The Value of Green Infrastructure

A Guide to Recognizing Its Economic, Environmental and Social Benefits

CNT

American Rivers
Thriving By Nature

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Introduction
What Is Green Infrastructure & Why Does It Matter?

Green infrastructure (GI) is a network of decentralized stormwater management practices, such as green roofs, trees, rain gardens and permeable pavement, that can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways. While there are different scales of green infrastructure, such as large swaths of land set aside for preservation, this guide focuses on GI's benefits within the urban context.

The ability of these practices to deliver multiple ecological, economic and social benefits or services has made green infrastructure an increasingly popular strategy in recent years. (See Case Study section.) In addition to reducing polluted stormwater runoff, GI practices can also positively impact energy consumption, air quality, carbon reduction and sequestration, property prices, recreation and other elements of community health and vitality that have monetary or other social value. Moreover, green infrastructure practices provide flexibility to communities faced with the need to adapt infrastructure to a changing climate.

Why This Guide?

Although valuation of green infrastructure's monetary benefits has advanced considerably in recent years, it is still a developing field. The EPA publication *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* (2007) documented the comparative construction costs of green infrastructure practices in residential construction but did not explore performance benefits. While numerous published studies address either the benefits coming from one type of practice, such as energy implications of green roofs, or the collective impacts of a single practice, such as urban forestry's impact on water, energy, and other elements, such studies do not achieve a cumulative assessment of multiple benefits.

Green infrastructure's value as a municipal or private investment depends in part on its effects beyond water management and thus upon a community's ability to model and measure these additional values. Short of conducting an intensive study and calculation of actions in a specific community, municipalities have generally lacked the tools to determine green infrastructure's multiple benefits. As such, defining or measuring the extent of green infrastructure's multiple benefits has remained a challenge. While a number of cities have begun to explore GI within their own municipal infrastructure programs, no general method for estimating or documenting such benefits has yet emerged.

Due to these gaps in information and methodology, decision-making regarding stormwater infrastructure investments has generally lacked recognition of the monetary benefits that GI provides communities. With limited ability to quantify GI's benefits, municipalities have often favored single-purpose grey infrastructure projects. However, any cost-benefit analysis comparing grey infrastructure with green infrastructure would be incomplete without factoring in the multiple benefits green infrastructure can provide.

Purpose of the Guide

This guide distills key considerations involved in assessing the economic merits of green infrastructure practices. It examines the steps necessary to calculate a variety of performance benefits gained by implementing GI strategies and then, where possible, demonstrates simplified illustrative examples that estimate the magnitude and value of these benefits.

In clarifying how to assign value to potential green infrastructure benefits, this guide can assist decision-makers in evaluating options for water management. A more clear view of GI's values will help communities decide where, when and to what extent green infrastructure practices should become part of future planning, development and redevelopment.

The guide aims to:
- **Inform decision-makers and planners about the multiple benefits green infrastructure delivers to communities.**
- **Guide communities in valuing the benefits of potential green infrastructure investments.**

Green Infrastructure Benefits and Practices

This section, while not providing a comprehensive list of green infrastructure practices, describes the five GI practices that are the focus of this guide and examines the breadth of benefits this type of infrastructure can offer. The following matrix is an illustrative summary of how these practices can produce different combinations of benefits. Please note that these benefits accrue at varying scales according to local factors such as climate and population.

Benefit / Practice	Reduces Stormwater Runoff				Increases Available Water Supply	Increases Groundwater Recharge	Reduces Salt Use	Reduces Energy Use	Improves Air Quality	Reduces Atmospheric CO_2	Reduces Urban Heat Island	Improves Community Livability					Improves Habitat	Cultivates Public Education Opportunities
	Reduces Water Treatment Needs	Improves Water Quality	Reduces Grey Infrastructure Needs	Reduces Flooding								Improves Aesthetics	Increases Recreational Opportunity	Reduces Noise Pollution	Improves Community Cohesion	Urban Agriculture		
Green Roofs	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Maybe	Yes	Maybe	Maybe	Yes	Yes
Tree Planting	Yes	Yes	Yes	Yes	No	Maybe	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Maybe	Yes	Yes
Bioretention & Infiltration	Yes	Yes	Yes	Yes	Maybe	Maybe	No	No	Yes	Yes	Yes	Yes	Maybe	Maybe	Maybe	Maybe	Yes	Yes
Permeable Pavement	Yes	Yes	Yes	Yes	No	Maybe	Yes	Maybe	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes
Water Harvesting	Yes	Yes	Yes	Yes	Yes	Maybe	No	Maybe	Maybe	Maybe	No	No	No	No	No	No	No	Yes

Legend: ● Yes ◐ Maybe ○ No

Green Roofs

A green roof is a rooftop that is partially or completely covered with a growing medium and vegetation planted over a waterproofing membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. Green roofs are separated into several categories based on the depth of their growing media. **Extensive** green roofs have a growing media depth of two to six inches. **Intensive** green roofs feature growing media depth greater than six inches (GRHC).

As green, or vegetated, roof systems become more prevalent in the United States, the benefits they can provide to a wide range of private and public entities become more apparent. These benefits are outlined below.

Reduces Stormwater Runoff:
• Green roofs can store significant amounts of water in their growing media. This water is eventually evaporated from the soil or transpired by the plants on the roof, thus reducing the runoff entering sewer systems and waterways, which can help alleviate the risk of combined sewer overflows (CSO).

Reduces Energy Use:
• Additional insulation provided by the growing media of a green roof can reduce a building's energy consumption by providing superior insulation compared to conventional roofing materials.
• The presence of plants and growing media reduces the amount of solar radiation reaching the roof's surface, decreasing roof surface temperatures and heat influx during warm-weather months.
• Evaporative cooling from water retained in the growing media reduces roof surface temperatures.

Improves Air Quality:
• Locally, the vegetation planted on green roofs takes up air pollutants and intercepts particulate matter.
• The cooling effect of vegetation lessens smog formation by

slowing the reaction rate of nitrogen oxides and volatile organic compounds.

- By reducing energy use, green roofs lessen the air pollution caused by electricity generation.

Reduces Atmospheric CO$_2$:
- Green roof vegetation directly sequesters carbon.
- By reducing energy use and the urban heat island effect, green roofs lower carbon dioxide emissions from regional electricity generation.

Reduces Urban Heat Island:
- The local evaporative cooling provided by green roofs can reduce elevated temperatures present in urban areas as a result of heat-absorbing surfaces such as streets and conventional roofs.

Improves Community Livability:
- Green roofs improve the local aesthetics of a community.
- Soil and vegetation help reduce sound transmission, thus reducing local noise pollution levels.

- Green roofs can increase recreational opportunities by providing outdoor areas for people to use and enjoy. They also have the potential to foster improved community interactions that help build social capital.
- Green roofs may also provide opportunities for urban agriculture.

Improves Habitat:
- Increased vegetation helps to support biodiversity and provides valuable habitat for a variety of flora and fauna.

Cultivates Public Education Opportunities:
- Managing future economic and environmental constraints will require full community participation and partnership. Green infrastructure provides an opportunity to develop community awareness and understanding around the importance of sustainable water resource management.
- Green roofs increase community interest in green infrastructure through their aesthetic appeal, which provides a great opportunity for public education.

Tree Planting

Planting trees provides many services which have ecological, economic and social implications. Whether measured on a tree-by-tree basis or on a larger scale such as an urban forest, tree planting has a multitude of benefits.

Reduces Stormwater Runoff:
- Trees intercept rainfall and help increase infiltration and the ability of soil to store water.
- Tree canopies diminish the impact of raindrops on barren surfaces.
- Transpiration through leaves minimizes soil moisture, which reduces runoff.

Increases Groundwater Recharge:
- Trees can contribute to local aquifer recharge and to the improvement of watershed system health, from both quantity and quality standpoints.

Reduces Energy Use:
- When properly placed, trees provide shade, which can help cool the air and reduce the amount of heat reaching and being absorbed by buildings. In warm weather, this can reduce the energy needed to cool buildings.
- Trees reduce wind speeds. Wind speed, especially in areas with cold winters, can have a significant impact on the energy needed for heating.
- Trees release water into the atmosphere, resulting in cooler air temperatures and reduced building energy consumption.

Improves Air Quality:
- Trees absorb air pollutants (e.g. NO_2, SO_2, and O_3) and intercept particulate matter (PM10).
- Trees reduce energy consumption, which improves air quality and reduces the amount of greenhouse gases, including N_2O and CH_4.

Reduces Atmospheric CO_2:
- Through direct sequestration, trees reduce atmospheric carbon dioxide levels.
- Tree planting reduces energy consumption, which in turn reduces CO_2 levels.

Reduces Urban Heat Island:
- The various cooling functions of trees help to reduce the urban heat island effect, thereby reducing heat stress-related illnesses and fatalities.

Improves Community Livability:
- Trees provide beauty and privacy, which improve community aesthetics.
- Planting trees increases recreational opportunities for communities by improving pathways, creating places to gather and providing shade during warm weather.
- Trees provide a sense of place and well-being, which can strengthen community cohesion.
- Trees help to reduce sound transmission, reducing local noise pollution levels.

- Tree planting may provide opportunities for urban foraging and food production.

Improves Habitat
- Planting trees increases wildlife habitat, especially when plant species native to the region are used.

Cultivates Public Education Opportunities:
- Managing future economic and environmental constraints will require full community participation and partnership. Green infrastructure provides an opportunity to develop community awareness and understanding around the importance of sustainable water resource management.
- Community tree planting provides a valuable educational opportunity for residents to become more aware of the benefits of green infrastructure.

Bioretention and Infiltration Practices

Bioretention and infiltration practices come in a variety of types and scales, including rain gardens, bioswales and wetlands. Rain gardens are dug at the bottom of a slope in order to collect water from a roof downspout or adjacent impervious surface. They perform best if planted with long-rooted plants like native grasses. Bioswales are typically installed within or next to paved areas like parking lots or along roads and sidewalks. They allow water to pool for a period of time and then drain, and are designed to allow for overflow into the sewer system. Bioswales effectively trap silt and other pollutants that are normally carried in the runoff from impermeable surfaces. While the multitude of benefits provided by wetlands has been well documented elsewhere, this guide only addresses smaller scale practices.

Reduces Stormwater Runoff:
- These practices store and infiltrate stormwater, which mitigates flood impacts and prevents the stormwater from polluting local waterways.

Increases Available Water Supply:
- By reducing the amount of potable water used for outdoor irrigation, these practices may also increase available water supplies.

Increases Groundwater Recharge:
- Bioretention and infiltration practices have the potential to increase groundwater recharge by directing rainwater into the ground instead of pipes.

Improves Air Quality:
- Like other vegetated green infrastructure features, infiltration practices can improve air quality through uptake of criteria air pollutants and the deposition of particulate matter.
- By minimizing the amount of water entering treatment facilities, these practices also reduce energy use which, in turn, reduces air pollution by lowering the amount of greenhouses gases emitted.

Reduces Atmospheric CO_2:
- Bioretention and infiltration practices reduce carbon dioxide emissions through direct carbon sequestration.

- By reducing the amount of energy needed to treat runoff, as well as reductions in energy use for cooling purposes, bioretention and infiltration practices reduce atmospheric CO_2.

Reduces Urban Heat Island:
- Through evaporative cooling and reduction of surface albedo, these practices work to mitigate the urban heat island effect, reducing energy use.

Improves Community Livability:
- When well-maintained, bioretention and infiltration practices improve local aesthetics and enhance recreational opportunities within communities.
- There is also the potential for these practices to help reduce noise transmission through sound absorption and to improve social networks in neighborhoods.

Improves Habitat:
- Bio-retention and infiltration practices provide habitat and increase biodiversity.

Cultivates Public Education Opportunities:
- Managing future economic and environmental constraints will require full community participation and partnership. Green infrastructure provides an opportunity to develop community awareness and understanding around the importance of sustainable water resource management.
- Rain gardens and bioswales provide an opportunity for residents to contribute to the benefits of neighborhood place-making via green infrastructure.

Permeable Pavement

Permeable pavement allows for the absorption and infiltration of rainwater and snow melt onsite. There are several different names that refer to types of permeable pavement, including pervious or porous concrete, porous asphalt and interlocking permeable pavers.

Reduces Stormwater Runoff:
- Permeable pavement reduces surface runoff volumes and rates by allowing stormwater to infiltrate underlying soils.
- By reducing runoff volumes and rates, permeable pavement can lower water treatment costs and reduce flooding and erosion.

Increases Groundwater Recharge:
- By allowing rainfall to infiltrate, permeable pavement can help increase groundwater recharge.

Reduces Salt Use:
- Permeable pavement has been demonstrated to substantially delay the formation of a frost layer in winter climates, which mitigates the need for salt use. By reducing the need for salt, communities are able to save money and reduce pollution in local waterways and groundwater sources.

Reduces Energy Use:
- The use of permeable pavements also has the potential to reduce energy use by lowering surrounding air temperatures, which in turn reduces demand on cooling systems within buildings.

Improves Air Quality:
- Because permeable pavement captures rainfall onsite, communities can reduce the amount of water treatment needed, in turn reducing air pollution from power plants.

- By reducing the urban heat island effect, permeable pavement decreases ground level ozone formation, which directly impacts air quality.

Reduces Atmospheric CO_2:
- Permeable pavement captures rainfall onsite, enabling communities to reduce the amount of water treatment needed, in turn reducing CO_2 emissions from power plants.
- Permeable pavement also has the potential of reducing lifecycle CO_2 emissions compared to asphalt and cement, which produce high lifecycle CO_2 emissions.

Reduces Urban Heat Island:
- Permeable pavement absorbs less heat than conventional pavement, which helps to reduce the surrounding air temperature and decrease the amount of energy needed for cooling.

Improves Community Livability:
- Some types of permeable pavement reduce local noise pollution by increasing street porosity levels.

Cultivates Public Education Opportunities:
- Managing future economic and environmental constraints will require full community participation and partnership. Green infrastructure provides an opportunity to develop community awareness and understanding around the importance of sustainable water resource management.
- The installation of permeable pavement can provide an opportunity to further educate the public about the benefits of green infrastructure.

Water Harvesting

Water harvesting is defined as the redirection and productive use of rainwater by capturing and storing it onsite for irrigation, toilet flushing and other potential uses. Water harvesting treats rainwater as a resource rather than as a waste stream. There are two main water harvesting practices: downspout disconnection and the use of rain barrels or cisterns.

Downspout disconnection is the process of directing roof runoff away from sewer systems and onto local property for irrigation purposes. Using rain barrels or cisterns captures rainwater, diverting it directly into these storage containers. The stored water can be used onsite for multiple purposes such as flushing toilets and irrigation. The practice of water harvesting requires that catchment areas be sized according to projected water-use needs in order to maximize the benefits of this practice.

Reduces Stormwater Runoff:
- Water harvesting minimizes the negative impacts of stormwater runoff by capturing rainfall where it lands and reusing it onsite.
- Onsite reuse of rainwater helps to reduce water treatment needs, which allows communities to save on costs associated with potable water conveyance, treatment and use.

Increases Available Water Supply:
- It is estimated that, nationwide, outdoor irrigation accounts for almost one-third of all residential water use, totaling more than 7 billion gallons per day. Given this estimate, using rainwater for irrigation purposes can substantially reduce the amount of potable water used residentially, effectively increasing supply.

Increases Groundwater Recharge:
- Reusing rainwater for irrigation purposes can help increase groundwater recharge.

Reduces Energy Use:
- Water harvesting has the ability to reduce energy usage by cutting down on potable water use, which requires energy to produce, treat and transport.

Improves Air Quality:

- Because this practice can reduce energy usage, it can also reduce the amount of air pollutants being emitted from power plants.

Reduces Atmospheric CO_2:

- Water harvesting captures rainfall onsite, which can enable communities to reduce the amount of water treatment needed, in turn reducing CO_2 emissions from power plants.

Cultivates Public Education Opportunities:

- Managing future economic and environmental constraints will require full community participation and partnership. Green infrastructure provides an opportunity to develop community awareness and understanding around the importance of sustainable water resource management.
- By providing educational programs through fun activities such as rain barrel design and usage, communities can more effectively train residents in the benefits of green infrastructure.

Rainwater has been found to help improve plant health. Unlike potable water which contains salt, rainwater typically contains nutrients such as nitrogen and phosphorus, which is good for plants.

Economic Valuation in Action

Economic Valuation Methods & Tools

Comparing the benefits of different stormwater management practices requires a common unit of analysis. In making decisions about infrastructure investment, the value of a given set of possible investments is typically expressed monetarily.

One challenge inherent in valuing services provided by green infrastructure is that many of these services are not bought and sold. Fortunately, many techniques have been developed in order to economically value nonmarket ecosystem services. Nonmarket valuation methods include revealed preference methods, stated preference methods and avoided cost analysis.

Revealed preference methods attempt to infer the value of a nonmarket good or service using other market transactions. Hedonic pricing, for example, assumes that the price of a good is a function of relevant characteristics of that good and attempts to isolate the contribution of a given characteristic to the total price (most commonly used with housing prices).

Stated preference methods, such as contingent valuation, ask individuals how much they are willing to pay for a given good or service or how much they would be willing to accept as compensation for a given harm. These methods often assess non-use values; for example, what is the value of a protected wilderness for people who never see it?

Using previous estimates from other revealed or stated preference studies requires caution. These methods capture the value resulting from the complexity inherent in a specific study area. As such there is risk in applying these results to different contexts and subsequent benefit valuations.

Finally, avoided cost analysis examines the marginal cost of providing the equivalent service in another way. For example, rainfall retention and infiltration can offset a water utility's cost to capture, transport, treat and return each additional gallon of runoff. (Tomalty et al 2009; King and Mazzotta 2000).

Customized application of nonmarket valuation methods can be expensive and time consuming to perform. Contingent valuation, for example, can require conducting survey research; a hedonic pricing study may involve extensive data assembly.

There are many existing tools available to those interested in assessing the performance and value of green infrastructure practices, including online calculators, spreadsheet models and desktop software. These tools can be used as a companion to this guide and in many cases will be able to provide calculations with greater sensitivity to locally specific variables than those presented here. A full list and description of these tools can be found in Appendix A.

Our Framework

This guide outlines a framework for measuring and valuing green infrastructure's multiple ecological, economic and social benefits. The following sections integrate existing research on the benefits of five green infrastructure practices that are representative of the current vocabulary of GI in terms of applicable values and possible benefits. These sections explore how to:

• Measure the benefits from each particular practice
• Assign value to those benefits (in monetary terms when possible)

The guide follows a consistent sequence when analyzing each of the benefits defined in the previous section. This analysis allows users to evaluate the cumulative benefits of green infrastructure practices in a number of different benefit categories including water, energy, air quality and climate change. The following describes the two-step framework for this valuation process.

Step 1: Quantification of Benefits

It is first necessary to define a resource unit for the given benefit. For example, when evaluating energy benefits, the resource units are kilowatt hours (kWh) and British thermal units (Btu). Once the resource units are determined, the guide outlines the process for estimating the level of benefit for each practice. Step 1 concludes with an estimate of the total resource units received from a given benefit.

Step 2: Valuation of Quantified Benefits

In this step, values for each benefit are determined based on the resource units from the previous step. The method for translating resource units into a dollar figure differs for every benefit category.

For example, the average cost of a kilowatt hour of electricity provides the direct cost saving value of reduced energy use. Because these values are extremely location and site specific, it is beyond the scope of this guide to demonstrate all parameters and local values. Examples demonstrated in this section illustrate the process necessary for determining the accrued value of green infrastructure implementation. Resources and guidance are provided where possible to help tailor these estimates to local projects, however much of the localized information must be gathered by the user. Please note, given the current state of valuation research, this step has not been addressed in the following benefit sections:

• Urban Heat Island   • Habitat
• Community Livability   • Public Education

Even if no monetary value can be assigned, these services provide valuable benefits which are still worth recognizing in a broader assessment of infrastructure investments.

It is important to keep in mind that the methods described here face a number of limitations. Although the discussion will focus on benefits, estimating the net value of a project would require a comparison of the net benefits compared to the lifecycle cost of constructing and maintaining a given green infrastructure practice. While life cycle cost analysis is beyond the scope of this guide, the Green Values™ Calculator (CNT 2009) can describe the relative cost of the green infrastructure practices (using cost data information through 2009).

Finally, several benefits face uncertainties about both spatial and temporal scale. The "Considerations and Limitations" section at the end this guide further addresses these and other concerns.

The figure below is an illustrative example of the process for valuing the Climate Change benefit section of green infrastructure.
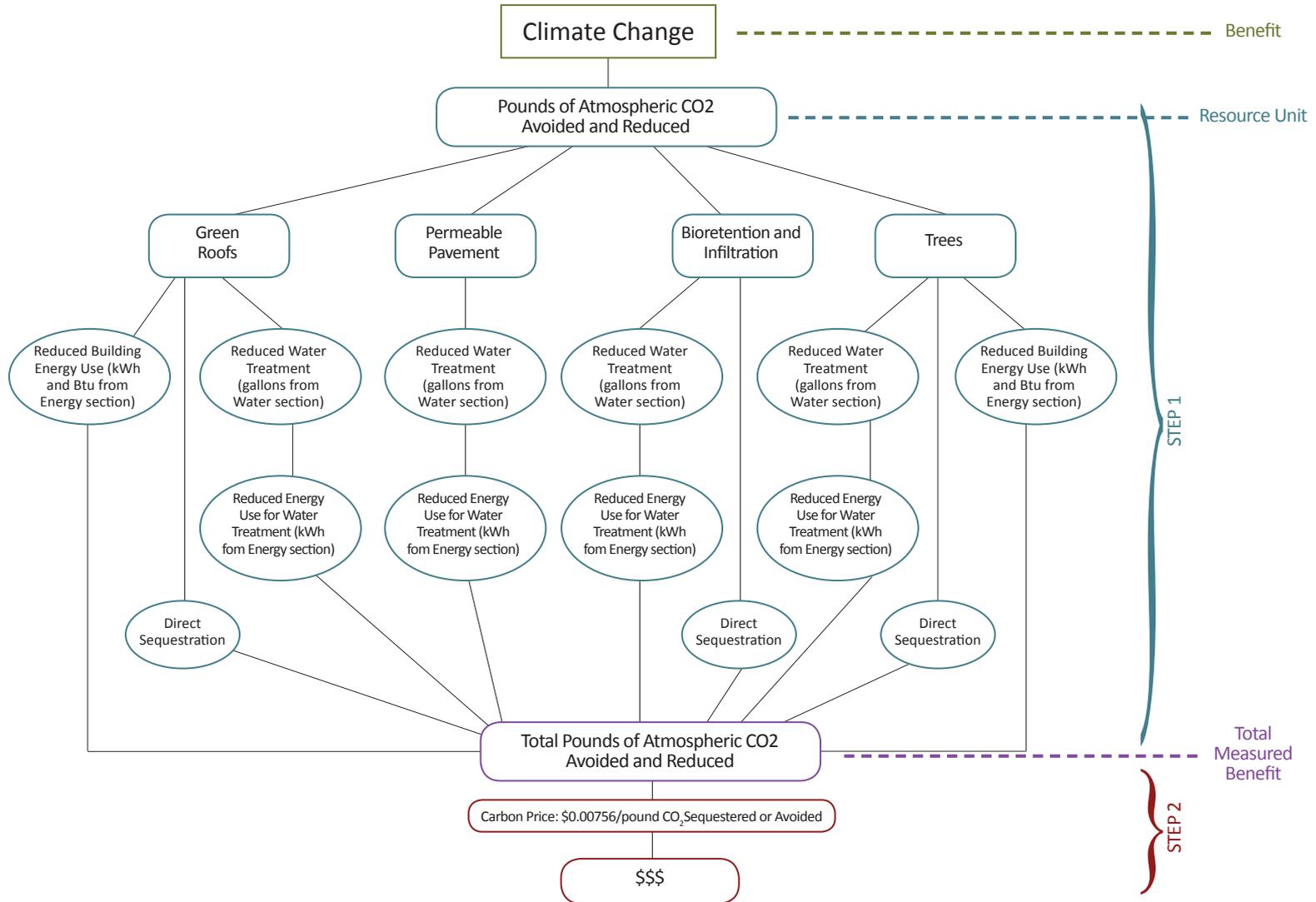
Benefit Measurement and Valuation
1. WATER

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

Benefit Measurement and Valuation
2. ENERGY

STEP 1 - QUANTIFICATION OF BENEFIT:
REDUCED ENERGY USE

The first step to valuing the benefits of reduced energy use is determining the amount of energy saved by each practice. This section quantifies the benefit of energy savings in terms of kilowatt hours (kWh) of electricity and British thermal units (Btu) of natural gas reduced.

Practices that reduce building energy use include green roofs and trees. In addition, green infrastructure can reduce off-site energy use by preventing runoff and by reducing the demand for potable water. Both of these benefits lead to a decrease in water treatment needs, thereby lowering energy use at treatment facilities. Because facility energy costs are incorporated into the cost of treatment, direct energy cost savings have already been captured. Thus, this section will not value the energy benefit from reduced water treatment, as this would result in double counting.

However, benefits from reduced treatment-plant energy use go above and beyond direct cost savings. This guide will provide methods for estimating the indirect benefits of reduced energy use from both air quality improvements and reduced climate change impacts. Therefore, refer to the "Air Quality" and "Climate Change" sections to quantify these.

GREEN ROOFS

When considering to what degree green roofs reduce building energy use, it is important to keep in mind that heat flux through the roof is only one of many factors influencing building energy consumption. A dramatic improvement in energy performance from green roofs compared to conventional roofs may have only a small impact on overall building energy use. That said, to provide a simple estimate of building energy savings, the suggested method treats green roofs as insulation and assumes that a reduction in heat flux translates directly into energy savings (Clark, Adriaens, and Talbot 2008). Equations for both cooling and heating savings can be derived as follows:

> **annual number of cooling degree days (°F days) * 24 hrs/day * ΔU = annual cooling savings (Btu/SF)**
>
> **annual number of heating degree days (°F days) * 24 hrs/day * ΔU = annual heating savings (Btu/SF)**
>
> **Where:**
> **U = heat transfer coefficient, or 1/R; and**
> **R = a measure of thermal resistance.**

Therefore, the main pieces of information necessary for this calculation are the average degree days (both cooling and heating) and the ΔU, which will be calculated from R-values (for both the green roof and a conventional roof with which to compare it).

Determining Cooling and Heating Degree Days (°F days)

The EPA defines Cooling and Heating Degree Days as follows:

"*Cooling degree days* are used to estimate how hot the climate is and how much energy may be needed to keep buildings cool. CDDs are calculated by subtracting a balance temperature from the mean daily temperature, and summing only positive values over an entire year. The balance temperature used can vary, but is usually set at 65°F (18°C), 68°F (20°C), or 70°F (21°F).

Heating degree days are used to estimate how cold the climate is and how much energy may be needed to keep buildings warm. HDDs are calculated by subtracting the mean daily temperature from a balance temperature, and summing only positive values over an entire year. The balance temperature used can vary, but is usually set at 65°F (18°C), 68°F (20°C), or 70°F (21°F)."
http://www.epa.gov/hiri/resources/glossary.htm

To assign values for cooling and heating degree days, this guide recommends using the cooling and heating degree day "Normals" from the National Climatic Data Center of the National Oceanic and Atmospheric Administration.
http://lwf.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html

Determining R-Values and ΔU

According the USEPA, "*R-value* or 'thermal resistance value' is a measure of the resistance of a material to heat flow. The term is typically used to describe the resistance properties of insulation. The higher the R-value, the greater the insulation's resistance to heat flow."
http://www.epa.gov/hiri/resources/glossary.htm

R-values are reported in the units of square feet * degrees Fahrenheit * hours per British thermal unit (SF * °F * hrs/Btu).

The U-value, or the overall heat transfer coefficient, is defined as the inverse of R. Therefore, to find the ΔU, R-Values for the given conventional and green roof are necessary. Clark, Adriaens and Talbot (2008) provide a valuable explanation for estimating R-values for conventional roofs as well as green roofs based on media depth (p. 2,156). For illustrative purposes, the subsequent example uses default values as follows:

For conventional roofs: **R = 11.34 SF * °F * hrs/Btu**
For green roofs: **R = 23.4 SF * °F * hrs/Btu**
(Clark, Adriaens, and Talbot 2008)

The ΔU can be calculated as follows:

$$\Delta U = \left(\frac{1}{R_{conventional\ roof}} \right) - \left(\frac{1}{R_{green\ roof}} \right) \quad \text{or} \quad \Delta U = \left(\frac{Btu}{11.34 * SF * °F * hrs} \right) - \left(\frac{Btu}{23.4 * SF * °F * hrs} \right)$$

Example 2.1:

In this example, the annual cooling savings (kWh) of a 5,000 SF green roof in Chicago, Ill. is calculated as follows:

At Station 32: Illinois Chicago Botanical Garden, the 1971–2000 Normals for Annual Cooling Degree Days is 702 °F days.

annual number of cooling degree days (°F days) * 24 hrs/day * ΔU = annual cooling savings (Btu/SF)

$$702°F\,days \times \frac{24\,hrs}{day} \times \left[\left(\frac{Btu}{11.34*SF*°F*hrs}\right)\right] - \left[\left(\frac{Btu}{23.4*SF*°F*hrs}\right)\right] = \textit{annual cooling savings}$$

$$16,848°F * hrs \times \left[\left(\frac{Btu}{11.34*SF*°F*hrs}\right)\right] - \left[\left(\frac{Btu}{23.4*SF*°F*hrs}\right)\right] = \textit{annual cooling savings}$$

$$\frac{16,848\,Btu}{11.34\,SF} - \frac{16,848\,Btu}{23.4\,SF} = \textit{annual cooling savings}$$

$$\frac{1,485.71\,Btu}{SF} - \frac{720\,Btu}{SF} = \textit{annual cooling savings}$$

$$765.71\,Btu/SF = \textit{annual cooling savings}$$

In order to find how cooling savings results in electricity savings (kWh), the Btu units should be converted to kWh using the conversion rate of 1 kWh/3412 Btu. By converting Btu to kWh, annual cooling savings becomes:

$$\frac{765.71\,Btu}{SF} \times \frac{1\,kWh}{3,412\,Btu} = 0.2244kWh/SF = \textit{annual cooling savings}$$

Thus, for the 5,000 SF green roof, annual electricity cooling savings is: **5,000 SF * 0.2244 kWh /SF = 1,122 kWh**

Example 2.2:

In this example, the annual heating savings (Btu) of a 5,000 SF green roof in Chicago, Ill. is calculated as follows:

At Station 32: Illinois Chicago Botanical Garden, the 1971–2000 Normals for Annual Heating Degree Days is 6,630 °F days.

annual number of heating degree days (°F days) * 24 hrs/day * ΔU = annual heating savings (Btu/SF)

$$6{,}630°Fdays \; \times \; \frac{24hrs}{day} \; \times \; \left[\left(\frac{Btu}{11.34*SF*°F*hrs}\right)\right] - \left[\left(\frac{Btu}{23.4*SF*°F*hrs}\right)\right] = \textit{annual heating savings}$$

$$159{,}120°F*hrs \; \times \; \left[\left(\frac{Btu}{11.34*SF*°F*hrs}\right)\right] - \left[\left(\frac{Btu}{23.4*SF*°F*hrs}\right)\right] = \textit{annual heating savings}$$

$$\frac{159{,}120\ Btu}{11.34\ SF} - \frac{159{,}120 Btu}{23.4\ SF} = \textit{annual heating savings}$$

$$\frac{14{,}031.75\ Btu}{SF} - \frac{6{,}800\ Btu}{SF} = \textit{annual heating savings}$$

$$7{,}231.75\ Btu/SF \quad = \textit{annual heating savings}$$

Since the assumption here is that heating is provided by natural gas, the annual heating natural gas (Btu) savings for the 5,000 SF green roof is:

5,000 SF * 7,231.75 Btu/SF = 36,158,750 Btu

The actual benefits realized in terms of energy savings due to the implementation of a green roof will be significantly impacted by the following variables:
- Growing media composition, depth and moisture content
- Plant coverage and type
- Building characteristics, energy loads and use schedules
- Local climate variables and rainfall distribution patterns

TREE PLANTING

Many variables affect the ability of trees to reduce energy use in neighboring buildings. Perhaps the largest determinant is climate zone. Shading buildings in cool regions can actually increase energy demand, while reducing wind speeds in warm regions will have little to no impact. As the two following examples show, the location of tree plantings relative to buildings also plays a critical role in determining the level of benefits. Climate zone and building aspect must be considered in conjunction to realize the greatest building energy reduction benefits. The size, and therefore age, as well as the type of tree also significantly impacts the level to which trees evapotranspire, provide shade and act as windbreaks.

The Center for Urban Forest Research of the US Forest Service using its STRATUM model, 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

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) as well as the location of the tree with respect to buildings. Average reductions in building energy use can then be estimated based on these factors on a per tree basis.

As an example, Tables 2.1 and 2.2 show the 40-year average electricity and natural gas savings from trees in the Midwest Region.

Table 2.1: 40-year Average Electricity Savings from Trees in the Midwest Region

	Residential Yard Opposite West-Facing Wall	Residential Yard Opposite South-Facing Wall	Residential Yard Opposite East-Facing Wall	Public Tree on a Street or in a Park
Small tree: Crabapple (22 ft tall, 21 ft spread)	96 kWh	54 kWh	68 kWh	48 kWh
Medium tree: Red Oak (40 ft tall, 27 ft spread)	191 kWh	99 kWh	131 kWh	67 kWh
Large tree: Hackberry (47 ft tall, 37 ft spread)	268 kWh	189 kWh	206 kWh	136 kWh

Source: McPherson, E. et al. 2006

Table 2.2: 40-year Average Natural Gas Savings from Trees in the Midwest Region

	Residential Yard Opposite West-Facing Wall	Residential Yard Opposite South-Facing Wall	Residential Yard Opposite East-Facing Wall	Public Tree on a Street or in a Park
Small tree: Crabapple (22 ft tall, 21 ft spread)	1,334 kBtu	519 kBtu	1,243 kBtu	1,534 kBtu
Medium tree: Red Oak (40 ft tall, 27 ft spread)	1,685 kBtu	-316 kBtu	1,587 kBtu	2,099 kBtu
Large tree: Hackberry (47 ft tall, 37 ft spread)	3,146 kBtu	2,119 kBtu	3,085 kBtu	3,430 kBtu

Source: McPherson, E. et al. 2006

Example 2.3:

Using the data in Tables 2.1 and 2.2, the estimated average annual energy savings from a large tree located opposite a west facing wall of a house in the Midwest Region will be 268 kWh in cooling (electricity) savings and 3,146 kBtu (or 3,146,000 Btu, as 1 kBtu = 1,000 Btu) in heating/natural gas savings.

REDUCED ENERGY FROM REDUCED WATER TREATMENT

As mentioned earlier, it is important to recognize the off-site means by which green infrastructure practices also reduce energy use through reduced water treatment needs in communities with combined sewer systems. While the "Water" section has already accounted for the cost savings of this reduction (i.e. the "valuation" step of this direct benefit), the reduction in energy use will also provide indirect air and climate benefits from reduced emissions, which will be discussed later. Because of these indirect benefits, it is necessary to quantify the amount of energy reduced from water treatment.

To estimate the energy savings from reduced water treatment needs, it is necessary to have calculated the nega-gallons (i.e. gallons of reduced stormwater runoff) resulting from green infrastructure practices, as estimated in the "Water" section.

Table 2.3 outlines how much energy (kWh) is consumed per million gallons of water treated by six different treatment plant sizes using four different types of treatment methods. These should be referenced as default values only when calculating the energy savings from reduced treatment. Local utilities can provide more site-specific figures.

Table 2.3

Treatment Plant Size million gallons/day	Unit Electricity Consumption | kWh/million gallons			
	Trickling Filter	Activated Sludge	Advanced Wastewater Treatment	Advanced Wastewater Treatment Nitrification
1 MM gal/day	1,811	2,236	2,596	2,951
5 MM gal/day	978	1,369	1,573	1,926
10 MM gal/day	852	1,203	1,408	1,791
20 MM gal/day	750	1,114	1,303	1,676
50 MM gal/day	687	1,051	1,216	1,588
100 MM gal/day	673	1,028	1,188	1,558

Source: EPRI 2002

Example 2.4:

Referring back to Example 1.1 and relying on the default values in Table 2.3, it is possible to estimate the energy saved from reduced water treatment needs from a green roof. If water treatment needs are reduced by 71,100 gallons in an area with an advanced wastewater treatment nitrification plant with a 100 MM gal/day capacity, electricity consumption could be reduced as follows:

71,100 gal saved = 0.0711 million gal saved

*0.0711 million gal * 1,558 kWh/million gal = 110.77 kWh*

Thus, the 5,000 SF green roof example contributes to an annual electricity savings from reduced water treatment needs of 110.77 kWh.

STEP 2 - VALUATION OF QUANTIFIED BENEFITS: REDUCED ENERGY USE

Having calculated the direct kWh and Btu saved in reduced building energy use, it is possible to assign a dollar value to these savings. Again, note that energy savings resulting from reduced water treatment needs have previously been accounted for and should NOT be valued here. The kilowatt hours of reduced energy from reduced water treatment should be carried directly to the "Air Quality" and "Climate Change" sections to be valued there. (In other words, the answer from Example 2.6 is not valued here, but this figure will be used later to calculate indirect emissions benefits.)

One may calculate the direct cost savings by multiplying the kilowatt hours or Btus of electricity and natural gas, respectively, by local utility rates. If local utility rates are not available, use national average retail electricity and natural gas prices.

The values below represent the U.S. average retail price for electricity for April 2010 and the 2010 forecast retail price for natural gas (US EIA 2010).

The following two equations provide a formula for calculating the value of cooling (kWh) and heating (Btu) savings respectively and rely on these national utility rate averages:

> **kWh reduced * $0.0959/kWh**
> **= value of cooling or electricity savings**
>
> **Btu reduced * $0.0000123/Btu**
> **= value of heating natural gas savings**

Example 2.5:

Using the cooling savings from Example 2.1 and the heating savings from Example 2.2, the following example calculates the annual direct cost savings provided by a 5,000 SF green roof:

*0.2244 kWh/SF for cooling savings * 5,000 SF * $0.0959/kWh = $107.60 annual cooling or on-site electricity savings*

*7,231.75 Btu/ SF for heating * 5,000 SF * $0.0000123/Btu = $444.75 annual heating natural gas savings*

The combined benefits from the green roof result in an average annual on-site energy savings of $552.35.

Example 2.6:

Referencing Tables 2.1 and 2.2 and the cost saving established in Example 2.5, if a house in the Midwest Region has one large tree located opposite a west-facing wall, the direct cost savings can be calculated as:

*268 kWh * $0.0959 = $25.70 annual cooling or on-site electricity savings*

*3,146,000 Btu * $0.0000123 = $38.70 annual heating natural gas savings*

The combined benefits from the large tree result in an average annual on-site energy savings of $64.40.

Benefit Measurement and Valuation
3. AIR QUALITY

STEP 1 - QUANTIFICATION OF BENEFIT: REDUCED CRITERIA POLLUTANTS

This section quantifies the direct (uptake and deposition) and indirect (avoided emissions) air quality impacts of green infrastructure and provides instructions for valuing these impacts in monetary terms. The criteria pollutants addressed here are nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2) and particulate matter of aerodynamic diameter of ten micrometers or fewer (PM-10).

Practices that provide a direct benefit of uptake and deposition include green roofs, trees and bio-infiltration.

GREEN ROOFS

Direct air quality benefits from green roofs depend on several local factors. Different plant species take up pollutants at different rates, so the type of species planted will influence the magnitude of air quality improvement. Local climate factors also influence plants' air quality effects. In cold weather climates, plant uptake will be lower during seasons when plants may be covered in snow. Climates with longer growing seasons will see greater air quality improvements, all else being equal, than those with shorter seasons.

To estimate the direct benefits of green roofs on air quality, we recommend the following range of values as an initial order of magnitude approximation of annual pounds of pollutant removed per square foot of practice installed:

Table 3.1

	Low (lbs/SF)	High (lbs/SF)
NO_2	3.00×10^{-4}	4.77×10^{-4}
O_3	5.88×10^{-4}	9.20×10^{-4}
SO_2	2.29×10^{-4}	4.06×10^{-4}
PM-10	1.14×10^{-4}	1.33×10^{-4}

Source: Currie and Bass (2008) and Yang, Qian and Gong (2008)

The following equation illustrates how to quantify the direct benefit received based on the area of the practice and the average pollutant uptake/deposition for that practice:

> **area of practice (SF) ***
> **average annual pollutant uptake/deposition (lbs/SF)**
> **= total annual air pollutant uptake/deposition (lbs)**

Keep in mind that the subsequent example calculations will only walk through the quantification of reduced NO_2. Other criteria pollutants will not be illustrated, but they should be calculated when conducting a comprehensive benefit analysis.

Example 3.1:
Using the above equation, a 5,000 SF green roof could lead to an improved direct nitrogen dioxide (NO_2) uptake capacity as follows:

Lower Bound (using 3.00×10^{-4} lbs/SF/yr)
*5,000 SF * 3.00×10^{-4} lbs/SF = 1.50 lbs total annual NO_2 uptake*

Upper Bound (using 4.77×10^{-4} lbs/SF/yr)
*5,000 SF * 4.77×10^{-4} lbs/SF = 2.39 lbs total annual NO_2 uptake*

In this case, the 5,000 SF green roof would on average take up between about 1.50 and 2.39 pounds of NO_2 annually.

TREE PLANTING

Climate zone, existing air quality and pollutant levels, and the size, age and type of tree all play a role in determining the uptake potential of tree planting.

The Forest Service *Tree Guides* estimate the level of air quality benefits from trees according to climate zone. The tables in the guides' appendices are structured based on the size of the tree (with example tree types provided) and the location of the tree with respect to a surrounding building. One can then estimate air quality benefits based on these factors (on a per tree basis) using the "Uptake and Avoided" data provided in the *Tree Guides*' appendices.

As an example, Table 3.2 shows the 40-year average air quality impacts from trees in the Midwest Climate Region.

Table 3.2
Annual Criteria Pollutant Reductions (uptake and avoided) 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)
NO_2 Uptake and Avoided	0.39 lbs	0.63 lbs	1.11 lbs
SO_2 Uptake and Avoided	0.23 lbs	0.42 lbs	0.69 lbs
O_3 Uptake	0.15 lbs	0.2 lbs	0.28 lbs
PM-10 Uptake and Avoided	0.17 lbs	0.26 lbs	0.35 lbs

Source: McPherson, E. et al. 2006

The following equation illustrates how to reach a quantified benefit from a tree planting:

> **no. of trees * average annual uptake and avoided pollutant emissions (lbs/tree) = total annual air pollutant reduction (lbs)**

Example 3.2:
Given the data from Table 3.2, it is possible to use the above equation to determine the annual nitrogen dioxide (NO_2) benefit of 100 medium-sized trees planted in the Midwest Region.

*100 medium trees * 0.63 lbs NO_2/tree = 63 lbs total annual NO_2 reduction*

Figures provided by the *Tree Guides* for criteria air pollutant abatement include both the direct (uptake and deposition) and indirect (avoided power plant emissions) benefits, which must be kept in mind in order to avoid double-counting these benefits in later calculations. Once a total abatement figure is reached, it is possible to move directly to calculating the monetary value of that tree practice, as outlined in the "Valuation of Quantified Benefits" section.

BIORETENTION AND INFILTRATION

Although many studies agree that vegetative infrastructure elements such as bioswales, rain gardens and other bio-infiltration techniques can provide considerable air quality benefits, there is currently a lack of scientific research measuring and quantifying the direct air pollution uptake potential of these practices. Without studies that derive specific uptake values for

bio-infiltration practices, this guide cannot provide the steps to calculate the direct uptake benefit at this time, as further field research and data collection is needed.

Once an average value is quantified (in lbs/SF), provided sufficient research data is published, it can be substituted into the equation below:

> **total area of practice (SF) * average annual uptake/ deposition (lbs /SF)**
> **= total annual pollutant uptake/deposition (lbs)**

This equation could then be used to derive the total air pollutant uptake benefit for a given bioswale or rain garden and later to monetize the practice's direct uptake benefit.

Indirect Benefits

As stated above, this section quantifies not only the direct (uptake and deposition) means by which air quality is improved, but also the indirect means (avoided emissions) that provide air quality improvements.

Practices that indirectly lower emissions of air pollution include any practices that reduce energy consumption through decreased energy use in neighboring buildings or through reduced water treatment needs. These benefits are quantified in the "Energy" section, and they should be accounted for here to estimate in pounds the reduction of criteria air pollutants stemming ultimately from reduced water treatment.

The production of electricity in fossil fuel power plants entails the emission of nitrogen dioxide and sulfur dioxide. Furthermore, the burning of natural gas in homes and businesses produces additional indirect air pollutant emissions. In order to quantify this impact, multiply the estimated electricity use reduction calculated here in the "Energy" section by emissions factors provided by the US EPA. It is important to keep in mind that the net air quality benefit from trees was already calculated above, so to avoid double counting, do not recalculate the reduced pollutants from trees here.

The following equations are used to calculate the total avoided criteria pollutant emissions from reduced energy usage in terms of electricity and natural gas, respectively. Specific practice-based calculations follow from the calculations completed in the "Energy" section and do not require additional individual explanation.

Benefit from kWh of Electricity Saved

> **annual electricity reduction (kWh) ***
> **emissions factor (lbs/kWh)**
> **= annual avoided pollutant emissions (lbs)**

In its online eGRIDweb application, the USEPA provides the following figures for estimated annual output emissions rates of national electricity production:

- **NO_2: 1.937 lbs/MWh » 0.001937 lbs/kWh**
- **SO_2: 5.259 lbs/MWh » 0.005259 lbs/kWh**
Source: USEPA 2005

Please note that although power plants and electricity generators emit both ozone and certain particulates into the atmosphere, data could not be found to quantify the emissions factors for those variables.

Example 3.3:
Using the example 5,000 square foot green roof again, remember the annual cooling savings determined in Example 2.1:

5,000 SF * 0.2244 kWh/SF = 1,122 kWh in cooling savings annually

Given the reduced electricity use of 1,122 kWh, the NO_2 emission benefits from that reduction are:

1,122 kWh * 0.001937 lbs/kWh = 2.17 lbs avoided NO_2 emissions from cooling savings annually

More locally-specific figures can be found in the eGRIDweb application. This tool provides emission rates by state, grid region and power plant or generating company.

Benefit from Btu of Heating Natural Gas Saved

> **annual heating natural gas savings (Million Btu) ***
> **emissions factor (lbs/Million Btu)**
> **= annual avoided criteria pollutant emissions (lbs)**

In the same online eGRIDweb application used previously, the USEPA provides the following figures for the national annual emission factors per Btu of natural gas input:

- **NO_2: 0.721 lbs/Million Btu**
- **SO_2: 0.266 lbs/Million Btu**

Source: USEPA 2005

Please note that although the burning of natural gas emits both ozone and certain particulates into the atmosphere, data could not be found to quantify the emissions factors for those variables.

Example 3.4:
Using the example 5,000 square foot green roof again, remember the annual heating natural gas savings (Btu) determined in Example 2.2:

7,231.75 Btu/SF * 5,000 SF = 36,158,750 Btu = 36.15875 Million Btu annually in heating natural gas savings

Given the reduced heating natural gas use of 36.15875 Million Btu and using the US EPA emissions factors above of 0.721 lbs NO_2 / Million Btu, the NO_2 emission benefits from that reduction are:

36.15875 Million Btu * 0.721 lbs NO_2/Million Btu = 26.07 lbs avoided NO_2 emissions from heating natural gas savings annually

Total Benefit from Electricity and Heating Natural Gas Savings
Now that the indirect air quality benefits from electricity and natural gas savings have been quantified, the pounds of criteria pollutants calculated from both can be added together. This summation will make the later valuation calculation less complicated.

> **annual avoided pollutant emissions from reduced electricity (lbs) + annual avoided criteria pollutant emissions from reduced heating natural gas (lbs)**
> **= total avoided criteria pollutant emissions from electricity and heating natural gas savings annually**

Example 3.5:
Taking the answers from Examples 3.3 and 3.4, the total indirect benefit from electricity and heating natural gas savings can be quantified as:

2.17 lbs avoided NO_2 (Example 3.3) + 26.07 lbs avoided NO_2 (Example 3.4) = 28.24 lbs avoided NO_2 emissions from reduced cooling and heating energy use annually.

Now, one can quantify the total air quality benefit by adding together the total direct criteria pollutant uptake/deposition benefit and the total indirect avoided emissions benefit (from reduced energy use) for each practice.

> **Σ total criteria pollutant uptake/deposition benefit (lbs) + total avoided criteria pollutant emissions (lbs) = total annual criteria pollutant reduction benefit (lbs)**

STEP 2 - VALUATION OF QUANTIFIED BENEFITS: REDUCED CRITERIA POLLUTANTS
In order to arrive at a value for the benefits of air quality improvements from green infrastructure, one must estimate the price or cost (per pound) of the standard air pollutants discussed in this guide.

The following numbers represent US Forest Service recommendations for valuation of criteria air pollutants:

- **NO_2 = $3.34/lb**
- **O_3 = $3.34/lb**
- **SO_2 = $2.06/lb**
- **PM-10 = $2.84/lb**

Source: McPherson et al. (2006), Wang and Santini (1995)

The equation below allows for valuation of air quality benefits derived from using green infrastructure practices:

> **total annual criteria pollutant reduction benefit (lbs) * price of criteria pollutant ($/lb) = total value of pollutant reduction ($)**

Example 3.6:
Recall that Example 3.1 found that a hypothetical 5,000 SF green roof yields an annual nitrogen dioxide (NO_2) uptake benefit between 1.50 and 2.39 pounds of NO_2 reduction, or an average of 1.95 pounds. Furthermore, Example 3.5 found the same roof yields 28.24 pounds of indirect NO_2 reduction. Notice that these figures are the same resource unit and can be summed as follows:

Σ 1.95 lbs NO_2 + 28.24 lbs NO_2 = 30.19 lbs NO_2

Given the above valuation equation and a price per pound of NO_2 of $3.34/lb, the following calculation determines the monetary value of the on-site uptake and off-site emissions benefits, as follows:

*30.19 lbs NO_2 * $3.34/lb NO_2 = $100.83*

Thus, the green roof would lead to a monetary benefit from on-site and off-site NO_2 benefits of about $100.83 annually.

The Role of Permeable Pavement in Improving Air Quality

In addition to green roofs, trees, and bioretention and infiltration practices, permeable pavement can also improve air quality and reduce atmospheric CO_2. Permeable pavement reduces the amount of water treatment needed by allowing stormwater to infiltrate on site, in turn reducing air pollution and CO_2 emissions from power plants. It also decreases ground level ozone formation and helps to lower pavement surface temperatures by reducing the amount of heat absorbed. This helps to cool the air and decrease the amount of energy needed for cooling. It also mitigates the urban heat island effect.

A recent study comparing pervious concrete to traditional pavement found that "…while the pervious concrete becomes hotter than the surrounding air temperature during the daytime much less heat is transferred and stored in the underlying soil than the traditional pavement. Even though the pervious concrete became warmer than the traditional [concrete], at night the pervious concrete was equal to or cooler than the [traditional concrete] pavement. This indicates less heat storage potential and a greater rate of cooling in the pervious concrete versus the traditional system" (Kevern, J.T. et al. 2009b).

While research has demonstrated the ability of permeable pavement to improve air quality and reduce atmospheric CO_2, not enough data exists to walk through a valuation of these benefits at this time.

Benefit Measurement and Valuation
4. CLIMATE CHANGE

STEP 1 - QUANTIFICATION OF BENEFIT: REDUCED ATMOSPHERIC CO_2

This section provides instructions on how to quantify and value direct (sequestration) and indirect (avoided emissions) climate benefits. While recognizing that there are other types of greenhouse gases that contribute to climate change, the focus in this section is specifically on the climate benefits of reducing atmospheric CO_2, as this is the greenhouse gas most directly affected by green infrastructure. A similar framework can be used to value the climate impacts of those other gases, particularly when they are put in terms of CO_2-equivalents. Outlining those additional steps, however, is outside the scope of this guide.

Green infrastructure practices specifically addressed in this section for their direct benefit of carbon sequestration include green roofs, trees and bio-infiltration. The authors acknowledge that there are additional climate benefits from other practices, such as permeable pavement, which cannot be explicitly quantified at this time due to the infancy of the research surrounding this benefit within those practices. Finally, it is important to note that sequestration benefits only last as long as the plants or trees are alive and that they vary with the age of the vegetation.

The following equation is used to quantify the amount of carbon sequestered for a given area and green infrastructure practice, keeping in mind that the pounds of carbon sequestered per unit area depend on several local factors, including the specific practice, the types of species planted and the local climate:

$$\text{total area of practice (SF)} *$$
$$\text{average annual amt. of carbon sequestered (lbs C /SF)}$$
$$= \text{annual amount of carbon sequestered (lbs C)}$$

It is important to note that a common point of confusion when quantifying carbon sequestration benefits is how many pounds of CO_2 are avoided from a certain amount of stored carbon. Due to the molecular structures involved, the pounds of carbon stored in plants do not equal the pounds of carbon dioxide that are removed from the atmosphere (because an atom of carbon has a smaller atomic mass than a carbon dioxide molecule). Employ the following conversion factor ($44/12$ or 3.67) to arrive at the equivalent CO_2 impacts of a specific carbon sequestering practice.

GREEN ROOFS

Research synthesized in a Michigan State University report offers average carbon sequestration values provided by extensive green roofs' aboveground biomass (Getter et al. 2009). Using the data from that report, it is possible to arrive at an estimated range of carbon sequestration per square foot for similarly implemented extensive green roofs. Because one of the two studies lacks belowground sequestration figures, this guide does not take belowground biomass into account when determining the recommended range. (See below.) As such, the given range may provide an underestimate of the practice's full sequestration potential. Further field research and data collection are needed in order to more precisely determine the full carbon sequestration potential of green roofs.

The recommended range of grams of carbon sequestered per square meter from aboveground biomass, as determined by

the averages of the two Michigan State University studies (which include data from extensive green roofs surveyed in both Michigan and Maryland), is as follows:

162 g C/m² to 168 g C/m² (Getter et al. 2009)

Converting to lbs C/SF from metric units[2], the range can be defined: 0.0332 lbs C/SF to 0.0344 lbs C/SF

Example 4.1:
A hypothetical 5,000 SF extensive green roof provides an estimated carbon sequestration capacity as follows:

Lower Bound (using 0.0332 lbs C/SF)
*0.0332 lbs C/SF * 5,000 SF = 166 lbs of carbon per year*

Upper Bound (using 0.0344 lbs C/SF)
*0.0344 lbs C/SF * 5,000 SF = 172 lbs of carbon per year*

In this case, the hypothetical 5,000 SF extensive green roof would sequester between about 166 and 172 pounds of carbon annually, or an average of 169 pounds of carbon per year.

TREE PLANTING
Local conditions—such as climate zone, existing air conditions and season—as well as size, age and species type all play a role in determining the carbon sequestration potential of a tree.

The referenced Forest Service *Tree Guides* provide an estimate of the level of CO_2-related benefits from trees according to climate zone. Once the climate zone is determined, the tables in the tree guides' appendices are structured on the basis of size of tree (with example tree types provided) as well as the location of the tree with respect to a surrounding building. Climate benefits can then be estimated based on these factors (on a per tree basis) using the "Net CO_2" data provided in the tree guides' appendices. These benefits vary by region and according to energy sources.

As an example, Table 4.1 shows the 40-year average CO_2 benefits from trees in the Midwest Climate Region.

Table 4.1: Annual Net CO_2 (lbs) Benefits from 1 tree, 40-year average, Midwest Region

Net CO_2 (lbs)	Residential Yard Opposite West-Facing Wall	Residential Yard Opposite South-Facing Wall	Residential Yard Opposite East-Facing Wall	Public Tree on a Street or in a Park
Small tree: Crabapple (22 ft tall, 21 ft spread)	390	226	335	336
Medium tree: Red Oak (40 ft tall, 27 ft spread)	594	212	487	444
Large tree: Hackberry (47 ft tall, 37 ft spread)	911	665	806	734

Source: McPherson, E. et al. 2006

[2] Converting g C /m² into lbs. C/SF, we multiply the metric units by a conversion factor 0.00220462262 lbs/g to arrive at lbs C/m², then we multiply by a conversion factor of 0.09290304 m² /SF to arrive at the desired lbs C/SF

Example 4.2:

Given the data in Table 4.1, it is possible to determine the benefits of planting 100 medium trees in a public space. In this case, the number of trees planted is used instead of the amount of vegetated area in the equation to arrive at the final figure:

*number of medium trees planted * total CO_2 abated (lbs /tree) = total annual climate benefit (direct and indirect) (lbs CO_2)*

100 medium trees * 444 lbs total CO_2/tree = 44,400 lbs of total annual CO_2 abatement

Please note that these "total CO_2" figures include both direct (sequestration) and indirect (avoided power plant emissions) benefits for trees, to avoid double-counting these benefits in later calculations. Once an abatement figure is reached, it is possible to calculate the monetary value of the green infrastructure practice following the steps outlined in the "Valuation of Quantified Benefits: Reduced Atmospheric CO_2" section. Notice also that the above figure is already in "pounds of CO_2," thus no conversion from carbon to CO_2 will be necessary.

BIORETENTION AND INFILTRATION

Although many studies agree that vegetative infrastructure such as bioswales, rain gardens, and other bio-infiltration techniques can provide a considerable amount of carbon sequestration benefit, there is a current lack of scientific research measuring and quantifying the sequestration potential of those practices. Without studies that demonstrate average values for the carbon sequestration potential per square foot of certain bio-infiltration practices, this guide cannot provide the steps to estimate the direct benefit.

Once an average value is quantified (in lbs/SF), it can be used in the equation below:

> **total area of practice (SF) ***
> **average annual amt. of carbon sequestered (lbs C /SF)**
> **= annual amt. of carbon sequestered (lbs C)**

Once it is possible to determine the total amount of carbon sequestration for a given bioretention or infiltration practice, the resulting pounds can be used to monetize the practice's direct sequestration benefit.

Indirect Benefits

As previously stated, this section quantifies the direct (sequestration) means by which CO_2 is reduced. It also quantifies the indirect means (avoided emissions) that provide climate change improvements.

Practices that provide an indirect benefit of avoided emissions include any practice that reduces energy consumption through reduced energy use in a neighboring building or through reduced water treatment needs. The "Energy" section quantifies these benefits, and they should now be accounted for to estimate the reduced pounds of criteria pollutants.

This section outlines a process for calculating the total avoided CO_2 emissions from reduced energy usage. Specific practice-based calculations follow from the calculations completed in the "Energy" section.

Benefit from kWh of Electricity Saved

The first step toward calculating the total avoided CO_2 emissions is to quantify the amount of electricity (in kWh) saved for a given area and green infrastructure practice. GI practices will reduce energy consumption on site as well as off site at water treatment facilities. These energy reductions depend on several local factors, including the specific practice, the types of species planted and local climate. The total annual electricity-saved calculation from the "Energy" section can be substituted into the equation below to calculate the total pounds of avoided CO_2:

> **total annual electricity saved (kWh) * lbs CO_2 /kWh**
> **= lbs annual avoided CO_2 emissions from**
> **practice's electricity savings**

Because the amount of CO_2 emissions from power plants varies depending on the electricity source (e.g. coal, nuclear, wind, etc), use Table 4.2 to specify the appropriate figure for "**lbs CO_2 /kWh**" (in the above equation) given the specific region under consideration.

Example 4.3:

Using the example 5,000 SF green roof again, remember the annual building electricity savings determined in Example 2.1 and the water treatment electricity savings determined in Example 2.4:

total electricity savings from a 5,000 SF green roof = 1,122 kWh in building electricity savings + 110.77 kWh in water treatment electricity savings =   1,232.77 kWh annually

Using the U.S. average of 1.33 lbs CO_2/kWh from Table 4.2, the reduced electricity savings would provide the following indirect climate benefit:

*1,232.77 kWh * 1.33 lbs CO_2/kWh = 1,639.58 lbs avoided CO_2 emissions from reduced electricity annually*

Table 4.2
Year 2005 eGRID Subregion Emissions, CO_2 Greenhouse Gas

eGRID Subregion Acronym	eGRID Subregion Name	CO_2 Output Emission Rate (lb CO_2/KWh)
AKGD	ASCC Alaska Grid	1.23236
AKMS	ASCC Miscellaneous	0.49886
AZNM	WECC Southwest	1.31105
CAMX	WECC California	0.72412
ERCT	ERCOT All	1.32435
FRCC	FRCC All	1.31857
HIMS	HICC Miscellaneous	1.51492
HIOA	HICC Oahu	1.81198
MORE	MRO East	1.83472
MROW	MRO West	1.82184
NEWE	NPCC New England	0.92768
NEWPP	WECC Northwest	0.90224
NYCW	NPCC NYC/Westchester	0.81545
NYLI	NPCC Long Island	1.5368
NYUP	NPCC Upstate NY	0.7208
RFCE	RFC East	1.13907
RFCM	RFC Michigan	1.56328
RFCW	RFC West	1.53782
RMPA	WECC Rockies	1.88308
SPNO	SPP North	1.96094
SPSO	SPP South	1.65814
SRMV	SERC Mississippi Valley	1.01974
SRMW	SERC Midwest	1.83051
SRSO	SERC South	1.48954
SRTV	SERC Tennessee Valley	1.51044
SRVC	SERC Virginia/Carolina	1.13488
U.S.		1.32935

Source: USEPA 2008c

Year 2005 eGRID Subregion Emissions, CO$_2$ Greenhouse Gas
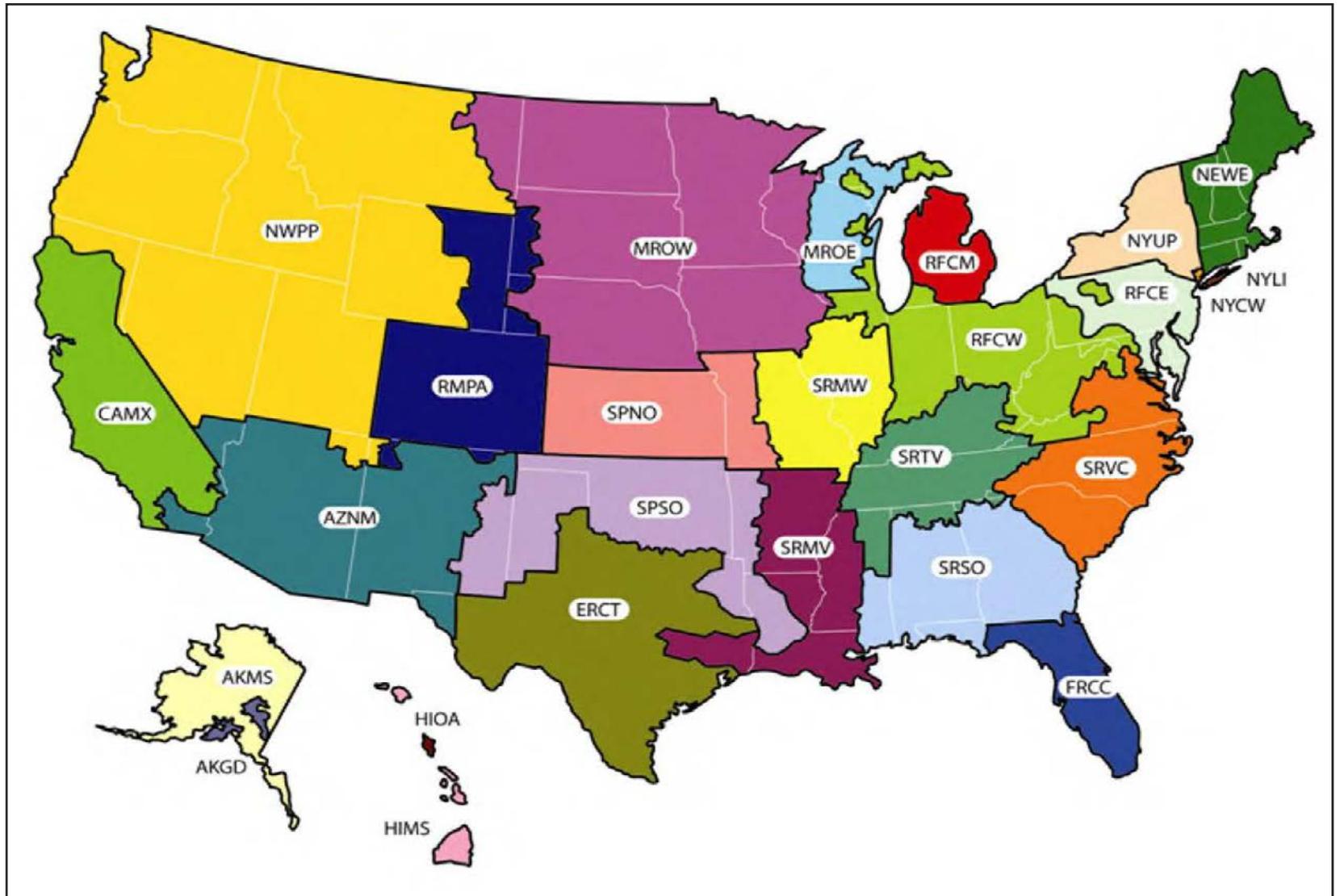
Benefit from Btu of Natural Gas Saved

Using the calculation of reduced natural gas from the "Energy" section, the total amount of avoided CO_2 emissions for the given area and green infrastructure practice can be estimated using the following equation:

> **total heating natural gas saved (Million Btu) * lbs CO_2 /Million Btu = lbs of avoided CO_2 emissions annually from heating natural gas savings**

Note that the previous equation relies on the CO_2 emissions factor of 116.89 lbs CO_2/Million Btu of natural gas[3] (i.e. the number of pounds of CO_2 released per million Btu) (US EPA 2009).

Example 4.4:

Using the example 5,000 SF green roof again, remember the annual heating natural gas savings (Btu) determined in Example 2.2:

*7,231.75 Btu/SF * 5,000 SF = 36,158,750 Btu = 36.15875 Million Btu annually in heating natural gas savings*

Using the CO_2 emissions factor above of 116.89 lbs CO_2/Million Btu, the reduced natural gas savings would provide the following indirect climate benefit:

*36.15875 Million Btu * 116.89 lbs CO_2/Million Btu = 4,226.6 lbs avoided CO_2 emissions from reduced natural gas annually*

---

[3] Converting the USEPA Code of Federal Regulations standard of 53.02 kg CO_2 / Million Btu into lbs CO_2 /Million Btu, multiply the metric units by a conversion factor of 2.20462262185 lbs/kg to arrive at the desired lbs CO_2/ Million Btu.

Total Benefit from Electricity and Heating Natural Savings

Now that the indirect benefits from electricity and natural gas savings have been quantified, the pounds of CO_2 from both calculations can be added together. This summation will make the later valuation calculation less complicated.

> **lbs avoided CO_2 emissions from electricity savings + lbs avoided CO_2 emissions from heating natural gas savings = total lbs avoided CO_2 emissions from electricity and heating natural gas savings annually**

Example 4.5:

Recall that Example 4.3 calculated the annual avoided CO_2 from electricity of the 5,000 SF green roof and that the annual avoided CO_2 from natural gas savings was calculated in Example 4.4. Notice that these figures are the same resource unit and can be summed as follows:

1,639.58 lbs CO_2 + 4,226.6 lbs CO_2 = 5,866.18 lbs avoided CO_2 emissions from reduced building cooling and heating and reduced water treatment energy use annually

Now, the total benefit can be quantified by adding together the total carbon sequestered and the total CO_2 emissions avoided (from reduced energy use) for each practice. To do so, any carbon sequestration benefit (lbs C) must be converted, as previously mentioned, to its CO_2 equivalent.

To convert pounds of carbon sequestered into pounds of carbon dioxide equivalent:

> **total lbs carbon sequestered (lbs C) * 3.67 lbs CO_2/lb C = total annual equivalent sequestration benefit (lbs CO_2)**

Then, the user can combine the direct (sequestration) and indirect (off-site avoided emissions) benefits into a figure for the total climate benefit, as follows:

> **$\sum$ total equivalent sequestration benefit (lbs CO_2) + total avoided CO_2 emissions (lbs CO_2) = total annual climate benefit (lbs CO_2)**

An example of this calculation will follow; please refer to Example 4.6.

STEP 2 - VALUATION OF QUANTIFIED BENEFITS: REDUCED ATMOSPHERIC CO_2

With the total pounds of CO_2 reduced, the following equation estimates the monetary value:

> **total climate benefit (lbs CO_2) * price of CO_2 ($/lb) = total annual value of climate benefit ($)**

Example 4.6:
Following from Example 4.1, which quantified the direct and indirect climate benefits of a hypothetical 5,000 SF green roof, it was found that the green roof sequestered between 166 and 172 pounds of carbon per year. (An average of 169 pounds of

carbon is used below.) In Example 4.5, this green roof had the indirect benefit of avoiding 5,866.18 lbs of CO_2 emissions from reduced energy use. One can calculate the monetary value of the total climate benefit as follows:

*169.0 lbs C * 3.67 lbs CO_2/lb C = 620.23 lbs CO_2 in total annual sequestration benefit*

5,866.18 lbs CO_2 in total annual indirect emissions benefit (Example 4.5)

$\sum$ 620.23 lbs CO_2 + 5866.18 lbs CO_2 = 6486.41 lbs CO_2 in total annual climate benefits

This total climate benefit can be valued by multiplying by a price for carbon. In the following parts (4.6.a. and 4.6.b.), the guide walks through calculations of a lower and upper bound for valuing these carbon benefits.

Example 4.6.a:
Lower Bound: EU ETS Carbon Price of $0.00756 / lb CO_2

*6,486.41 lbs CO_2 * $0.00756 / lb CO_2 = $49.04 monetary value of the total annual climate benefits*

This lower-bound calculation shows that the hypothetical green roof could provide about $49.04 in annual climate change benefits.

Example 4.6.b:
Upper Bound: Stern's Value of $0.0386/lb CO_2

*6,486.41 lbs CO_2 * $0.0386/lb CO_2 = $250.38 monetary value of the total annual climate benefits*

This upper-bound calculation shows that the hypothetical green roof could provide about $250.38 in annual climate change benefits.

Pricing Carbon

To complete the valuation of the direct and indirect climate benefits for a given practice, a monetary price for carbon must be determined. In other words, it is necessary to assign a value to the **$/ lb of CO_2** figure found in the final equation.

Assigning a price for carbon is not an exact science, and a degree of uncertainty still exists about the "best" or true price of carbon. It is generally accepted within the scientific community, however, that one can arrive at a working price estimate for the purpose of economic valuation of climate change.

Existing literature concerning the price of carbon dioxide and other greenhouse gas emissions offers a wide range of values for the market price of carbon. The latest report by the Intergovernmental Panel on Climate Change (IPCC) surveyed 100 peer reviewed studies and found an average estimated price per metric tonne[4] (Mg) of $12 (or $0.00544/lb) in a wide range that tops out at $95/Mg (or $0.0431/lb) (IPCC 2007).

The European Union's Emissions Trading System (EU ETS) is an example of a fully functioning carbon cap and trade market. A current average price within this market is about 12€, which according to today's conversion rate is about $16.66[5] per metric tonne of carbon (Chevallier, J. 2010). However, it is important to note this is only a partial market given that it is not globalized and its prices are dependent upon specific regulatory parameters. In contrast, a widely read and cited report on the economic impact of climate change values carbon emissions at $85/Mg (or $0.0386/lb) (Stern 2006). However, this value is strictly academic since it has not been tested in the market.

The IPCC and other experts note that current carbon prices are very likely underestimated in the marketplace, given the exclusion of many unquantifiable risks associated with climate change (for example, future damages from more intense rain events) (IPCC 2007, Clarkson & Deyes 2002). Given the range of potential value for a unit of carbon in the market, the guide provides a low- and high-end valuation example that can be applied to the climate benefit calculations in this section.

[4] Mg=metric tonne or megagram; Conversion: 1 Mg = 2204.62262 lbs.

[5] currency conversion based on a rate of 1 EUR = 1.389 USD from Google Finance, 11/1/2010, 7:00PM

Example 4.7:
Following from the earlier tree example in Example 4.2, the 100 medium trees planted in a public space abated a net amount of 44,400 pounds of CO_2 annually.

Remember that because the *Tree Guide* value includes the net benefit from CO_2 abatement—the direct and indirect benefits—the indirect energy benefit for a given tree practice does not need to be recalculated here. (Otherwise, that calculation would double count the indirect energy benefit.) Instead, just multiply the total amount of CO_2 abatement (44,400 lbs in this case) by a given carbon price.

In the following (4.7.a. and 4.7.b.), the guide walks through calculations of a lower and upper bound for valuing these carbon benefits.

Example 4.7.a:
Lower Bound: EU ETS Carbon Price of $0.00756 / lb CO_2

44,400 lbs CO_2 * $0.00756 /lb CO_2 =
$335.66 in total annual climate benefits

This lower-bound calculation shows that 100 medium trees planted in a public space could provide about $335.66 in annual climate change benefits.

Example 4.7.b:
Upper Bound: Stern's Value of $0.0386/lb CO_2

44,400 lbs CO_2 * $0.0386/lb CO_2 =
*$1,713.84 in total annual climate benefits*

This upper-bound calculation shows that 100 medium trees planted in a public space could provide about $1,713.84 in annual climate change benefits.

Benefit Measurement and Valuation
5. URBAN HEAT ISLAND

The USEPA describes the process by which urban heat islands form as follows: "As urban areas develop, changes occur in the landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist generally become impermeable and dry. This development leads to the formation of urban heat islands—the phenomenon whereby urban regions experience warmer temperatures than their rural surroundings" (US EPA n.d. a).

Source: Lawrence Berkeley National Laboratory
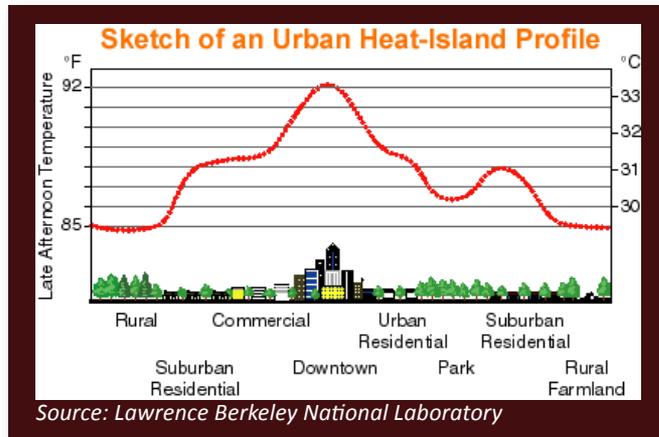
The urban heat island (UHI) effect compromises human health and comfort by causing respiratory difficulties, exhaustion, heat stroke and heat-related mortality. UHI also contributes to elevated emission levels of air pollutants and greenhouse gases through the increased energy demand (via greater air conditioning needs) that higher air temperatures cause. Additionally UHI puts a greater demand on outdoor irrigation needs thus increasing water demand and its associated energy uses. Green infrastructure practices within urban areas can help to mitigate UHI and improve air quality through increased vegetation, reduced ground conductivity and decreased ground level ozone formation.

Various studies have estimated that trees and other vegetation within building sites reduce temperatures by about 5°F when compared to outside non-green space. At larger scales, variation between non-green city centers and vegetated areas has been shown to be as high as 9°F. Likewise, recent studies done on permeable pavement have found that it reduces or lowers the negative impacts of UHI through its porosity, which serves to insulate the ground better and allow more water evaporation. Both of these effects aid in cooling temperatures and mitigating the UHI effect.

One study, evaluating the benefit of reduced extreme-heat events, estimates that, at a city level, 196 premature fatalities can be avoided in Philadelphia (over a 40-year period) by integrating green infrastructure throughout the city landscape to address its combined sewer overflows (McPherson et al 2006; Akbari et al 1992; Stratus 2009). According to figures from the USEPA (n.d. b), the value of a statistical life (VSL) is $7.4 million (in 2006 dollars). Thus, applied to the Philadelphia study, reductions in UHI-related fatalities could save over $1.45 billion. Likewise, the Lawrence Berkeley Lab Heat Island Group estimates that each one degree Fahrenheit increase in peak summertime temperature leads to an increase in peak demand of 225 megawatts, costing ratepayers $100 million annually (Chang 2000).

While the benefits of mitigating the UHI are important to community health and vitality, current valuation of these benefits is not extensive enough to work through quantifying methods and equations in this section.

Benefit Measurement and Valuation
6. COMMUNITY LIVABILITY

Using green infrastructure for stormwater management can improve the quality of life in urban neighborhoods. In addition to the ecological and economic values described elsewhere in this handbook, the goods and services provided by urban vegetation and other green infrastructure practices carry socio-cultural values—aspects that are important to humans because of social norms and cultural traditions. This set of related benefits is grouped under the umbrella category of 'community livability' to describe the many ways in which increasing the use of green infrastructure can improve neighborhood quality of life. Community livability is classified into four categories:

- Aesthetics
- Recreation
- Reduced noise pollution
- Community cohesion

While all of these benefits carry significant value in communities, the literature regarding how to quantify their economic value is not extensive, widespread or well agreed upon at this time. Given the high levels of uncertainty involved in quantifying community livability benefits, this guide does not present methods and equations for quantification or valuation in this section. It does, however, points to ranges of benefit values that have been presented and proposed in various studies.

AESTHETICS
Increased greenery within urban areas increases the aesthetic value of neighborhoods. The positive impact of green infrastructure practices on aesthetics can be reflected in the well-observed relationship between urban greening and property value. People are willing to pay more to live in places with more greenery. To measure this value, various studies employ a Hedonic price method (calculating increases in property value adjacent to green features).

Several empirical studies have shown that property values increase when an urban neighborhood has trees and other greenery. For example, one study reported an increase in property value of 2–10 percent for properties with new street tree plantings in front (Wachter 2004; Wachter and Wong 2008). Another study done in Portland, Oregon, found that street trees add $8,870 to sale prices of residential properties and reduce time on market by 1.7 days (Donovan and Butry 2009). An extensive study on the benefits of green infrastructure in Philadelphia also explores the effect that these practices have on property values (Stratus 2009). While the authors conclude that property values are notably higher in areas with LID and proximity to trees and other vegetation, they also note the difficulty in isolating the effect of improved aesthetics and avoiding double-counting of benefits such as air quality, water quality, energy usage (often relating to heat stress) and flood control that also impact property values. In this study, a range of 0– 7 percent is presented as suggested in literature, and a mean increase of 3.5 percent is chosen (Status 2009). Ward et al. (2008) estimate property values in the range of 3.5–5.0 percent higher for LID adjacent properties in King County, Washington.

The Forest Service *Tree Guides*, referenced previously, provide estimates of the property value benefits trees provide in an urban setting. The property value benefit is found to be the second largest component of the total benefits derived from trees. Benefits are presented on a per tree basis, based on type and size of each tree as well its location.

Table 6.1
Annual Property Value Gains 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)
Residential Yard	$4.50	$10.73	$23.44
Public Space	$5.32	$12.67	$27.69

Source: McPherson, E. et al. 2006

RECREATION

Green infrastructure has been shown to increase recreational opportunities (for example, walking the dog, walking or jogging on sidewalks, bench sitting or picnicking) when increased vegetation and treed acreage is added within a community. The value of added recreational opportunities is measured by the increase in recreational trips or "user days" gained from urban greening. Use values can then be assigned to the various recreational activity trips.

In one study, Philadelphia, Pennsylvania, estimated an increase of almost 350 million recreational trips (over a 40-year period) when utilizing green infrastructure within the proposed implementation of its *Green City Clean Waters* plan to control stormwater. The 2009 monetized present value of these added trips could amount to over $520 million (Stratus 2009). Furthermore, a report by the Trust for Public Lands for the Philadelphia Parks Alliance provided critical data on recreational uses, activities and visitation at parks in Philadelphia (Trust for Public Land 2008).

User Day Methodology

User day estimates from the Philadelphia study, although not necessarily universal, may provide a helpful starting point for valuing improved recreation from green infrastructure and increased vegetation.
- 1 additional vegetated acre provides ~1,340 user days per year
- 1 additional vegetated acre provides ~27,650 user days over a 40-year period
- 1 user day provides ~$0.71 in present value for 40-year project period (Stratus 2009)

This translates to a benefit of about $951.40 for each additional vegetated acre per year and about $19,631.50 for each additional vegetated acre over a 40-year project period.

For a complete methodology, please refer to the Stratus (2009) report.

Another approach to valuing recreation is determining the avoided costs in connection to health benefits. An example of this would be studies that correlate lowered medical expenses with increased levels of routine physical activity. In a 2000 study, researchers found that when previously inactive adults regularly incorporated moderate physical activity into their routines, annual mean medical expenditures were reduced by $865 per individual (Pratt et al. 2000).

REDUCED NOISE POLLUTION

Green infrastructure, particularly vegetative practices and permeable pavement, have the added benefit of reducing noise pollution. Planes, trains and roadway noise are significant sources of noise pollution in urban areas—sometimes exceeding 100 decibels, which well exceeds the level at which noise becomes a health risk.

A study in Europe using porous concrete pavement found a reduction in noise level of up to 10 decibels (Olek et al 2003;

Gerharz 1999). Likewise, the British Columbia Institute of Technology's Centre for the Advancement of Green Roof Technology measured the sound transmission loss of green roofs as compared to conventional roofs. The results found transmission loss increased 5–13 decibels in low- and mid-frequency ranges, and 2–8 decibels in the high frequency range (Connelly and Hodgson 2008). Hedonic pricing studies assessing the impact of road and aircraft noise on property values find average reductions in property value per one decibel increase in noise level of 0.55 percent and 0.86 percent, respectively (Navrud 2003).

COMMUNITY COHESION

One way that green infrastructure can make communities better places to live is through its effect on 'community cohesion'—improving the networks of formal and informal relationships among neighborhood residents that foster a nurturing and mutually supportive human environment (Sullivan, Kuo and Depooter 2004).

A study done by the Landscape and Human Health Laboratory at the University of Illinois at Urbana/Champaign (UIUC) found that, "Exposure to green surroundings reduces mental fatigue and the feelings of irritability that come with it. . . . Even small amounts of greenery . . . helped inner city residents have safer, less violent domestic environments." (Kuo and Sullivan 2001b).

Another study documents a link between increased vegetation and the use of outdoor spaces for social activity, theorizing that urban greening can foster interactions that build social capital (Sullivan, Kuo and Depooter 2004). Related to this effect, a further study found a meaningful relationship between increased greenery and reduced crime (Kuo and Sullivan 2001a).

Urban Agriculture Opportunities

As urban populations grow and the costs associated with rural food production and distribution continue to increase, urban agricultural systems are being considered in order to address concerns related to food security and cost (Argenti 2000). According to the USDA, 15 percent of the world's food supply is currently produced in urban areas (AFSIC 2010).

Green infrastructure practices such as green roofs and tree planting can provide increased opportunities for urban agriculture and urban foraging. Urban agriculture can include a multitude of benefits to urban areas, including economic development, recreational and community-building activities, educational opportunities for youth and increased habitat within the urban ecosystem.

While local food production via green infrastructure provides a variety of valuable community benefits, the current state of its valuation is not extensive enough to work through quantifying methods and equations in the guide at this time.

Benefit Measurement and Valuation
7. HABITAT IMPROVEMENT

Many vegetated green infrastructure features can improve habitat for a wide variety of flora and fauna. Rain gardens and other vegetated infiltration features hold particular value in this regard insofar as they perform best when planted with native species. Ecological economists recognize two aspects of habitat which are preconditions for the provision of a whole array of ecosystem services. First, habitat is living space for both resident and migratory species. Second, habitat provides nurseries for species which live their adult lives elsewhere.

Habitats are typically economically valued using either contingent valuation methods (especially where the conservation of an endangered species is concerned) or using the market price of traded goods that are harvested at the habitat in question (or of traded goods that are harvested elsewhere but for which the relevant habitat provides breeding and/or nursery grounds). The latter method can be useful, for example, in the case of coastal estuaries that provide nurseries for commercially harvested fish, but this approach is less applicable to the relatively small-scale urban vegetated features in question here. Contingent valuation studies might be more useful, but unfortunately, few have been conducted examining the habitat value of urban green space. Thus, this guide does not attempt to provide a framework for valuing this benefit.

Benefit Measurement and Valuation
8. PUBLIC EDUCATION

The USEPA (2008b) has listed public education as one of its six stormwater best management practices, further supporting the need for communities to be educated about water conservation and stormwater management. This is particularly important given the public's lack of understanding about the primary causes of and solutions to water pollution problems. A 2005 report by the National Environmental Education & Training Foundation (NEEFT) came to the following conclusion:

"78 percent of the American public does not understand that runoff from agricultural land, roads, and lawns, is now the most common source of water pollution; and nearly half of Americans (47 percent) believes industry still accounts for most water pollution (NEEFT 2005)."

While quantifying and valuing public education is difficult and the guide does not attempt to do this, educating and informing the general public about the efficient use of water resources is a valuable service that can build support for better water management decisions in the future. It is a vital precursor to achieving widespread adoption of green infrastructure solutions and realizing the many benefits they offer to communities.

Example Demonstration 1: Benefit Assessment of a Single Green Roof

The demonstration below walks through the quantification and valuation steps for the benefits provided by the 5,000 square foot green roof example that recurs throughout this handbook. This example is not a full lifecycle analysis and therefore does not take into account long-term benefits such as extended longevity of the roof membrane.

The table below is set up such that one may easily compile the annual monetary gains from each benefit. Although the green roof's net monetary benefit is calculated at the end of the table, please keep in mind that this will be an underestimate of the green roof's true value. Some benefits, such as reducing the urban heat island effect or improving community livability, are not quantifiable or valued at this time. In addition, this example only considers the benefits from one relatively small project. Initiating a community-wide program that embeds green infrastructure throughout the urban landscape would provide far greater benefits.

Benefit	Step 1: Benefit Quantification resource unit(s)	Step 2: Benefit Valuation resource unit * price	Annual Benefit $
Reduces Stormwater Runoff	**Annual Stormwater Retention Performance:** 71,100 gal retained *(Example 1.1)*	**Value of Annual Avoided Treatment Cost:** 71,100 gal * $0.0000919/gal = $6.53 *(Example 1.6)*	$6.53
Reduces Energy Use	**Annual Building's Cooling (electricity) Savings (kWh):** 1,122 kWh *(Example 2.1)*	**Value of Annual Building's Cooling Savings:** 1,122 kWh* $0.0959/ kWh = $107.60 *(Example 2.5)*	
	Annual Building's Heating Natural Gas Savings (Btu): 36,158,750 Btu *(Example 2.2)*	**Value of Annual Building's Heating Savings:** 36,158,750 Btu * $0.0000123/Btu = $444.75 *(Example 2.5)*	
	Annual Off-site Water Treatment Electricity Savings (reduced treatment needs of 71,100 gal): 110.77 kWh *(Example 2.4)*	Annual Off-site Water Treatment Electricity Savings will not be valued here because the value has already been accounted for above *(Example 1.6)*.	
	Total Annual Electricity Savings (kWh, from on-site and off-site benefits): $\sum$ 1,122 kWh in cooling savings + 110.77 kWh in water treatment electricity savings = 1,232.77 kWh	The Total Annual Electricity Savings will not be valued here to prevent double counting. Instead, it is used to quantify "Air" and "Climate" benefits.	$107.60 + $444.75
Improves Air Quality *Note: The figures used here only account for the benefits of reduced NO_2. Similar steps should be performed for the other criteria pollutants, when possible.*	**Annual Direct NO_2 Uptake:** Lower Bound = 1.50 lbs NO_2 Upper Bound = 2.39 lbs NO_2 Average = 1.95 lbs NO_2 *(Example 3.1)*	**Value of Total Annual NO_2 Benefit:** 30.19 lbs NO_2 * $3.34/lb NO_2 = $100.83 *(Example 3.6)*	
	Annual Indirect Reduction in NO_2 Emissions (from reduced electricity and natural gas): 28.24 lbs NO_2 *(Example 3.5)*		
	Total Annual NO_2 Benefit (Direct uptake using the average NO_2 uptake value + Indirect avoided emissions): $\sum$ 1.95 lbs NO_2 + 28.24 lbs NO_2 = 30.19 lbs NO_2 *(Example 3.6)*		$100.83
Reduces Atmospheric CO_2	**Total Annual Indirect Benefit** (from electricity and heating natural gas savings): 1,639.58 lbs CO_2 + 4,226.6 lbs CO_2 = 5,866.18 lbs CO_2 *(Example 4.5)*	**Value of Total Annual Climate Benefit:** 6,486.41 lbs CO_2 * $0.00756/ lb CO_2 = $49.04 in total annual climate benefits *(Example 4.6a)*	
	Annual Direct Carbon Sequestration Benefit in CO_2 Equivalent (multiplying lbs C from Example 4.1 by conversion factor): = 620.23 lbs CO_2 *(Example 4.6)*	*Note: Here the lower bound (EU's ETS Carbon Price) of the range of carbon pricing was used. Keep in mind that this provides a conserva-* *tive estimate of the economic, environmental and other social values of* *carbon abatement.*	
	Total Annual Climate Benefit (Direct + Indirect): $\sum$ 620.23 lbs CO_2 + 5,866.18 lbs CO_2 = 6,486.41 lbs CO_2 *(Example 4.6)*		$49.04
		Total Annual Benefit ($\sum$ Annual Benefits)	**$708.75**

Example Demonstration 2: Benefit Assessment of a Neighborhood Scale

This demonstration will walk through the quantification and valuation steps for scaling up the benefits of converting a hypothetical area of Chicago rooftops to green roofs. Following from Example Demonstration 1, these calculations show, in simplified terms, how scaling up the build out of green roofs has the potential to provide significant benefits to a community or urban area.

In this hypothetical demonstration, the City of Chicago plans to implement a green roof program to cover 1,200,000 square feet of viable rooftop area (assuming each green roof is 5,000 square feet in area) and calculates the total annual value of implementing this program. For reference, this converted area covers approximately five city blocks, provided that the average size of a city block in Chicago is 239,580 square feet[6].

In order to scale up the green roof benefits found earlier, one must calculate the number of roofs affected over the converted area (which will become the multiplier used to scale up the benefits):

1,200,000 SF area to be converted / 5000 SF per roof = 240 converted rooftops

The table below summarizes the benefits and corresponding monetary value of converting these 240 rooftops into green roofs.

Benefit	Annual Benefit ($) per 5,000 SF green roof (Example Demonstration 1)	Annual Benefit ($) from scaled green roof program (= annual benefit per roof * 240 converted roofs)
Reduces Stormwater Runoff	$6.53	$6.53 * 240 = $1,567.20
Reduces Energy Use	$107.60 + $444.75= $552.35	$552.35 * 240 = $132,564.00
Improves Air Quality Note: The figures used here only account for the benefits of reduced NO_2. Similar steps should be performed for the other criteria pollutants, when possible.	$100.83	$100.83 * 240 = $24,199.20
Reduces Atmospheric CO_2	$49.04	$49.04 * 240 = $11,769.60
Total Annual Benefit ($\sum$ Annual Benefits)	**$708.75**	**$708.75 * 240 = $170,100.00**

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[6] Average block size for the City of Chicago was determined using U.S. Census block group data collected from the Center for Neighborhood Technology's H+T® Affordability Index: 5.5 acres = 239,580 SF. Since block size varies from city to city, it is important to use local numbers for block area when available (CNT 2010b).

The previous calculations rely on a few central assumptions. First, the entire area in question will be converted into working and viable green roofs. Second, any additional scaling of green roof area will yield proportional benefits (hence the constant multiplier). Although the economic, environmental and social benefits of green roofs are calculated here, the total benefit value does not include a number of benefit categories, most notably reduced urban heat island effect, improved community livability, enhanced water quality and reduced flood risk. This guide has not attempted to quantify and value these benefits at this time, but they can be expected to significantly increase the overall value of the green roof.

It is also important to note that this example only considers the benefits from a relatively small application of green roofs. Initiating an even larger community-wide program that includes other forms of green infrastructure spread throughout the urban landscape would provide even greater benefits.

A similar example of a scaled-up urban application of green roofs has been done for the city of Washington, D.C. This case study looks at the impacts of green roofs over different coverage scenarios and details a methodology for analyzing an "opportunity area" for green roof implementation within the city (Deutsch et al. 2005). Findings show that both stormwater and air quality benefits are significant for a 20 percent green roof coverage scenario. These benefits include a predicted 13 percent reduction in CSO discharges and the same air quality benefits as would be provided by approximately 19,500 trees. The report concludes that the 20 percent green roof coverage case is both a "reasonable" and "feasible" target for the District of Columbia (Deutsch, B. et al. 2005).

Considerations and Limitations

This section explains key considerations and limitations to the preceding quantitative research and analysis. Due to the nature and scope of this report, every local project will have its own set of case-specific variables and uncertainties that must be evaluated. Particularly when undertaking a more rigorous benefit analysis of a specific green infrastructure program, please keep the following considerations in mind.

Full Life-Cycle Analysis

While a full life-cycle analysis is an important piece of the decision making process, it is beyond the scope of this guide, which has focused only on benefits. That said, it is important to note that when performing this type of valuation analysis, consideration of the counterfactual comparison is necessary. In other words, clearly defining what is being compared is critical. For example, is the analysis comparing whether or not to use green infrastructure instead of conventional grey infrastructure, or is the comparison between no change and the implementation of a green infrastructure project? This counterfactual understanding is important when valuing the overall costs and benefits of an action and should be clearly defined prior to working through a life-cycle analysis comparison.

Local Performance and Level of Benefits Realized

Detailed considerations of local and site-specific variables that impact green infrastructure performance are largely addressed in the previous quantitative section on a case-by-case basis. However, the need for local data when working through a framework for valuing a green infrastructure project or program remains crucial.

Recall that, as stated previously, the placement of trees relative to neighboring buildings will impact the amount of energy saved or that the media depth of a given green roof will impact its water retention capacity. Site-specific considerations should be made (when possible) for each benefit analysis in order to more precisely calculate the benefits accrued from a given project.

Regional and local variables, such as climate, also play a large role. Two green infrastructure installations with the exact same specifications can result in drastically different levels of benefits when implemented in different locations. For example, climate largely determines the reduction in building energy use resulting from trees. As discussed in the "Energy" section, shading

buildings in cool regions can actually cause an increase in energy demand, while reducing wind speeds in warm regions has little to no impact.

Spatial Scaling and Thresholds

Given the lack of large-scale green infrastructure programs and research analyzing their performance, it is uncertain whether one can estimate potential benefits from a community-wide program simply by scaling up smaller-site data. In other words, the benefits from a specific practice may or may not have a linear relationship to the scale of a project.

Some examples used in this guide provide estimates for linear multipliers (for example, the energy saved per square foot of a green roof in the "Energy Section") and rely on the assumption that the benefit from one unit of a practice is proportional to the benefit from 100 units of the same practice. The complexity of natural functions, however, does not necessarily lend itself to such a simplified aggregation, and system level considerations are important.

Instead of having a linear relationship, it is also possible that green infrastructure could function similarly to the concept of an "economy of scale." This would be the case if the benefits accrued from a practice have a proportionately greater effect on a large scale than they would if practiced over a small area. In effect, the green infrastructure practice would provide the maximum level of benefit only after achieving a certain scale of implementation. For example, the water quality improvement from a constructed wetland would be significantly and disproportionately larger than the water quality improvement from a smaller-scale rain garden.

An equally important consideration within spatial scaling is the concept of an ecological threshold, which can be described as "the point at which there is an abrupt change in an ecosystem . . . or where small changes in an environmental driver produce large responses in the ecosystem" (Groffman et al 2006). For example, urban heat island mitigation benefits that result from green infrastructure practices may only be realized at an as yet unknown level of incremental spatial implementation. A forest may provide significant cooling benefits, while a smaller number of individual trees in an urban area may have a negligible impact.

Temporal Considerations and Scale
Discounting
When evaluating an investment, economists use a process known as discounting, or present-value determination, to calculate the present-dollar equivalent of an investment's future benefits. In other words, discounting "translate[s] the values of future impacts into equivalent values in today's monetary units" (Goulder and Stavins 2002).

The term "discounting" refers to the adjustment one makes to account for future uncertainty (or the opportunity cost of money: a dollar today is not worth the same as a dollar five years down the road). Our society generally values what an investment gives us in the present more than what we might get for it in the future. The reason for this is future uncertainty, and as such, the future value or benefit of an investment must be adjusted or discounted. It is a technique widely used in benefit-cost analyses to understand and compare a project's implications (its rate of return) over a given temporal scale. Please note, however, that "applying a discount rate is not giving less weight to future generations' welfare" (Stavins 2005). Instead, it simply converts the net impacts from an investment over time into common units (Stavins 2005).

The controversy over discounting arises not from the concept itself but from how one determines which "social discount rate" is appropriate to use, particularly when evaluating environmental considerations. When a discount rate is chosen, there is an implicit judgment made about the value of the future. Oftentimes, an individual and a community value future benefits from a given green infrastructure project or program differently. Furthermore each green infrastructure practice behaves differently over time and requires specific considerations when performing discounting calculations. For these reasons, this guide makes no specific discount rate recommendations.

When proposing a large or long-term green infrastructure project, an in-depth discounting analysis, tailored to the specific case at hand, should be performed.

Operation and Maintenance
As is the case with conventional stormwater controls, green infrastructure depends upon regular maintenance to realize maximum benefits. When undertaking a green infrastructure project, it is important to fully consider the life cycle of the vegetation or capital used. Understanding the amount of maintenance involved in achieving the full benefit from a given practice is extremely important when undertaking large-scale green infrastructure. Many benefits of GI depend on regular maintenance. For example, vegetated green infrastructure elements, like plants on a green roof or tree plantings, will only sequester carbon as long as someone properly and routinely maintains them.

Other more capital-intense green infrastructure may require operational maintenance (for example, regularly cleaning permeable pavement for optimal performance) and repair over time to extend the life of the practice and to ensure that maximum benefits are realized. Conventional grey infrastructure, however, requires regular maintenance as well. Full lifecycle analysis must also evaluate operation and maintenance costs of conventional projects, which periodically require intense capital investments themselves.

Pricing Variability

During the valuation step (Step 2) in each subsection of the "Economic Valuation in Action" part of this guide, market prices are needed to calculate a final monetary value for each benefit. Although recommendations or sample prices for water treatment, electricity, criteria air pollutants and carbon can be found in the "Water," "Energy," "Air" and "Climate" sections, respectively, it is important to tailor these values to specific local data numbers whenever possible. The prices used in these calculations will have a significant impact on the magnitude of monetary value realized.

In addition, it is often difficult to find a strict market value for variables that may be too abstract or complicated to put in a market setting or in monetary terms. This lack of certainty is most pronounced in sectors that currently have few or no markets from which to derive prices. Prominent examples of this uncertainty can be taken from the debate over the value of a statistical life or the price of carbon. Property values and hedonic pricing (i.e. the perceived value of a good or service) also have an inherent degree of uncertainty and subjectivity when used to derive the value of a good or service.

For the purpose of this guide, it is necessary to rely on existing estimates to value the benefits of green infrastructure. However, given local variations, pricing uncertainty and economic fluctuation, market prices will likely vary over time. Please keep these considerations in mind when undertaking any in-depth analysis of green infrastructure valuation.

Double Counting

Summing up the benefits from multiple green infrastructure practices can be extremely complex, as many of the benefits are interconnected and correlated. This creates the risk of double counting or capturing the value of the same benefit multiple times. For example, in the "Water" section, valuation estimates from a property value study may account for both water treatment costs and reduced risk of flooding. Many of these specific precautions are directly addressed in each of the valuation sections.

It is important to keep in mind which aspects of each benefit are being captured in each stage of the valuation. For example, valuing the benefit of direct cost savings from reduced water treatment needs captures the cost of the energy associated with the treatment. It is, therefore, not necessary to account for the direct cost savings from the reduced energy use associated with reduced water treatment. It is, however, important to still calculate the energy reduction associated with reduced water treatment needs, because it is unlikely that the reduced emissions associated with the reduced energy use are captured in the direct cost savings from the reduced water treatment needs.

Also, as discussed in detail in the "Climate Change" and "Air Quality" sections, remember that the direct and indirect benefits realized from trees are combined. Because the *Tree Guides* consider carbon sequestration and avoided carbon dioxide emissions from reduced energy use in conjunction, it is important to not include these benefits twice. The same holds true for pollutant uptake and avoided emissions resulting from trees.

Case Studies:
Valuing Green Infrastructure Across the United States

Throughout the United States, there is a growing recognition of the benefits green infrastructure provides to communities. Many municipalities have begun to recognize the additional benefits green infrastructure and effectively incorporate these practices. The following case studies illustrate the process these municipalities have implemented and what some of the findings have been.

Aurora, Illinois

Faced with aging infrastructure, an already impaired local water way and projected population growth, Aurora wanted to strengthen its downtown economy while providing environmentally and economically sustainable solutions to its stormwater management issues.

The City's leaders recognized the potential value green infrastructure could provide in solving some of these issues and began to analyze where GI might be appropriate. The resulting plan, highlighted in Aurora's *Rooftops to Rivers* program, seeks to bring green infrastructure to scale and attain quantifiable, replicable results.

Early estimates conclude that current stormwater runoff issues within the city could be substantially reduced, with "nearly 141 million cubic feet of stormwater (about 1.05 billion gallons) [diverted] from the sewer" (NRDC 2009). These results would yield about $108,632 in annual savings and reduce energy use by 1.37 million kWh, or the equivalent of 990 metric tons (about 2.2 million pounds) of carbon dioxide.

Chicago, Illinois

In an effort to address and plan for the future impacts of climate change, including increased flood risks and public health stresses, Chicago adopted and is currently implementing its *Chicago Climate Action Plan*. The plan emphasizes green infrastructure

(including green roofs, tree plantings and rainwater harvesting) as a strategy for adapting to the risks this region faces as climate change develops (Chicago 2008).

Chicago has also been a leader in promoting urban green roofs due to the combined sewer overflows problems within the region. The 20,000 square foot roof atop City Hall has helped decrease stormwater runoff and improve urban air quality by reducing the urban heat island effect around the site. Since its completion in 2001, the green roof has saved the city $5,000 a year in energy costs (Chicago Green Roofs 2006). Monitoring of local temperatures found that the "cooling effects during the garden's first summer showed a roof surface temperature reduction of 70 degrees and an air temperature reduction of 15 degrees" (ASLA 2003). To date, Chicago has over 400 green roof projects in various stages of development, with seven million square feet of green roofs constructed or underway.

Milwaukee, Wisconsin

In an effort to reduce the occurrence of combined sewer overflows and reduce stress on aging grey infrastructure, the Milwaukee Metropolitan Sewerage District (MMSD) created a program called GreenSeams, which purchases upstream land for infiltration and riparian services. The program makes voluntary purchases of undeveloped, privately owned properties in areas expected to have major growth in the next 20 years. It also purchases open space along streams, shorelines and wetlands.

MMSD estimates that the total acreage holds over 1.3 billion gallons of stormwater at a cost of $0.017 per gallon. In contrast, one of its flood management facilities holds only 315 million gallons at a cost of $0.31 per gallon (MMSD 2010). While the comparison is not an apples-to-apples application, Milwaukee has found that, for managing stormwater and its potential flooding and overflow problems in urbanized areas, upstream conservation and the use of green infrastructure is cheaper than capital infrastructure build-out. This type of GI program works to save money for both the utility and its ratepayers.

New York, New York

Like most municipalities across the country, New York City (NYC) faces economic challenges. It must look at new strategies for getting the greatest amount of value out of every dollar invested in infrastructure. Due to its high percentage of impervious surfaces, the city generates a significant volume of stormwater runoff. In addition, NYC's aging infrastructure is under increasing pressure due to current and projected population growth. In an effort to address these issues while providing benefit to its residents, the city has adopted a Green Infrastructure Plan as part of its PlaNYC initiative. The plan presents "an alternative approach to improving water quality that integrates green infrastructure, such as swales and green roofs, with . . . smaller-scale grey or traditional infrastructure" (NYC 2010). One of its goals is to manage 10 percent of the runoff from impervious surfaces in combined sewer watersheds through these detention and infiltration approaches.

Additionally, since 1991, New York City has committed upwards of $1.5 billion toward maintaining and preserving its source waters in the Catskill and Delaware Watersheds (NYC DEP 2006). This initiative has thus far eliminated the need for a filtration plant that could cost as much as $10 billion. The city has not only improved its water quality, it has reduced the potential cost of water supply service to its ratepayers and reduced downstream flooding concerns. It has at the same time increased habitat and recreational opportunities for surrounding communities.

Philadelphia, Pennsylvania

Philadelphia faced the fact that conventional grey infrastructure approaches to managing the region's growing stormwater management issues would be cost prohibitive and would not adequately enable the City to meet its water quality standards. So, it turned to green infrastructure for possible solutions. The City hired Stratus Consulting to do a triple bottom-line assessment comparing traditional and green infrastructure. The final report's analysis shows that the net present-value of the benefits from green infrastructure greatly outweigh those of traditional grey infrastructure. For example, the city-wide implementation of green infrastructure at a 50 percent LID level—an option that would manage runoff from 50 percent of impervious surfaces in Philadelphia through green infrastructure—would provide a net benefit of $2,846.4 million. A 30-foot tunnel—the grey infrastructure option—would provide a net benefit of only $122 million (Stratus 2009).

In seeing the additional value that green infrastructure would provide its residents, Philadelphia has gone on to create a long-term combined sewer overflow control plan that invests heavily in GI initiatives. The program, titled *Green City Clean Waters*, is designed "to provide many benefits beyond the reduction of combined sewer overflows, so that every dollar spent provides a maximum return in benefits to the public and the environment" (PWD 2009).

Portland, Oregon

As in most urbanizing areas, Portland's increasing development has led to greater volumes and velocities of stormwater runoff, which has threatened critical waterways. Combined sewer overflows have also decreased water quality in the region. In search of methods to alleviate these environmental strains, the City of Portland Bureau of Environmental Services analyzed the key ecosystem benefits of replacing traditional grey infrastructure with green infrastructure in their ten year "Grey to Green" program, which encourages innovative stormwater management.

In addition to ecosystem benefits, the city has begun to research the many additional social and economic benefits that GI can provide. For example, in its "Energy and Greenhouse Gases" section, the report calculates the energy savings from the Grey to Green's proposed 43 acres of green roofs. The calculations estimate an annual savings of 63,400 kWh (ENTRIX 2010). The next step would be to translate this energy-savings benefit into a monetary value by multiplying by a price per kilowatt-hour. While as yet no monetary value has been assigned for these benefits, the city is working toward a better understanding of the underlying additional value green infrastructure can provide its communities.

Seattle, Washington

Since the late 1990s, the Seattle Public Utilities (SPU) agency has undertaken a variety of green infrastructure pilot programs including the well-known Street Edge Alternative (SEA) project. This and similar programs aim to reduce and treat runoff impacting water quality and aquatic habitat in the Puget Sound watershed by managing stormwater more effectively at a localized level. With this and other pilot programs, Seattle has collected performance data and made the case for substituting green infrastructure practices for traditional grey infrastructure in urban and suburban areas. For example, SPU estimates that a local street converted to the SEAStreet design saves $100,000 per block (330 linear feet) compared to a traditional street design, while achieving the same level of porosity (35 percent impervious area). In addition to these avoided-cost savings, the program claims these designs have provided additional community benefits such as traffic calming, improved neighborhood aesthetic and bioremediation (SPU 2010).

For more examples of communities implementing green infrastructure practices, please check-out The Conservation Fund's Green Infrastructure Leadership Program, which has assembled an online database of green infrastructure projects being planned and implemented across the country.
http://www.greeninfrastructure.net/content/projects

Conclusion

This guide distills some of the considerations involved in assessing the financial viability of common green infrastructure practices that are gaining ground in municipal water management. It aims to assist decision-makers in evaluating options and deciding where, when and to what extent green infrastructure practices should become part of future planning, development and redevelopment within communities.

In clarifying how to assign value to potential green infrastructure benefits, the guide begins to describe and demonstrate a process that works toward estimating the monetary value of GI, when possible, through the following steps:

Step 1: Quantification of Benefit
Step 2: Valuation of Quantified Benefit

By dividing this process into the above steps, this handbook allows for the cumulative assessment of the values associated with these practices. Clarifying these steps enables decision-makers to develop a better understanding of the potential benefits green infrastructure investments can provide their communities.

The field of green infrastructure and its valuation is still developing. Challenges in assigning value still exist. The following list outlines critical next steps in fully realizing the values of green infrastructure in the market place:

- More research regarding the social benefits of GI in order for these types of values to be included in the overall monetary valuation process
- A full life cycle analysis to recognize the long-term value of potential GI programs in municipal budgeting and infrastructure decisions
- Further development of tools, such as CNT's GreenValues Stormwater Calculator, to include the monetary benefits of GI in benefit-cost analysis
- Valuation of a range of GI practices beyond the five common practices listed in this guide
- Increased availability of local and regional data and modeling to more accurately assess the valuation of GI practices within a particular area
- The ability to better scale up the benefits of a proposed GI program in order to develop a clearer picture of the municipal or regional impact such practices can have on community's quality of life

While the above steps will help to improve the range and accuracy of benefit calculations from GI practices, the "Case Study" section demonstrates the growing trend of green infrastructure adoption throughout the country. Decision-makers are coming to understand the full range of infrastructure choices available to them. Recognizing green infrastructure's benefits will help municipalities make choices that not only provide solutions to urban stormwater management issues but also bring a plethora of additional benefits to their communities.

Appendix A

CNT's Green Values® Calculator
http://greenvalues.cnt.org/national/calculator.php

CNT's Green Values Calculator™ is a tool for quickly comparing the performance, costs, and some benefits of green infrastructure practices to those of conventional stormwater management practices. The GVC takes users through a step-by-step process of determining the average precipitation at the site, choosing a stormwater runoff volume reduction goal, defining the impervious areas of the site under a conventional development scheme and then choosing from a range of green infrastructure best management practices (BMPs) to find the combination that meets the runoff volume reduction goal in a cost-effective way. The calculator provides construction, annual maintenance and lifecycle (NPV) cost comparisons to manage a specified volume of stormwater for green infrastructure and conventional scenarios. The calculator also estimates some of the non-hydrologic benefits of using green infrastructure.

GreenSave Calculator
http://www.greenroofs.org

The *GreenSave Calculator*, developed by Green Roofs for Healthy Cities and the Athena Institute, allows for the analysis of various roof types over a set period of time in order to compare life-cycle costs. The tool is intended to help users examine future operating, maintenance, repair or replacement costs, as well as benefits such as energy savings. This enables users to determine whether higher initial costs are justified by reducing future costs. It also makes it possible to determine whether some roofs have lower initial costs that may increase over time.

Urban Forest Effects Model (UFORE)
http://www.ufore.org/

The UFORE model, developed by United States Department of Agriculture Forest Service researchers at the Northeastern Research Station in Syracuse, New York, is able to provide detailed, locally specific results regarding the air quality, building energy, greenhouse gas emissions, carbon storage and sequestration impacts of the existing urban forest. The model does, however, require substantial field data collection by users.

Street Tree Resource Analysis Tool for Urban Forest Managers (STRATUM)
http://www.fs.fed.us/psw/programs/cufr/stratum.shtml

Like the UFORE model, STRATUM, developed at the Center for Urban Forest Research at the Pacific Southwest Research Station of the US Forest Service, uses field data collected by the user in order to model tree impacts. Unlike UFORE, STRATUM is designed to assess not the entire urban forest but street trees in particular. The model not only quantifies benefits but also includes costs, making it more applicable as an asset management tool. In addition to quantifying and valuing the energy conservation, air quality improvement and

climate benefits of trees, STRATUM also includes stormwater management benefits and property value impacts.

i-Tree Software Suite
http://www.itreetools.org/index.php

The i-Tree Software Suite from the USDA Forest Service is a helpful tool for analyzing and assessing the benefits of urban trees. Developed by adapting both the UFORE model (in i-Tree Eco) and the STRATUM model (in i-Tree Streets), the suite examines the pollution mitigation, reduction of stormwater run-off, and carbon sequestration benefits of urban trees.

The National Tree Benefit Calculator
http://www.treebenefits.com/calculator/

Casey Trees and Davey Tree Expert Co. have developed a National Tree Benefit Calculator which allows users to determine the stormwater, property value, energy (both electricity and natural gas), air quality and climate benefits and values for an individual tree. Users are required to input a zip code, the tree species, the tree's diameter and the land-use type.

Green Roof Energy Calculator
http://greenbuilding.pdx.edu/test.php#retain

The Green Building Research Laboratory at Portland State University is developing an online calculator to allow users to compare the energy performance of a building with a green roof to the performance of the same building with a conventional (black) or high-albedo (white) roof. Users input building location, roof area, and building type information, as well as green roof growing media depth and leaf area index. Users also have the option of inputting their own utility cost data or accepting default values. The calculator returns comparative annual electricity and natural gas consumption and total annual energy costs for the three roofing scenarios.

Low Impact Development Rapid Assessment Tool (LIDRA 2.0 model)
http://www.lidratool.org/

The Low Impact Development Rapid Assessment Tool is a model designed to compare the life-cycle values of implementing various green infrastructure techniques used in reducing runoff versus conventional stormwater management practices. The tool pulls from a database of performance and cost values derived from national data.

CITYgreen
http://www.americanforests.org/productsandpubs/citygreen/

American Forests' CITYgreen is an extension of ESRI's ArcGIS software. It converts stormwater and energy impacts (among others) from trees and other vegetation into monetary values based on local specifications.

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