# Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits

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Reducing the negative impacts of storm water is gaining priority in United States communities' efforts to develop more sustainably and to comply with Clean Water Act requirements. Nationwide, communities may need to invest hundreds of billions of dollars in coming decades to meet clean water goals, assuming expansion and repair of conventional infrastructure (US EPA 2002). These projections include $54.8 billion for combined sewer overflow (CSO) control, and another nine billion dollars for storm water management programs (US EPA 2008a). The Clean Water Act's regulatory requirements, along with perennial budget struggles facing many municipalities, are driving cities and utilities to identify and choose the most cost-effective approaches to storm water management.

The parallel needs to improve water quality and prioritize cost-effective infrastructure investments have brought Green Infrastructure (GI) and Low Impact Development (LID) practices to the fore of cities' water infrastructure investment strategies. Several major metropolitan areas, including Portland, Seattle, Philadelphia, Kansas City, New York, Washington, Louisville, and others, have sought to integrate green infrastructure into their control plans for combined sewer overflows, and many more are or will be facing similar strategic investment choices soon.

Green infrastructure and LID practices (we use these terms interchangeably) produce a range of economic and social benefits in conjunction with managing storm water. Incorporating the value of those benefits into investment decisions is essential in comparing GI and conventional infrastructure's costs and ecological, economic and social effectiveness. Natural drainage practices improve storm water management and water quality. Recent studies also indicate that GI storm water benefits are accompanied by capital and avoided cost savings compared to conventional infrastructure (EPA 2007b). Research has identified other economic impacts of LID, including impacts on energy consumption, property value, urban heat island effect, community health, and global climate change.

Green infrastructure's benefits accrue across varied geographical scales. Previous studies have surveyed economic benefits literature (MacMullan and Reich, 2007). Numerous studies define benefits specific to particular practices or impacts. And others summarize benefits of one or several practices in a single locale (e.g., Stratus Consulting, 2009). The difficulty lies in integrating valuation of these multiple benefits, in quantifying benefits that may not be easily monetized, and in bringing recognition of these values into infrastructure investment decisions by developers, communities, and agencies.

This paper reviews current methods, tools and case studies of valuation of the economic and social benefits produced by green infrastructure practices, particularly as they are applied in urban settings. It begins to define a framework for assessing the economic benefits of LID practices on site and community scales.

Analysis begins by defining benefits that accrue with a set of common GI practices: tree planting, infiltration practices, permeable pavement, water harvesting, and green roofs. Each practice suggests input units as the basis for benefit calculations, explores variables that affect the accumulation of benefits, and scales at which the benefit occurs. We explore the relationship between input units of green infrastructure practice with resource units representing the value of individual benefits. Finally, we discuss how calculation of site scale benefits can be aggregated at larger scales and between practices.

Although some of the benefit calculations discussed vary according to regional or local cost factors and site-dependent impact measurements, the ultimate aim is to allow assessment of GI benefits that is flexible in accounting for such local and regional differences. We also recognize that cost-effective infrastructure decisions require comparing the benefits evaluated here with costs and performance related to both GI and conventional practices. GI practices could conceivably incur costs that do not occur with conventional practices, either in construction or maintenance. A full economic analysis including costs and benefits is beyond the scope of this paper, but the research presented here focuses on beginning to clarify the benefits side of the equation to improve future infrastructure investment decisions.

## Green Infrastructure Practices

### Urban Forests

Trees provide many ecosystem services which are detailed below. For the purposes of this paper, most of the benefits from urban forests will be assessed on a *per tree* basis. When considering trees as an infrastructure method at larger scales (e.g. municipal or watershed planning), percent canopy cover may be a more meaningful measure. Finally, for some services provided, the percentage of a given land area that is vegetated can also be a useful unit of measurement.

#### *Stormwater Retention*

Through the direct interception of rainfall and by increasing the ability of soil to store water, trees provide significant stormwater retention benefits. Many studies attempt to begin measuring these benefits by considering the gallons of rainfall intercepted, and assuming a reduction in conventional treatment costs. As the volume of water intercepted is clearly a function of the size of the tree, or the area of canopy cover, both per tree measures based on tree size and percent canopy cover methods have been utilized (McPherson et al 2006; NRDC 2009; CNT 2009). On a per tree basis, estimates range from 292 gallons intercepted annually (40-year average) by a small tree (21 ft. spread) to 2,162 gallons intercepted annually by a large tree (37 ft. spread) (McPherson et al 2006).

### *Reduce Demand for Energy for Cooling and Heating*

Through the cooling impacts provided by evapotranspiration and shade, trees reduce the need for air conditioning in buildings, thus reducing building energy consumption. By reducing wind speeds and the infiltration of outside air into buildings and homes, as well as reducing heat transfer, trees can also have a significant impact on energy needs for heating. Reduced energy consumption leads to direct costs savings for building owners as well as in reduced emissions from power plants and from burning natural gas.

Studies estimate the energy savings resulting from trees as a per tree function, dependent primarily on climatic region, size and type of tree, and the location and orientation to residential buildings. Estimates range from a low end of 48 kWh (40-year average annual savings) from a small tree on a public street or in a park in the Midwest Region, to a high end of 268 kWh from a large tree in a residential yard opposite a west-facing wall in the Midwest Region for electricity savings for cooling. For natural gas, estimates range from a low end of a gain of 316 kBtu (40-year average annual savings) from a medium size tree in a residential yard opposite a south-facing wall in the Midwest region, to a high end of 3,430 kBtu from a large tree on a public street or in a park in the Midwest Region for heating (McPherson et al 2006).

### *Reduce Negative Health Impacts from Extreme Heat Events*

The various cooling functions of trees help to reduce the urban heat island (UHI) effect, and in turn, reduce heat stress-related fatalities. To estimate the impact of trees and the level of benefit, it is necessary to first calculate the resource unit of degrees cooled. While individual trees may have a negligible impact, measuring an overall percentage of green or vegetated space can show significant impact. Various studies estimate the impact of trees and other vegetation within building sites as reducing temperatures as much as 5°F when compared to outside non-green space. Variation between non-green city centers and vegetated areas at larger scales has been shown to be as high as 9°F. 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) from if 50% of the City’s runoff is managed with low-impact development including trees and other GI practices. (McPherson et al 2006; Akbari et al 1992; Stratus Consulting 2009).

*Air Quality Improvements*

By absorbing gaseous pollutants ($NO_2$, $SO_2$, and $O_3$) and intercepting particulate matter ($PM_{10}$), as well as reducing energy consumption, trees contribute in multiple ways to improved air quality.  The resource units necessary to estimate air quality improvements can be measured as the sum of both avoided emissions and pollutant uptake in pounds of $NO_2$, $SO_2$, $O_3$, and $PM_{10}$ per tree, varying by tree size. Studies show the annual net reductions over a 40-year period of $NO_2$ (including both uptake and avoided pounds) to range from 0.39 lbs to 1.11 lbs; $SO_2$ reductions (both uptake and avoided) range from 0.23 lbs to 0.69 lbs; reductions in $O_3$ (uptake only) range from 0.15 lbs to 0.28 lbs; and $PM_{10}$ reductions (including both uptake and avoided pounds) have been estimated to range from 0.17 lbs to 0.35 lbs.

*$CO_2$ Reductions (Avoided and Sequestered)*

Through reduced energy consumption and through direct sequestration, trees contribute to an overall reduction in atmospheric carbon dioxide levels. To estimate the value of reductions in atmospheric $CO_2$, it is necessary to calculate both the pounds sequestered as well as the pounds avoided from reduced energy consumption per tree. Studies estimate annual net reductions (40-year average) in $CO_2$ to range from 226 pounds avoided and sequestered to 911 pounds from a large tree opposite a west-facing residential wall.

Trees also increase recreational opportunities and local property values. These benefits are discussed in further detail below, in the section on the economic valuation of the benefits of green infrastructure.

## Permeable Pavement

Permeable pavement is paving that allows for the infiltration of rainwater and snow melt onsite. Permeable pavement increases stormwater retention, reduces ground conductivity and reduces noise pollution compared with conventional pavement.

The input unit to determine benefits accruing from the use of permeable pavement is the percentage of a site's total paved surface which is permeable. Variables that affect the performance of permeable pavement include slope of pavement, soil content and aggregate depth below pavement, porosity level, frequency of surface cleaning, and rainfall intensity.

*Increased Stormwater Retention*

Permeable pavements allow stormwater to infiltrate into underlying soils on a site, reducing surface run-off volumes and rates, recharging groundwater, and filtering pollutants. The benefits of these services include cleaner air and water, lower water treatment costs, lower risk of flood damage, and less erosion.

Studies comparing the runoff volumes between impervious surfaces and pervious surfaces have found a significant difference in the amount of runoff each generates. Some findings have shown that pervious pavement can infiltrate as much as 80% of the rain which falls on a site (Booth et al 1996; Bean et al 2005; USEPA and LID Center 2000). For small storm events, permeable pavement can achieve 100% infiltration (Milwaukee Metropolitan Sewerage District, 2007).

*Reducing Energy Use, Air Pollution and Greenhouse Gas Emissions*

By capturing rain water onsite, communities are able to reduce the amount of water entering conveyance systems for treatment at wastewater facilities. This reduction in gallons of water needing treatment also reduces energy use, which in turn reduces emissions from power plants. A recent study of the Sonoma County Water Agency found that the Agency emitted 2.34 Mg of $CO_2$ for each million gallons of wastewater treated (Rosenblum 2009). A similar study of the Aurora, Illinois water utility found that the utility requires 1,300 kWh per million gallons of water treated (NRDC 2009).

*Reduced Ground Conductivity*

Increased paved surface exacerbates the urban heat island effect (Kevern et al 2009a), as well as increasing the use of salt to melt ice in cold climates. Recent studies demonstrate that pervious or porous pavement can reduce or lower the negative impacts that the urban heat island effect and salt use cause (Kevern et al 2009b).

*Reducing Air Pollution*

UHI contributes to elevated emission levels of air pollutants and greenhouse gases through increased energy demand for air conditioning that higher air temperatures cause. Permeable pavements have the ability to reduce the amount of emissions caused by the urban heat island effect. The benefits of reducing the urban heat island effect are described below, in the section on economically valuing green infrastructure's benefits.

*Reducing Salt Use*

Reducing salt use saves money for both property owners and municipalities while also protecting water supplies and the environment as a whole. The National Research Council (NRC) indicates that road-salt use in the U.S. 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/ton for road salt; projections for 2009 report salt prices in the range of $50-$70 per ton (Associated Press 2009; Singer 2009). Furthermore, aquifer contamination from road salt represents a severe and long-term threat to drinking water quality. A recent study and simulation of a well field in southwestern Ontario found that even if road salt use were discontinued immediately, it would take decades to completely flush the aquifer of residual chloride (Bester et al 2006). Research has indicated that using pervious pavement can reduce the need for road salt use by as much as 75% (Houle 2006).

*Reduced Noise Pollution*

Pavements can have a significant effect on the generation of noise. Recent studies have demonstrated that the use of porous concrete can reduce roadway noise pollution by as much as 10dB (Olek et al 2003; Gerharz 1999). Variables that affect noise pollution reduction from permeable pavement include pavement porosity and traffic speed.

## Water Harvesting

Water harvesting practices capture and store rainwater onsite for future use such as irrigation. Disconnecting downspouts is the process of directing downspout runoff away from sewer systems and onto local property for irrigation purposes. Rain barrels and cisterns are other water harvesting tools to capture rainwater collected from a roof or other catchment area for future use. The benefits of water harvesting practices include stormwater retention, reduced potable water use, and public education opportunities.

Benefits from water harvesting are based on the input unit of gallons stored. Determining water harvesting volume requires understanding 1) how much capacity is available for storage (e.g., 150 gallon rain barrel) and 2) how large is the contributing area (e.g., a 1,000 square foot roof). Below is a simple formula for calculating how much rain water can be captured through water harvesting:

1" of rain falling on 1,000 sq. ft. of surface = 623 gallons
(*1" of rain x 1 sq. ft. = 0.623 gallons*)

Applying this 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.

### *Reduced Potable Water Use*

Property owners are able to reduce their potable water use by capturing rainwater onsite and utilizing this resource for irrigation or other purposes. Reducing potable water use provides multiple benefits, which include reduced water costs, increasing available water supply, and improving plant health. Water harvesting can also reduce energy use, costs and emissions associated with potable water conveyance and treatment. Moving and treating water is an energy-intensive activity. Estimates of the national average energy intensity for publicly owned treatment works range from 955 to 1,911 kWh per million gallons treated, depending on the level of treatment (EPRI 2002). Reducing potable water use, however, not only reduces treatment costs, but avoids the need to convey water from its source into the treatment and distribution system. In areas where water must be pumped from deep underground or transported over long distances, this cost dominates the energy requirements of the water supply system. In southern California, for example, the energy used for water supply, conveyance, treatment and distribution comes to 12,700 kWh per million gallons (CEC 2005).

### *Increasing Available Water Supply*

Using rainwater for irrigation purposes saves potable water supplies. 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 (US EPA 2007). The reduced demand on the supply of potable water can be measured by the total volume of captured rainwater that replaces irrigation water that was previously drawn from the treated water system. An avoided cost approach would value this benefit as the marginal cost to the utility of supplying the given volume of water.

*Improving Plant Life*

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

*Public Education*

Water harvesting practices provide a valuable public education opportunity. Many communities throughout the country have outreach events centered on water use education through the distribution of rain barrels. The U.S. EPA 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. Reports have found that a majority of the American public is not aware of their impact on water pollution (US EPA 2008b).

## Green Roofs

Green or vegetated roof systems are becoming more prevalent in the United States and recognized for the multitude of benefits they can provide to a wide range of private and public entities. On top of the layers of a conventional roof, green roofs typically add waterproofing and root barrier components, drainage and filter layers, and finally growing media (soil mix) and vegetation.

*Storm Water Retention*

Green roofs retain rainwater primarily in the growing media. Much of this rainwater is eventually evapotranspired, preventing it from running off into the sewer system. A range of studies of green roof storm water retention performance has found that these roofs can retain and evapotranspire anywhere from 40 to 80 percent of annual precipitation (Carter and Rasmussen 2006; VanWoert et al 2005; Deutsch et al 2005; Hutchinson et al 2003). Factors which influence this performance include roof slope, local climate, and growing media porosity. As with other vegetated GI practices, for any given storm event, the antecedent moisture of the growing media will also impact rainfall retention.

*Reduced Building Energy Use*

Green roofs provide superior insulation compared to conventional roofs, reduce solar radiation reaching the roof surface, and reduce roof surface temperatures through evaporative cooling. Estimates of reduced heat flux of a green roof as compared to a conventional roof range from 70-90 percent in summer to 10-30 percent in winter (Liu and Minor 2005; Liu and Baskaran 2003). The difference in seasonal performance is due to the fact that frozen growing media is a less effective insulator.

Also, the advantages of direct shading and evaporative cooling only apply during warm weather. Models of the impact of a green roof on office building energy consumption in Chicago and Houston found a 2% reduction in total building electricity consumption in both cities; a 9% reduction in natural gas consumption for Chicago and an 11% reduction in natural gas consumption for Houston (Sailor 2008). Another modeling study of an eight-story residential building in Madrid found a 1.2% reduction in annual building energy consumption. The bulk of the benefit comes from reduced summer cooling costs, where the authors found a 6% reduction compared to the conventional roof (Saiz et al 2006).

The reduced heating and cooling loads that a green roof can provide depend on local temperatures, the portion of a building's heating and cooling load due to heat flow through the roof,  the thickness of the soil layer, extent of foliage, relative humidity and wind speed, and moisture content of the growing media. (Clark et al 2008; Theodosiou 2003; Gaffin 2005).

### *Carbon Sequestration*

A study of eight green roofs in Michigan and four green roofs in Maryland over two years found that extensive green roof systems sequestered 375 g C in above- and belowground biomass and substrate organic matter per square meter of rooftop (Getter et al 2009). Factors influencing a green roof's carbon sequestration performance include species selection and management techniques (e.g., fertilizer application; substrate composition; irrigation).

### *Greenhouse Gas Emissions Reductions*

The greenhouse gas emissions impacts of green roofs are derived from reduced building energy use and reduced urban heat island effect. The emissions impacts of reduced energy use are dependent on whether the building uses gas or electricity for heating as well as the emissions profile of regional electricity generation.

### *Urban Heat Island Mitigation*

Like other vegetated green infrastructure features, green roofs can help mitigate the urban heat island effect through evaporative cooling. Further discussion of quantifying and valuing this benefit can be found in the concluding section of this paper.

### *Improved Air Quality*

Vegetated roofs provide air quality benefits though take up of gaseous pollutants like nitrogen compounds and sulfur dioxide, primarily through leaf stomata, as well as intercepting particulate matter. In addition, reducing building energy use results in less air pollution from electrical generation. Finally, by reducing the urban heat island effect, green roofs can lessen smog formation by slowing the reaction rate of nitrogen oxides and volatile organic compounds which form smog (Currie and Bass 2008).

A recent study published in *Urban Ecosystems* used the Urban Forest Effects (UFORE) module D to estimate the air quality impacts of several green roofing scenarios in Toronto. The authors found that greening all of the available roof area in

Toronto's midtown neighborhood could remove on an annual basis 1.2 metric tons $NO_2$, 3.14 metric tons $O_3$, 2.17 metric tons PM10, and 0.61 metric tons $SO_2$ (Currie and Bass 2008).

Clark et al (2008) used data from Morikawa et al (1998) to estimate the annual $NO_2$ uptake potential of vegetated roofs at 0.27 ± 0.44 kg per square meter of planted area. The pollutant uptake and deposition of any given roof will vary widely based on what species are used in planting. The orientation of the existing urban forest may also influence green roofs' air quality performance, insofar as shaded green roofs have less impact on air quality than unshaded roofs (Currie and Bass, 2008).

### *Noise Reduction*

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. They field tested two green roofs and found that relative to a reference roof, transmission loss increased 5-13 decibels in low- and mid-frequency ranges, and 2-8 decibels in the high frequency range. Soil moisture content and texture as well as species selection can influence the acoustical performance of green roofs (Connelly and Hodgson 2008).

### *Biodiversity and Habitat*

Several studies have documented the ability of green roofs to support biodiversity and provide valuable habitat for a variety of flora and fauna. A study of vegetated roofs in Berlin found plant species diversity representing close to seven percent of the species present in the region. A study of green roofs in the Greater London area found that at least 10% of the fauna species identified on the roof were classified as "nationally rare and scarce". The author identified spider species representing 30% of the region's known spider species. The heterogeneity of habitat exposures and roof surfaces (e.g. sunny/shady; moist/dry) is an important parameter influencing roof biodiversity and habitat value. In addition, a greater diversity of flora will in general support greater faunal diversity. (Köhler 2006; Kadas 2006).

### *Longer Roof Life*

Green roofs are generally expected to extend roof life by at least 20 years relative to a conventional roof, though some vegetated roofs in Germany have lasted for over 90 years without requiring replacement or major repair. Additional durability represents a life cycle cost savings compared to conventional roofs.

## Infiltration Practices: rain gardens, bioswales and constructed wetlands

### Rain gardens

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

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 are particularly effective at trapping silt and other pollutants that are normally carried in the runoff from impermeable surfaces.

### Constructed wetlands

These are the largest infiltration green infrastructure practice both in area and in depth, and may be used in a wide variety of settings. Constructed wetlands are filled with native plants, grasses, and (sometimes) fish and wildlife to maximize pollutant removal through biological uptake. Among the infiltration practices, wetlands are the most effective at pollutant removal because of their ability to more closely replicate the organic processes of natural wetlands. They can also be the least expensive to construct per square foot. Constructed wetlands may offer increased biodiversity, but often far less than their natural counterparts. They also provide substantial recreational and aesthetic benefits.

*Stormwater Retention and Pollutant Removal*

We first need to estimate the hydrologic performance of each infiltration practice, including its effects on runoff volume and quality, measured by pollutant content. Input units for infiltration practice benefit values are estimated per square foot of each GI practice installed, assuming a depth of 6 inches for rain gardens, 8 inches for bioswales, and 12 inches for constructed wetlands. In the following sections, we will translate these characteristics to economic benefits.

Although rain gardens, bioswales, and wetlands can be dug at various depths, this analysis evaluates each based on the depth of each GI practice in descending order, after assuming that the type of wetland best suited to urban settings is the “surface flow” wetland, usually a foot deep (SMRC 2009a). Infiltration per square foot, then, is simply a 1 ft. by 1 ft. by depth (ft.) volume, measured in gallons. Typical proportion of total drainage area helps us understand how land-intensive each practice is. Land-intensity varies depending on the soil type: better draining soils require less land for the same infiltration performance.

**Hydrologic Specifications**

| BMP | % of total drainage area | Infiltration/ft$^2$ |
|---|---:|---:|
| **Rain garden (6 in.)** | 5% of impervious area | 45 gallons |
| **Bioswale (8 in.)** | 5-10% of impervious area | 60 gallons |
| **Constructed Wetland (12 in.)** | 3-6% of impervious area | 90 gallons |

**Pollutant Removal Capabilities (SMRC 2009b) (%)**

| BMP | TSS | N | P | Metals | Bacteria |
|---|---:|---:|---:|---:|---:|
| **Rain garden** | 75 | N/A | 60 | N/A | N/A |

| BMP | TSS | N | P | Metals | Bacteria |
|---|---|---|---|---|---|
| **Bioswale** | 81 | 49 | 29 | 51-71 | -58 |
| **Constructed Wetland** | 83±51 | 26±49 | 43±40 | 36 - 85 | 76% |

*Uncertainties and Other Considerations*

Soil characteristics, the depth of the given practice, and storm size and intensity will all influence rainfall infiltration performance (Bannerman 2003). In addition, the extent and usage of impervious area which drains into the infiltration feature will affect performance: roads and parking lots with more frequent use will produce more pollutants. Pollutant removal capacities vary widely in the extant literature, and are highly site-specific.

Like other vegetated green infrastructure features, infiltration practices can improve air quality through uptake of gaseous pollutants and deposition of particulate matter; reduce the urban heat island effect through evaporative cooling and reduction of surface albedo; sequester carbon; increase biodiversity and habitat; reduce the risk of flood damage; increase the value of proximate properties; enhance recreational opportunities; and contribute to groundwater recharge. The general methods used to quantify these benefits are similar to those applied to tree plantings and green roofs. A further discussion of economically valuing the benefits of infiltration and other vegetated green infrastructure features is found below.

## Economic Valuation of Green Infrastructure Benefits

*Methods of Economically Valuing Ecosystem Services*

Economists use a range of methods to value ecosystem services, and many of these methods are applied in valuation of the benefits of green infrastructure practices. What follows is a brief summary of methods of ecosystem service valuation, followed by a review of how these methods can be applied to the green infrastructure practices and associated benefits discussed above.

Ecosystem services are most easily valued where a market exists that can set a price for the good being provided. For GI practices that displace potable water use, such as water harvesting, local water rates might be used in order to determine the value of benefits. In many cases, however, nonmarket valuation methods must be used. Nonmarket valuation methods included 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 ask individuals how much they are willing to pay to for a given good or service, or how much they would be willing to accept as compensation for a given harm. These methods are often used to assess non-use values; e.g., what is the value of a protected wilderness for people who never see it? Finally, avoided cost analysis examines the marginal cost of providing the equivalent service in another way; e.g., valuing rainfall retention and infiltration by using a water utility's cost to capture, transport, treat and return each additional gallon of runoff. (Tomalty et al 2009; King and Mazzotta 2000).

### *Reduced Energy Use*

The economic value of reduced building energy use is calculated using the market price of natural gas and electricity. Trees and green roofs directly reduce building energy use. Reducing storm water runoff or harvesting rainfall reduces the energy consumption of water utilities for conveyance and treatment. Infiltration features can reduce energy required for pumping by raising groundwater levels. The value of this benefit can be calculated by multiplying the kWh or BTUs of electricity and natural gas consumption, respectively, by local utility rates.

### *Improved Air Quality*

The Urban Forest Effects (UFORE) model gives dollar values for gaseous pollutants and particulate matter on a per-Mg basis as follows:

$NO_2$= \$6,752 $t^{-1}$, PM10 = \$4,508 $t^{-1}$, $SO_2$ = \$1,653 $t^{-1}$, and CO = \$959 $t^{-1}$

These values are estimated using the median externality value for the United States for each pollutant (UFORE 2009; Murray 1994).

An EPA study estimates health benefits (fewer premature deaths; fewer cases of chronic bronchitis) of reduced $NO_2$ emissions at \$1680 to \$6380 per Mg in 2006 dollars (Clark et al 2008; US EPA 1998).

Trees, green roofs, and vegetated infiltration practices produce these benefits at the rates discussed above.

### *Value of Avoided $CO_2$ Emissions and Carbon Sequestration*

The literature on the cost of carbon dioxide and other greenhouse gas emissions offers a wide range of values. The latest IPCC report surveyed 100 peer reviewed estimates and found an average value of \$12/Mg in a range that tops out at \$95/Mg. The report further notes that these are very likely underestimates given the exclusion of many unquantifiable impacts of global warming. (IPCC 2007). The most widely read and cited report on the economic impact of climate change values carbon dioxide emissions at \$85/Mg (Stern 2006; Stratus Consulting 2009).

### *Property Value*

There is an extensive literature regarding the impact of proximity to green space on property values which can be used in estimating the property value benefit of the vegetated green infrastructure practices discussed here.

Studies estimating the impact of new tree plantings find an increase in surrounding property values of two to ten percent. The broad range is due to the contention of one study that what is perceived as added value due to tree plantings is in fact rather the trees' function as a signaling mechanism for other valuable characteristics (Wachter 2004; Wachter and Wong 2008). A study in Portland, Oregon found that street trees add $8,870 to sales prices of residential properties, and reduce time on market by 1.7 days (Donovan and Butry 2009).

Researchers have also attempted to estimate the impact on property value of proximity to parks, gardens and ponds. A San Francisco study found that properties within 500 feet of a park were valued $125,838 higher than properties more than 1000 feet from a park (Edwards 2007). A review of the literature suggests a 20% guideline for increased property value for those properties fronting or abutting a park (Crompton 2005). A study of the impact of community gardens found an increase in property values for properties within 1000 feet of the garden; this effect was most pronounced in low-income areas, where property value increased 9.4% over five years (Voicu and Been 2008). Studies of the impacts of pond frontage on property value have found increases ranging from ten to 25 percent (EPA 1995; Emmerling-Dinovo 1995).

As with other benefits that occur beyond the borders of a site treated with green infrastructure, the challenge of determining property value benefits lies partially in measuring the geographic range of the associated benefit. It may be necessary to first describe the area affected (or radius around treated sites or neighborhood) and then multiply an average or other reasonable property value increment by local property statistics. We propose that for a large vegetated feature, valuators refer to the literature on park value. Smaller features might be more accurately assessed by referring to new tree plantings or the impact of private gardens on house prices.

### *Recreation Value*

To measure the recreational value of green infrastructure practices, we can use established methods of recreation valuation in American public park systems. Public parks can be valued in a number of ways -- using the Hedonic price method (increases in property values adjacent to parks), the Travel-Cost Method (a measurement of market demand), or Contingent Valuation (willingness to pay). A contingent valuation study of Boston's park system found direct use value of $70,308 per acre of parkland (Harnick and Welle 2009). A similar study of Philadelphia's park system found direct use values approaching $100,000 per acre (Trust for Public Land 2008).

### *Avoided Gray Infrastructure Costs*

The Midwest Tree Guide estimates avoided infrastructure costs in one convenient value by taking the value of single-family residential sewer service fees, which cover the "capital, operation, and improvements of citywide sewer and stormwater-management systems" -- a value of $3.43 per 100 cubic feet, or $0.0046 a gallon (McPherson et al 2006). This figure will vary with the costs of the local water utility. It should also be noted that the avoided utility cost value of retaining and infiltration or evapotranspiring stormwater is greater for cities with combined sewer systems than it is for those with separate sewer systems.

*Avoided Construction Costs*

We can also think about avoided gray infrastructure costs in terms of the reduced need for new investment in conventional stormwater practices like surface storage, detention basins, retention basins, and deep tunnels. Several cities, including Chicago, Milwaukee, Portland, and Washington, D.C. have begun deep storage tunnel projects to control CSOs, costing billions of dollars (Chicago's TARP project began in the mid-1970's and will continue until 2019 at a cost of $3.4 billion so far) (NRDC 2006). A range of values for these costs is listed in the table below and adapted from (Heaney et al 2002) and adjusted for 2009 values:

| **Control** | **Cost Equation** | **Cost to Manage 10 mil. gallons** |
|---|---|---|
| Surface storage | $5.765V^{0.826}$ | $38.56 |
| Deep tunnels | $8.550V^{0.795}$ | $53.33 |
| Detention basins | $75{,}503V^{0.69}$ | $369,797.70 |
| Retention basins | $83{,}739V^{0.75}$ | $470,899.00 |

***Where $0.15 < V < 30$ Mgal, and costs are in millions of dollars for surface storage and deep tunnels and dollars for detention and retention basins.***

These values can be used to determine the cost savings for specific developments based on their water volume requirements.  We do not conduct this type of analysis here, but case studies in Maryland and Illinois point to savings ranging from $3,500 to $4,500 per quarter-to-half acre residential lots (NRDC 2006).

CNT's Green Values Calculator® allows comparisons of green and conventional infrastructure costs on a site basis, calculated on a life cycle basis including construction and long-term maintenance (CNT 2009). Infrastructure costs and performance values in the Green Values Calculator are based on published literature as well as reports from selected utilities' internal studies.

*Reduced Treatment Costs*

The values stated above from the Midwest Tree Guide technically account for a reduction in treatment costs; however, it may also be useful to quantify reduced treatment costs per pound of pollutant removed. CNT reports that it costs a large treatment facility $8.50 to remove a pound of suspended solids, and $6 to $12 to remove a pound of phosphorus (CNT 2009). Braden and Johnston (2004) stress that savings are site-specific, such that benefits in this category are "difficult to generalize." Due to differences in the origins of runoff, pollutant removal effectiveness varies immensely (Heaney 2002). There is much room for further study in this area.

A simplified approach to assigning treatment cost per gallon (across the whole range of pollutants) is to use a value based on the expenses of a local utility like the Metropolitan Water Reclamation District of Greater Chicago, a value used in CNT's

Green Values Calculator: $29.94 per acre foot of runoff reduced, or $0.0000765 per gallon.

While it is convenient to defer to the per-gallon costs provided by the Midwest Tree Guide, these values do not allow us to discriminate among compartmental costs of gray infrastructure (i.e., energy savings, treatment cost reductions, maintenance and repair reductions). Furthermore, the Midwest Tree Guide uses stormwater fees for the City of Minneapolis only; a more precise method would use fees for a specific region where green infrastructure practices are employed.

*Reduced Flood Risk/Damage*

There are several ways to assess the value of the reduced risk of flood damage provided by green infrastructure practices. 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; still others have employed contingent valuation methods. Braden and Johnson (2004) estimate reducing flood risk can increase property value up to five percent for properties removed from the 100-year floodplain. This valuation method means little for a small scale practice, and is more usefully applied at the watershed scale.

*Groundwater Recharge*

The value of groundwater recharge varies according to its use as well as its quality, and increasing the amount of recharge may produce a range of cost savings from reduced pumping costs to savings in irrigation practices (USDA 1967). The value of groundwater recharge is difficult to determine through market demand. A 1967 study by the US department of agriculture found a wide range of values for groundwater recharge because of site specificity (water recovered for cities or industries was $100 per acre-foot, while water for pasture irrigation was $5 per acre-foot). Braden and Johnston (2004) point out that, because of time lags and discounting, “water that becomes available for use in a year or two is much more valuable than water that takes tens or hundreds of years to percolate through geologic strata to a useable aquifer.” The use value of infiltrated water is difficult to capture.

Value *in situ*, or the value of ground water *in its place*, includes pumping cost reductions (reduction in pumping heads) and an increase in well pressure. These values, of course, are very site specific, and estimates were not found at this time.

Nevertheless, CNT (2009) reports a mid-range value of $86.42 per acre-foot infiltrated by the 1965 Illinois State Water Survey report on water resource availability and cost for the Northeastern Illinois region, although the methodology for this value is uncertain. CNT’s Green Values Calculator estimates that 62.5% of water infiltrated becomes groundwater recharge.

*Noise*

Navrud (2003) provides a comprehensive review of the literature on the economic valuation of noise. A survey of eleven studies using stated preference methods to value road transportation noise finds a average value of 32.10 euros (46.79 USD) and a median value of 23.5 euros (34.26 USD) per decibel per household per year. 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% and 0.86%, respectively (Navrud 2003). The economic value of noise reduction is neither as large nor as widespread as other GI benefits, but may be worth considering in areas near major roads, rail lines or flight paths where noise is an immediate concern.

### *Urban Heat Island Effect*

Nearly all of the green infrastructure practices described here potentially reduce the urban heat island effect, either through evaporative cooling, reducing building energy consumption, or reducing ground conductivity. Quantifying the impacts of these benefits on the urban heat island effect, however, is notoriously difficult. Rosenzweig et al (2006) estimated that greening 50% of the available flat roofs in New York City could reduce average surface temperatures by 1.4 degrees Fahrenheit. Bass et al (2002) did a similar simulation for Toronto and found that 50% coverage with irrigated roofs produced cooling of 2 degrees Celsius. The Lawrence Berkeley Lab Heat Island Group estimates that each one degree Fahrenheit increase in peak summertime temperature in Los Angeles leads to an increase in peak electricity demand of 225 megawatts, costing ratepayers $100 million annually (Chang, 2000).

### *Assessing Effects at Larger Scales*

To calculate those benefits that only occur at larger scales, it may be necessary to evaluate the cumulative impact of GI practices in geographic context. Those cities that have done so have often linked geographic information system spatial analysis with hydrologic or other models. Examples include the Green Build-Out Model, which assessed combined effects of green roofs and tree plantings in Washington, DC using GIS and a complex hydrological model that simulated impacts within the subareas of the city corresponding to sewersheds (Deutsch et al 2007). The city of Chicago, for example, has recently developed model elements that examine GI potential within each four-block sub-catchment and by sewershed, in part to relate potential GI impacts to regional phenomena including basement flooding and heat island impact (Mulvaney 2009). British researchers linked the extent of GI with hydrologic and energy models to assess the percent change in regional GI necessary around metropolitan Manchester and its potential to mitigate projected impacts of climate change (Gill et al 2007). Such efforts suggest that the relevant input unit for heat island mitigation and other larger scale effects is an incremental percentage in regional GI coverage. The models cited do not translate GI regional impacts into economic value, but the valuation approaches described here should help to estimate benefits once the effective geographic distribution and incremental GI cumulative coverage is determined.

When scaling up green infrastructure and its associated benefits, furthermore, it is important to keep in mind that GI practices will not be installed in isolation, but can work together so that the overall benefit is more than the sum of its parts. Conservation design, for example, takes a comprehensive land use planning approach to the implementation of green infrastructure practices, and (Johnston et al 2006) have published strong evidence documenting the economic benefits of a conservation design approach. Similarly, cities are utilizing green streets as a flexible assembly or "treatment train" of practices including bioretention and tree trenches that manage stormwater within the right of way.

*Issues for Further Research*

This paper focuses almost exclusively on the benefits of green infrastructure. Utilities and other responsible stormwater infrastructure investors will be at least as concerned with the costs of these practices. Life cycle cost-benefit analysis of green infrastructure practices could allow for a better understanding of the net present value of these approaches as compared to current norms of stormwater management investment.

CNT's Green Values Calculator® originally incorporated a sampling of economic benefits based on available research in 2005. Updating and extending the number and type of economic benefits reviewed here would be one approach to bring a more holistic assessment of benefits into infrastructure investment cost comparisons as well as to integrate the economic benefits into existing life-cycle cost-benefit analysis.

Consistent methods for aggregating site practices and impacts into cumulative, regional effects at sewershed, watershed, metropolitan, or regional scale still requires additional modeling and development. It may also be useful to distinguish to whom benefits accrue. Some of the benefits described herein benefit individual property owners; other benefits accrue to water utilities; and still others increase the availability of public goods like clean air.

## References

Associated Press (2009). "Indiana road salt supplies up, cost down for 2009". 5 December 2009.

Akbari, H.; Konopacki, S. (2005). Calculating energy-saving potentials of heat island reduction strategies. *Energy Policy*, 33(6), 721–56.

Akbari, H., Davis, S., Dorsano, S., Huang, J., and Winnett, S., eds. (1992). "Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing", US EPA, Washington, DC.

Bean, E.Z., W.F. Hunt, D. Bidelspach (2005). "A Monitoring Field Study of Permeable Pavement Sites in North Carolina." NCSU Department of Biological and Agricultural Engineering, http://www.bae.ncsu.edu/info/permeable-pavement/SWFWMD.pdf

Bannerman, R. (2003). *Rain gardens: A How-To Manual for Homeowners.* Wisconsin Department of Natural Resources, Madison, WI.

Booth, D., J. Leavitt and K. Peterson (1996). "The University of Washington Permeable Pavement Demonstration Project: Background and First-Year Field Results." The Water Center at the University of Washington, Seattle, WA.

CASQA (2003). "California Stormwater BMP Handbook." Menlo Park, CA. p. 6.

CEC (2005). "California's Water-Energy Relationship", California Energy Comission, Sacramento, CA.

Chang, Sheng-chieh (2009). "Heat Island Group: Energy Use." <http://eetd.lbl.gov/HeatIsland/EnergyUse/>. Accessed 17 December 2009.

Clark, C. et al (2008). "Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits". *Environmental Science and Technology*, (2008) 42, 2155-2161.

CNT (2009). Green Values Calculator, Benefit Details. <http://greenvalues.cnt.org/national/benefits_detail.php#reduced-treatment>. Accessed 16 December 2009.

Cole, S. (1998). "The Emergence of Treatment Wetlands." *Small Flows*, 12(4): 6.

Conservation Research Institute (2005). "Changing Cost Perceptions: An Analysis of Conservation Development." Report prepared for the Illinois Conservation Foundation and Chicago Wilderness, Chicago, IL.

Currie, B.A. and B. Bass (2008). "Estimates of air pollution mitigation with green plants and green roofs using the UFORE model". *Urban Ecosystems*, 11:409-422.

Deutsch, B. et al (2007). "The Green Build-Out Model: Quantifying the Stormwater Management Benefits of Trees and Green Roofs in Washington, DC", CaseyTrees and Limnotech, Washington, DC.

EPRI (2002). "Water & Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment-the Next Half Century", Electric Power Research Institute, Palo Alto, CA.

Farber, S.C. and R. Constanza (2002). "Economic and Ecological Concepts for Valuing Green Infrastructure." *Ecological Economics*. 41: 375-90.

Gaffin, S. et al (2005). "Energy Balance Modeling Applied to a Comparison of White and Green Roof Cooling Efficiency". Proceedings of the 3rd Annual Greening Rooftops for Sustainable Cities Conference, May 4-6, 2005, Washington, DC.

Gerharz, B. (1999). "Pavements On the Base of Polymer-modified Drainage Concrete." *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 152:205-209.

Getter, K. et al (2009). "Carbon Sequestration Potential of Extensive Green Roofs". *Environmental Science and Technology*, 43: 7564-7570.

Gill, S.E.; J.F. Handley; A.R. Enos and S. Pauleit (2007). "Adapting Cities for Climate Change: The Role of the Green Infrastructure," *Built Environment,* 33(1): 115-133.

Houle, K.M. (2006). "Winter Performance Assessment of Permeable Pavements: a comparative study of porous asphalt, pervious concrete and conventional asphalt in a northern climate". Thesis submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering. September, 2008. http://www.unh.edu/erg/cstev/pubs_specs_info/unhsc_houle_thesis_9_08.pdf

Heaney, J., et al (2002). "Costs of Urban Stormwater Control," National Risk Management Research Laboratory, Office of Research and Development, EPA-600/R-02/021.

Johnston, D.M., J.B. Braden and T.H. Price (2006). "Downstream Economic Benefits of Conservation Development*." Journal of Water Resources Planning and Management*, Jan/Feb 2006.

Johnston, D.M. and J.B. Braden (2004). "Downstream Economic Benefits from Storm-Water Management." *Journal of Water Resources Planning and Management*, Nov/Dec 2004.

Kadas, G. (2006). "Rare Invertebrates Colonizing Green Roofs in London". *Urban Habitats* 4(1): 66-86.

Kevern, J.T. et al (2009a). "Hot Weather Comparative Heat Balances in Pervious Concrete and Impervious Concrete Pavement Systems." Second Annual Conference on Countermeasures to Urban Heat Islands. September 2009.

Kevern, J.T. et al (2009b). "Temperature Behavior of a Pervious Concrete System." *Transportation Research Record*. 2098: 94-101.

Köhler, M. (2006). "Long-term Vegetation Research on Two Extensive Green Roofs in Berlin". *Urban Habitats* 4(1): 3-25.

Kosareo, L. and R. Ries (2007). "Comparative environmental life cycle assessment of green roofs". *Building and Environment*. 42: 2606-2613.

Limburg, K.E. and R.V. O'Neill (2002). "Complex Systems and Valuation." *Ecological Economics*, 41: 409-418.

Liu, K. and B. Baskaren (2003). "Thermal performance of green roofs through field evaluation". *Proceedings for the First North American Green Roof Infrastructure Conference, Awards and Trade Show*. Chicago, IL. May 29-30, 2003, pp. 1-10.

MacMullan, E. and S. Reich (2007). "The Economics of Low-Impact Development: A Literature Review", ECONorthwest, Eugene, OR.

McPherson, E.G. et al (2006). *Midwest Community Tree Guide: Benefits, Costs, and Strategic Planting*. United States Department of Agriculture, Forest Service, Pacific Southwest Research Station, Davis, CA.

Milwaukee Metropolitan Sewerage District (2007). "Stormwater Runoff Reduction Program: Final Report." Milwaukee, WI.

Morikawa, H. et al (1998). "More than 600-fold variation in nitrogen dioxide assimilation among 217 plant taxa". *Plant, Cell and Environment,* 21, 180-190.

Mulvaney, Peter (2009). Chicago Department of Water Management, personal communication.

Murray, F.J.; Marsh, L.; Bradford, P.A. (1994). New York State energy plan, vol. II: issue reports. New York State Energy Office, Albany, NY.

NRDC (2009). "Rooftops to Rivers: Aurora", New York, NY.

NRDC (2006). "Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows", New York, NY.

Navrud, Ståle (2003). "State-of-the-art on economic valuation of noise". ECE/WHO Pan-European Program on Transport, Health and Environment, Workshop on Economic Valuation of Health Effects due to Transport, Stockholm, Sweden. June 12-13, 2003.

Olek, J. et al (2003). “Development of Quiet and Durable Porous Portland Cement Concrete Paving Materials.” Purdue University Report No. SQDH 200 – 5, West Lafayette, IN.

Rosenblum, J. (2009). “Climate Change in the Golden State”. *Water Efficiency*. May/June, p50.

Saiz, S. et al (2006). “Comparative Life Cycle Assessment of Standard and Green Roofs”. *Environmental Science and Technology,* 40:4312-4316.

Sharma, R. (2006) “Economic Analysis of Stormwater Management Practices.” Thesis presented to the Graduate School of Clemson University.

Singer, J. (2009). “Road salt price comes down, but local governments still limiting supply”. *Sandusky Register*. 16 December 2009.

Stratus Consulting (2009). “A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia Watersheds.” Office of Watersheds, City of Philadelphia Water Department, Philadelphia, PA.

SMRC (2009). Wetland Fact Sheet. <http://www.stormwatercenter.net/> Accessed Dec 2009.

Tanner, C.C. (2002). “Status of Wastewater Treatments in New Zealand.” EcoEng Newsletter, No. 1. <http://www.iees.ch/EcoEng021/EcoEng021_F4.html>

Trust for Public Land (2008). “How Much Value Does the City of Philadelphia Receive from its Park and Recreation System?” Philadelphia, PA.

USDA (1967). “Groundwater Recharge.” Conservation Service, Engineering Division, Technical Release, Geology, p. 18.

US EPA (2008a). “Clean Watersheds Needs Survey 2004: Report to Congress”. Washington, D.C.

US EPA (2008b). “Public Education and Outreach on Stormwater Impacts”. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=1. last updated 17 September 2008.

US EPA (2007). “Outdoor Water Use in the United States”. http://www.westlake-tx.org/images/EPA_outdoor_water_use_176_4323.pdf. accessed 21 December 2009.

US EPA (2007b) “Reducing Stormwater Costs through Low Impact Development Strategies and Practices”. EPA 841-F-07-006, Nonpoint Source Control Branch, Washington, DC.

US EPA (2002). “The Clean Water and Drinking Water Infrastructure Gap Analysis”, US EPA Office of Water, Washington, DC.

US EPA and Low-Impact Development Center (2000), “Low Impact Development (LID): A Literature Review”, Washington, DC.

US EPA (1999). “Free Water Surface Wetlands for Wastewater Treatment: A Technology Assessment.” Phoenix, AZ, pp. 5-13.

Voicu, I. and V. Been (2008). “The Effect of Community Gardens on Neighboring Property Values. *Real Estate Economics*, 36(2): 241-283.

Walker, C. (2004). “The Public Value of Urban Parks.” *Beyond Recreation: A Broader View of Urban Parks.* The Urban Institute, Washington, DC.

Weber, T. (2007). “Ecosystem Services in Cecil County’s Green Infrastructure.” The Conservation Fund, Annapolis, MD.

Wegner, W. and M. Yaggi. "Environmental Impacts of Road Salt and Alternatives in the New York City Watershed." *Stormwater*, July-August 2001.

Wossink, A. and B. Hunt (2008). "The Economics of Structural Stormwater BMPs in North Carolina." Report funded by the North Carolina Urban Water Consortium, through the Water Resources Research Institute of the University of North Carolina, Chapel Hill, NC.

Wossink, A. and B. Hunt (2003). "An Evaluation of Costs and Benefits of Structural Stormwater Best Management Practices in North Carolina." NC Cooperative Extension Service, Raleigh, NC.