the entire watershed. It found marginal implicit prices for changes of one milligram per liter in total suspended solids (TSS) concentration of $1,086 and in dissolved inorganic nitrogen (DIN) concentration of $17,642 for each home in the watershed (Poor et al 2007).

Reduced Flooding

By reducing the volume of stormwater runoff, green infrastructure can reduce the frequency and severity of flooding. The impact of green infrastructure on flooding is highly site and watershed specific, and thus this guide does not provide general instructions for quantifying the reduction in flood risk resulting from a green infrastructure program.

There are several ways to assess the value of reduced flood risk provided by green infrastructure practices on a watershed-scale once the risk impacts have been modeled. Some studies use hedonic pricing to examine how flood risk is priced into real estate markets; others use the insurance premiums paid for flood damage insurance as a proxy for the value of reducing the risk of flood damage; others take an avoided damage cost approach and still others have employed contingent valuation methods.
The most robust literature on the economic valuation of flood risk uses hedonic pricing methods to investigate the housing price discount associated with floodplain location. Most of these studies estimate the impact on residential home prices of locations inside or outside of the 100-year floodplain. Those considering implementing a green infrastructure program who are able to model resulting changes in floodplain maps—in particular, to identify the area where annual flood risk is greater than one percent and can be reduced to less than one percent through the use of green infrastructure—can apply the results of these studies to get an estimate of the range of value provided by green infrastructure's flood risk reduction impact.

Until recently, hedonic price studies have found that homes within the 100-year floodplain are discounted between two and five percent compared with equivalent homes outside the floodplain (Braden and Johnston 2004; Bin and Polasky 2004; MacDonald et al 1990; Harrison, Smersh and Schwartz 2001; Shilling, Benjamin and Sermins 1985; MacDonald, Murdoch and White 1987).

In recent years, hedonic pricing techniques have evolved to recognize that hazard risk may be correlated with spatial amenities or disamenities. In the case of flooding, a correlation exists between proximity to waterways and flood risk. Studies that fail to disentangle this correlation will likely underestimate the amount that flood-prone properties are discounted in the marketplace and thus underestimate the value of flood risk

Reduced Salt Use

Research indicates that using pervious pavement can reduce the need for road salt use by as much as 75 percent (Houle 2006). Reducing salt use saves money for individual property owners and municipalities while also protecting water supplies and the environment as a whole. The following variables affect the performance of permeable pavement in reducing salt use:

- Infiltration rate
- Frequency of surface cleaning
- Soil content and aggregate depth below pavement

A study in Iowa comparing the temperature behavior of traditional concrete and Portland Cement Pervious Concrete (PCPC) found the following: "The results show that the aggregate base underneath the pervious concrete substantially delayed the formation of a frost layer and permeability was restored when melt water is present. . . . The melt water immediately infiltrated the pervious concrete pavement, eliminating the potential for refreezing and reducing the slip/fall hazard associated with impervious surfaces" (Kevern et al 2009b).

The National Research Council (NRC) indicates that road-salt use in the United States ranges from 8 million to 12 million tons per year with an average cost of about $30 per ton (Wegner and Yaggi 2001), although this cost has increased in recent years. In winter 2008, many municipalities paid over $150 per ton for road salt; projections for 2009 reported salt prices in the range of $50–$70 per ton (Associated Press 2009; Singer 2009).

reduction. One study applied these new techniques to account for the correlation of flood risk and coastal amenities and found that homes in the 100-year floodplain were discounted an average of 7.8 percent compared to equivalent homes outside the floodplain (Bin, Kruse and Landry 2008). Therefore, we recommend that users of this guide apply the 2–5 percent range as a conservative estimate of the value of flood risk reduction.

US Census Summary File 3[1] provides median home price data and the number of owner-occupied housing units at the block group level.

An example application of this method can be found in a study on green infrastructure implementation in Blackberry Creek Watershed in Kane County, Illinois (Johnston, Braden and Price 2006). The authors used the USEPA's *Hydrologic Simulation Program—Fortan* to model the difference in peak flows of a green infrastructure versus a conventional development scenario. They then input their peak flow results into the Army Corps of Engineers' Hydrologic Engineering Center River Analysis System and found that conventional development would add 50 acres to the floodplain compared to development using green infrastructure for stormwater management. Applying an anticipated density of 2.2 units/acre and the census bureau's reported median home value of $175,600, the study then used the benefits transfer approach to estimate a range of values for flood risk reduction. Using a range of 2–5 percent property value increase for removal from the floodplain yields total benefits of between $391,600 and $979,000 for the flood risk reduction impact of the green infrastructure scenario.

[1] US Census Bureau. American Factfinder: http://factfinder.census.gov/home/saff/main.html?_lang=en