The Economic Benefits of Green Infrastructure

A Case Study of Lancaster, PA

About the Green Infrastructure Technical Assistance Program

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls in undeveloped areas, the water is absorbed and filtered by soil and plants. When rain falls on our roofs, streets, and parking lots, however, the water cannot soak into the ground. In most urban areas, stormwater is drained through engineered collection systems and discharged into nearby waterbodies. The stormwater carries trash, bacteria, heavy metals, and other pollutants from the urban landscape, polluting the receiving waters. Higher flows also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water. These neighborhood or site-scale green infrastructure approaches are often referred to as *low impact development*.

EPA encourages the use of green infrastructure to help manage stormwater runoff. In April 2011, EPA renewed its commitment to green infrastructure with the release of the *Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure*. The agenda identifies technical assistance as a key activity that EPA will pursue to accelerate the implementation of green infrastructure.

For more information, visit http://water.epa.gov/infrastructure/greeninfrastructure/gi_support.cfm.

Acknowledgements

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Executive Summary

Cities across the US are using green infrastructure to meet water quality goals and provide more livable communities. In 2011, the city of Lancaster, Pennsylvania released a comprehensive Green Infrastructure Plan (GI Plan) articulating a set of goals, opportunities, and recommendations for implementing green infrastructure in Lancaster. While the water quality benefits associated with the Plan were estimated, many of the additional environmental, social, and economic benefits cited in the Plan were not. The purpose of this analysis is to demonstrate how accounting for the multiple benefits of green infrastructure can provide a more complete assessment of infrastructure and community investments.

Lancaster, like hundreds of other cities across the county, has both a combined sewer system (CSS) and a municipal separate storm sewer system (MS4). While the CSS collects both sewage and stormwater and conveys flows to a wastewater treatment plant (WWTP), the MS4 collects only stormwater runoff and discharges flows directly to receiving streams. The benefits analysis summarized in this report evaluates how installing green infrastructure in the CSS area could reduce gray infrastructure capital investments and associated wastewater pumping and treatment costs; as well as how installing green infrastructure in both the CSS and MS4 areas could produce a range of environmental benefits across the city.

This screening-level analysis suggests that green infrastructure can be a cost-effective solution to stormwater management that provides multiple environmental benefits. Within the CSS area, the Plan was estimated to provide approximately $2.8 million in energy, air quality, and climate-related benefits annually. In addition, the Plan was estimated to reduce gray infrastructure capital costs by $120 million and to reduce wastewater pumping and treatment costs by $661,000 per year. These benefits exceed the costs of implementing green infrastructure in the CSS area, which were estimated to range from $51.6 million if green infrastructure projects were integrated into planned improvement projects to $94.5 million if green infrastructure projects were implemented as stand-alone projects.

Across the entire city, the GI Plan was estimated to provide approximately $4.2 million in energy, air quality, and climate related benefits annually. In addition, the GI Plan is expected to reduce gray infrastructure costs in both the CSS and MS4 areas. While cost reductions in the MS4 area were not included in this analysis, accounting for the reduced cost of green infrastructure in the MS4 area would increase the value of avoided costs beyond the $120 million estimated for the CSS area only. These benefits would be achieved at an estimated cost of $77 million if green infrastructure were integrated into planned improvement projects to $141 million if green infrastructure were implemented as stand-alone projects. In both the CSS and MS4 areas, the environmental and economic benefits provided by green infrastructure would continue to accrue year after year.[1]

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[1] As a distributed approach, green infrastructure practices would be built, become operational, and begin providing benefits during each year of the 25-year implementation plan. This simplified, screening-level analysis did not consider a projected implementation schedule and estimated annual benefits only after the entire green infrastructure plan would be implemented. In addition, the estimated annual future benefits were not discounted and do not represent the present value of benefits realized.

Introduction

As municipalities continue to grapple with limited budgets and growing stormwater management needs, finding lower cost solutions that provide additional benefits to communities has become a critical priority. Green infrastructure can play a key role in addressing this challenge. Green infrastructure refers to planning and design approaches that mimic or restore natural hydrologic processes within the built environment to manage stormwater at its source. In addition to stormwater management, green infrastructure can provide many community benefits, including reducing energy consumption, improving air quality, providing carbon sequestration, and increasing property values.
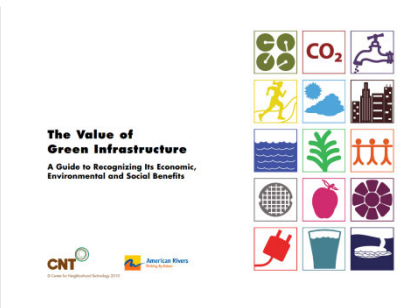
CNT Guide[1]

Green infrastructure's overall value as a municipal or private investment depends in part on the additional benefits it provides beyond stormwater, and thus upon a community's ability to model and measure these benefits. One resource available to assist communities in quantifying the additional benefits of green infrastructure is *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits* (Guide) (CNT and American Rivers, 2010). The Guide aims to inform decision-makers about the multiple benefits of green infrastructure, and to provide a generalized method for estimating the value of proposed investments.
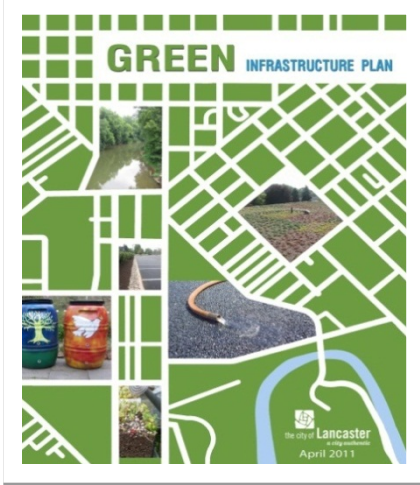
As part of EPA's ongoing efforts to build community capacity to develop cost-effective green infrastructure plans, EPA applied the generalized method developed in the Guide to the City of Lancaster, Pennsylvania. EPA conducted this case study to demonstrate the application of the Guide in a city with a comprehensive green infrastructure plan, and to illustrate the value of the multiple benefits that green infrastructure can provide (City of Lancaster, 2011).

Lancaster Green Infrastructure Plan

The city of Lancaster is located in Lancaster County in south-central Pennsylvania. The city has a population of nearly 60,000 and is one of more than 700 cities nationwide with a combined sewer system (CSS). Most of the time, the City's wastewater treatment facility is able to manage and treat the volume of wastewater flowing through the CSS. During intense precipitation events, however, the system becomes overwhelmed and mixed sewage and stormwater is discharged directly into area streams and rivers. Each year, combined sewer overflows (CSOs) discharge approximately 750 million gallons of untreated wastewater and stormwater into the Conestoga River. Despite significant progress in recent years through investments in gray infrastructure (e.g., increasing the capacity of conveyance and treatment infrastructure), the City estimated that the price tag to manage the remaining CSOs with gray infrastructure would be more than $250 million.

To link the significant investment required to meet water quality goals to a broader set of community improvements, the City of Lancaster opted for a strategy involving both gray and green infrastructure. The City began developing a comprehensive Green Infrastructure Plan (GI Plan) in 2010, and released the Plan in 2011. Developed with the assistance of city, county, and state agencies, the Plan identified opportunities for adding green infrastructure throughout the City within 5-year and 25-year timeframes; estimated the water quality benefits of 5-year and 25-year implementation scenarios; and articulated a series of policy, outreach, and technical recommendations to institutionalize green infrastructure in the City. Based on the assumed implementation level for the 25-year scenario as well as a series of system characteristics and performance assumptions documented in Chapter 5, the Plan estimated that long-term implementation of green infrastructure could reduce the average annual stormwater runoff in the study area by 1.053 billion gallons per year.[2] The Plan estimated the total and marginal costs of the 25-year scenario to be $141 million and $77 million, respectively. The marginal (or incremental) cost refers to the additional cost of adding green infrastructure to a planned improvement project (e.g., the additional cost of repaving a parking lot with permeable pavement instead of conventional pavement). As noted in the Plan, leveraging other projects is generally more cost effective than undertaking stand-alone green infrastructure projects, and can result in more widespread implementation.

While the City's Plan estimated the reduction in runoff volume, sediment loads, and nutrient loads associated with the 25-year green infrastructure scenario, many of the additional environmental, social, and economic benefits cited in the Plan were not calculated. Given the City's interest in understanding the added benefits of green infrastructure and the availability of a comprehensive green infrastructure plan, EPA selected the City of Lancaster to serve as a case study for the application of the Guide. The following report applies the Guide to estimate the value of Lancaster's proposed long-term green infrastructure investments in four benefits categories: water, energy, air quality, and climate change.

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[2] Note that the study area extends beyond the CSS area to include areas served by the Municipal Separate Storm Sewer System (MS4). Within the CSS area, note also that a one gallon reduction in stormwater runoff translates into a less than one gallon reduction in CSO discharges. The reduction in annual CSO discharges associated with the Plan is described further in the Water Related Benefits section below.

Methods and Assumptions

This case study applied the methodology discussed in *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits* (Guide) (CNT and American Rivers, 2010) to monetize several of the additional benefits of Lancaster's Green Infrastructure Plan. The Guide compiles extensive research on the benefits of five green infrastructure practices in eight benefit categories to develop a generalized methodology for valuing the additional benefits of green infrastructure. For each green infrastructure practice and benefit category for which adequate research is available, the Guide presents a two-step process for valuing benefits. The first step consists of a method for quantifying the benefits of a green infrastructure practice in a particular benefit category, while the second step consists of a method for valuing the quantified benefit in monetary terms. See Appendix A for a graphical representation of this process.

For this case study, four benefit categories were selected for valuation: water-related benefits, energy-related benefits, air quality-related benefits, and climate change-related benefits. To begin the analysis, a list of data requirements was generated based on the benefits selected for valuation. This "Data Requirements List" can be found in Appendix B. To the extent possible, all data needed to quantify and value the benefits of interest were derived from local sources. When local information was unavailable, reference values from the Guide were applied. The data sources for this case study are described in the Findings section of this report.

As described in Appendix B, the data requirements included significant data on the City's future green infrastructure projects. Because data on these future green infrastructure projects were not available in the resolution required by the Guide, one possible green infrastructure scenario was extrapolated from the 20 demonstration projects included in Lancaster's GI Plan. Lancaster's GI Plan estimates an average annual runoff reduction of 1.053 billion gallons at its long-term (approximately 25-year) implementation period (City of Lancaster, 2011). The Plan also includes 20 demonstration projects to be implemented in the next several years.[3] To extrapolate future green infrastructure implementation from these 20 demonstration projects, the annual reduction in runoff volume was obtained from the GI Plan for each of the 20 projects. The reduction in runoff volume provided by each project was then summed across all 20 projects, and the percentage of the total runoff reduction attributable to each type of green infrastructure practice was calculated. Permeable pavement accounted for approximately 26% of the total runoff reduction; bioretention and infiltration practices accounted for approximately 56%; green roofs accounted for 4.5%; tree planting accounted for 13%; and water harvesting accounted for 1%.

These percentages were then used to extrapolate how much of each type of green infrastructure practice would be installed during the long-term implementation period. For example, capturing 4.5% of the target capture volume of 1.053 billion gallons per year equates to 47 million gallons per year. In Lancaster, capturing 47 million gallons of runoff per year with green roofs would require almost 3 million square feet of green roofs, or 600 green roofs at 5,000 square feet each. Similarly, capturing 13% of the target capture volume with trees would require around 118,000 trees (both existing and to-be planted), and capturing 56% of the target volume with infiltration practices would require about 100 acres of bioretention and infiltration installations, such as rain gardens and bioswales. These

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[3] See p. 4-23 of the Lancaster *Green Infrastructure Plan*.

extrapolated levels of implementation were used to estimate the value of Lancaster's green infrastructure after a 25-year period.

The benefits of the mix of practices extrapolated from the demonstration projects were also compared to the costs. Lancaster's Plan estimated the cost of the 25-year implementation scenario by identifying feasible implementation levels for each type of impervious area within the city, and estimating the unit cost of green infrastructure implementation for each impervious area type. While the exact mix of green infrastructure practices to be implemented was not identified, the mix extrapolated from the demonstration projects represents one possible scenario. Note that this analysis presents both the benefits and costs of the Plan in 2010 dollars.

The following assumptions were applied to this valuation exercise:

- Results assume that implementing the Lancaster Plan achieves the long-term, 25-year runoff reduction benefit of 1.053 billion gallons per year.

- The 20 demonstrations projects listed in the Plan are representative of the future distribution of green infrastructure projects.

- All estimated monetary values would not begin fully accruing until the end of the Plan's long-term, 25-year implementation period.

Findings

For each of the benefits categories analyzed, this section describes how the benefits associated with the 25-year implementation scenario were valued and summarizes the results. As discussed in the Methods section, benefits were assumed to begin accruing after the 25-year implementation scenario. Also as discussed in the Methods section, these benefits represent only one possible implementation scenario. Since the exact mix of green infrastructure practices to be implemented is not known, this analysis should be considered a screening-level analysis.

The value of the benefits provided should also be considered in the context of the cost of implementation. While the Plan does not include a cost estimate for the particular mix of green infrastructure practices analyzed in this report, the Plan does include a general cost estimate based on assumed implementation levels for public and private property. The Plan estimates the total capital cost of the 25-year green infrastructure scenario to be up to $141 million. The Plan also estimates that the total marginal cost could be as low as $77 million if the green infrastructure projects are incorporated into other capital improvements. As noted in the Plan, the marginal cost is a critical concept. By incorporating green infrastructure into already-planned projects, green infrastructure implementation can be more cost effective and widespread.

WATER-RELATED BENEFITS

Within the water benefits category, both the avoided capital costs associated with reduced storage needs and the avoided operational costs associated with reduced wastewater treatment needs were valued. Green infrastructure practices such as green roofs, tree planting, permeable pavement, bioretention, and rainwater harvesting help to reduce the volume and rate of runoff entering sewer systems. In combined sewer systems such as Lancaster's, this could reduce both the storage and treatment required to manage CSOs. This, in turn, could reduce both the capital and operational costs of gray infrastructure systems such as storage tanks and pumping stations. These avoided costs would accrue only within the CSS area, and were compared to the cost of implementing green infrastructure within the CSS area. For the 25-year green infrastructure scenario, **the avoided capital cost of implementing gray infrastructure is $120 million and the avoided operational cost is $661,000 per year. Within the CSS area, these avoided costs would be achieved at a total cost for green infrastructure of approximately $94.5 million, or a total marginal cost of approximately $51.6 million** (see Figure 1).

For step one calculations, Lancaster provided the local, annual average of precipitation (42.04 inches). The U.S. Forest Service's *Northeast Community Tree Guide* (McPherson et al., 2007) provided detailed performance information for the type of trees Lancaster anticipates planting (2" red maples were used as a representative tree for estimating benefits). All other inputs were sourced from the Guide itself. For step one calculations, it also was necessary to determine the volume of CSO reduction within the CSS area. As noted previously, Lancaster's Plan estimates an average annual runoff reduction of 1.053 billion gallons/year at its long-term implementation period. Not all of this reduction, however, will translate into reductions in the volume of overflows discharged from the CSS. Lancaster's Plan assumes that 67% of the total area managed by green infrastructure will be located within the CSS area, and that the reduction in CSO volume will equal 75% of the reduction in stormwater runoff volume in the CSS. In other words, the Plan assumes that for every 1 gallon of stormwater captured by green infrastructure,

CSO discharges will be reduced by 0.75 gallons. Based on these assumptions, the green infrastructure installed within the CSS area will capture an average of 706 million gallons of stormwater runoff annually, and reduce CSO discharges by an average of 529 million gallons/year.

In step two, the average annual reduction in CSO volume was translated into avoided capital costs for gray infrastructure storage systems and avoided wastewater pumping and treatment costs. Lancaster provided the unit cost of wastewater treatment and pumping ($0.00125/gallon) and the unit cost for CSO reduction through gray infrastructure storage ($0.23/gallon of CSO treated in an average year[4]) to arrive at the values below. These values can be compared to the total and marginal costs of implementing green infrastructure within the CSS area. The Lancaster Green Infrastructure Plan assumes that approximately 67% of green infrastructure implementation will occur within the CSS area. Assuming that green infrastructure costs are directly proportional to the area of green infrastructure implemented, the total cost of green infrastructure in the CSS area would be 67% of $141 million (or $94.5 million) and the marginal cost of green infrastructure would be 67% of $77 million (or $51.6 million).
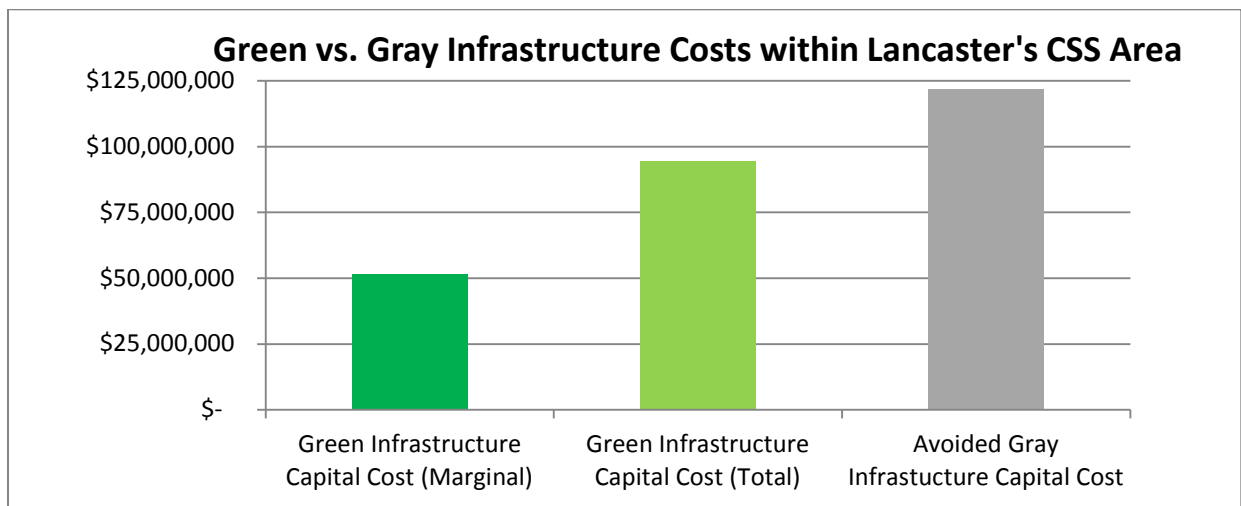

Figure 1: Comparison of avoided gray infrastructure costs to green infrastructure costs within Lancaster's CSS area.

Estimated Value of Avoided Costs for Wastewater Treatment & Storage at 25-Year Implementation*	
Reduced Pumping and Treatment Costs (per year)	$661,000
Reduced Gray Infrastructure Capital Costs	$120,000,000

*Benefits of green infrastructure stormwater reduction outside the CSS area were not included in this analysis

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[4] The unit cost per gallon of CSO treated in an average year was determined based on preliminary planning work for a 15 million gallon storage facility in Lancaster's North basin. Preliminary analyses indicated that the facility would achieve a 78% reduction in CSO volume in an average year and reduce CSO discharge frequency to 10 overflows annually (City of Lancaster, 2011). The capital cost of the facility was estimated to be $70,000,000, and the annual overflow reduction was estimated to be 302 million gallons in an average year. Based on these estimates, the unit cost per gallon of CSO captured in an average year was determined to be $0.23/gallon.

ENERGY-RELATED BENEFITS

The energy benefits measured were reduced electricity and natural gas usage. Green infrastructure features such as green roofs, tree planting, and rainwater harvesting reduce energy usage and costs by helping to dampen daily temperature variations in buildings, providing shading, wind blocking, and evaporation benefits, and reducing potable water use and associated energy demands. For the 25-year green infrastructure scenario, **the estimated annual benefit of reduced energy use is $2,368,000/year**. This figure represents the potential monetary savings for Lancaster and its residents in reduced heating and cooling needs.

Step one identified the amount of energy reduced in kilowatt hours (kWh) of electricity and British thermal units (Btu) of natural gas. The annual number of cooling degree days and heating degree days were identified using the National Oceanic and Atmospheric Administration's (NOAA) guide to climatography of the United States (NOAA, 2000). Average annual electricity savings (39 kWh/tree) and average annual natural gas savings (1,567,000 Btu/tree) were found in the *Northeast Community Tree Guide*. R values for conventional roofs and green roofs were sourced directly from the Guide. The total amount of reduced energy equaled 5.4 million kWh and 204 billion Btu annually. Note reduced energy use as a result of avoided wastewater treatment needs was not calculated here since this benefit was already quantified in the water section.

In step two, monetary benefits for reduced energy use were determined based on the total resource units identified in step one above. Lancaster provided the pricing information for the average price per Kilowatt hour (kWh/$0.1095) and British thermal unit (Btu/$0.00000871). Multiplying the total resource units by the price per unit generated the values below.

Estimated Value of Reduced Energy Use at 25-Year Implementation	
Reduced Electricity Use (kWh)	$592,000
Reduced Natural Gas Use (Btu)	$1,776,000
TOTAL (per year)	**$2,368,000**

AIR-QUALITY RELATED BENEFITS

The air quality benefits measured were reduced nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matter of aerodynamic diameter of ten micrometers or fewer (PM-10). Planting trees and installing green roofs, permeable pavement, and bioretention and infiltration practices can help reduce air pollutants through direct up-take and absorption, reduced electricity generation, and reduced ozone and smog formation. For the 25-year implementation scenario, **the estimated benefit of reduced air pollutants is $1,023,000/year**. This figure constitutes the value to Lancaster and its citizens of reduced air pollutant-related impacts as a result of the installation of green infrastructure.

Step one identified the amount of pollutant reduction by type of pollutant. Note that this calculation was only performed for green roofs and trees. According to the American Lung Association, Lancaster County is one of the nation's 40 most air polluted metropolitan areas. For this reason, upper-bound figures on pollutant uptake, where available, were used.

For green roofs, average annual pollutant uptake figures were sourced from the Guide:

- NO_2 uptake (0.0004770 lbs/SF)
- SO_2 uptake (0.0004060 lbs/SF)
- O_3 uptake (0.0009200 lbs/SF)
- PM-10 uptake (0.0001330 lbs/SF)

For tree planting, average annual pollutant uptake and pollutant avoided figures were derived from the *Northeast Community Tree Guide*:

- NO_2 uptake (0.37 lbs/tree)
- SO_2 uptake (0.40 lbs/tree)
- O_3 uptake (0.29 lbs/tree)
- PM-10 uptake (0.33 lbs/tree)

The indirect NO_2 and SO_2 reduction figures for reduced electricity use were found using the United States Environmental Protection Agency's (EPA) *eGRID2007 Summary Tables* (EPA, 2008):

- NO_2 emissions factor (0.0022880 lbs/kWh)
- SO_2 emissions factor (0.0089840 lbs/kWh)

The indirect NO_2 and SO_2 reduction figures for reduced natural gas use were sourced from the Guide:

- NO_2 emissions factor (7.21E-07 lbs/Btu)
- SO_2 emissions factor (2.66E-07 lbs/Btu)

The amount of reduced electricity and natural gas use was taken from the energy calculation section. The total amount of reduced pollutants was estimated to be

- 61,983 lbs NO_2/yr
- 37,220 lbs O_3/yr
- 68,376 lbs SO_2/yr
- 39,628 lbs PM-10/yr

In step two, monetary benefits for the reduction in pollutants were determined based on the total resource units identified in step one above. The value per pound for each pollutant was derived from the *Northeast Community Tree Guide*:

- NO_2 value ($4.59/lb)
- SO_2 value ($3.48/lb)
- O_3 value ($4.59/lb)
- PM-10 value ($8.31/lb)

| Estimated Value of Reduced Air Pollutants at 25-Year Implementation	
Reduced NO_2	$285,000
Reduced O_3	$171,000
Reduced SO_2	$238,000
Reduced PM-10	$329,000
TOTAL (per year)	**$1,023,000**

Climate Change-related Benefits

The climate change benefit valued was reduced CO_2. For the 25-year green infrastructure scenario, **the estimated benefit of reduced CO_2 is $786,000/year**. Green infrastructure vegetation helps reduce the amount of atmospheric CO_2 through direct carbon sequestration, reductions in water and wastewater pumping and treatment and the associated energy demands, and reductions in building energy use.

Step one used the assumed distribution of green infrastructure projects to estimate the amount of CO_2 reductions associated with the Plan. Note that this calculation was only performed for green roofs and trees. The average amount of annual carbon sequestered from green roofs (0.0338 lbs C/SF) and the indirect CO_2 emission factors for reduced electricity use (1.13907 lbs/kWh) and natural gas use (1.16890E-04 lbs/Btu) were sourced from the Guide. The amount of CO_2 abated from tree planting (250 lbs of CO_2/tree) was found in the *Northeast Community Tree Guide*. The total amount of reduced CO_2 was estimated to be approximately 34 million lbs CO_2/year (17,000 tons/year).

Step two placed a monetary value to this reduced CO_2 figure. An average of the lower- and upper-bound price per pound ($0.02308/lb) of reduced CO_2 was derived from the Guide.

Estimated Value of Reduced CO_2 at 25-Year Implementation	
TOTAL Reduced CO_2 (per year)	**$786,000**
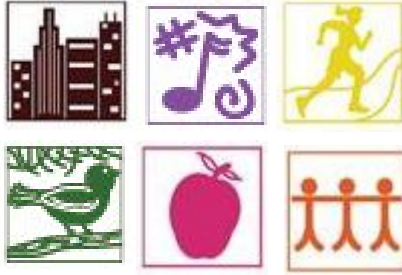
ADDITIONAL QUALITATIVE BENEFITS

It is important to note that in addition to the specific benefits valued in this case study there are a number of other benefits green infrastructure can provide that were not assigned a dollar value here. As noted in the Guide, these additional benefits include reduced urban heat island effect, increased property value, reduced noise pollution, increased recreational opportunities, habitat improvement, public education, and community cohesion. While the Guide does not outline a specific valuation method for these benefits, other studies have demonstrated their value, and it is important to acknowledge the additional worth (monetary or otherwise) that they can provide to Lancaster and other communities.

TOTAL CALCULATED BENEFITS OF CASE STUDY

The sum total of the benefits calculated for Lancaster's Plan in this case study came to an **estimated value of more than $120 million in avoided gray infrastructure capital costs and nearly $5 million in annual benefits** beginning after the 25-year implementation period. The value of the benefits provided by green infrastructure can be compared to the estimated cost. The Plan estimates a total capital cost of $141 million for the long-term implementation scenario, and a total marginal cost of $77 million if green infrastructure is incorporated into planned projects.

Total Calculated Benefits (at Long-Term 25-Year Implementation)	

Estimated Value from Water Benefits
    Reduced CSS Gray Infrastructure Capital Costs (one-time)
    Reduced Pumping and Treatment Costs (per year)
	$120,000,000
	$661,000

Estimated Value from Energy Benefits (per year)	$2,368,000
Estimated Value from Air Quality Benefits (per year)	$1,023,000
Estimated Value from Climate Change Benefits (per year)	$786,000
Estimated Value from other Qualitative Benefits	Not calculated

TOTAL
    Avoided Capital Costs
    Annual Benefits
	$120,000,000
	$4,838,000

INDIVIDUAL PROJECT VALUATION

In addition to estimating the value of a community's overall green infrastructure plan, the CNT Guide may be applied to individual green infrastructure projects as well. To demonstrate how the benefits of individual projects could be assessed, EPA applied the Guide to three demonstration projects that the City of Lancaster has recently implemented. The results are summarized below. Note that the following values apply to the green infrastructure features only, and not to their surrounding drainage areas.

Rain barrel, Lancaster, PA
Photo credit: Danielle Gallet, CNT

Porous pavement basketball court, Lancaster, PA
Photo credit: Danielle Gallet, CNT

Bioretention and infiltration, Lancaster, PA
Photo credit: Danielle Gallet, CNT

1. City Park

Brandon Park is located in the southwest part of Lancaster. The city recently redeveloped Brandon Park with a host of green infrastructure features, including over 23,000 square feet of bioretention and infiltration practices (with a drainage area of 132,400 square feet) and over 30,000 square feet of permeable pavement (with a drainage area of 48,300 square feet). To determine the total benefit of the project, the avoided gray infrastructure capital cost and annual green infrastructure benefits were calculated. Annual benefits consist of reduced pumping and treatment costs, energy-related benefits, air quality-related benefits, and climate related benefits.

Brandon Park Demo Project	Benefit Category	Value ($)
Bioretention & Infiltration	Avoided Capital Costs	$749,518
	Annual Benefits	$4,445
Permeable Pavement	Avoided Capital Costs	$232,958
	Annual Benefits	$1,382

2. Green Street

The City has also completed a commercial green street at Walnut and Plum Streets, in the northeast part of Lancaster. Green infrastructure features for this project include almost 6,000 square feet of bioretention and infiltration practices (with a drainage area of 68,400 square feet) as well as over 4,000 square feet of permeable pavement (with a drainage area of 7,300 square feet).

Green Street @ Walnut/Plum Demo Project	Benefit Category	Value ($)
Bioretention & Infiltration	Avoided Capital Costs	$358,225
	Annual Benefits	$2,125
Permeable Pavement	Avoided Capital Costs	$35,209
	Annual Benefits	$208

3. Parking Lot

Lancaster also reconstructed a public parking lot on South Plum Street located in the southeast part of the City. Green infrastructure features for this development include almost 6,000 square feet of bioretention and infiltration practices (with a drainage area of 33,800 square feet).

South Plum Street Parking Lot Demo Project	Benefit Category	Value ($)
Bioretention & Infiltration	Avoided Capital Costs	$191,031
	Annual Benefits	$1,133

Conclusion

This case study exemplifies how conducting a comprehensive analysis of benefits can help communities identify appropriate infrastructure investments that can achieve a broad array of community development objectives. It also highlights the role that green infrastructure can play in augmenting the existing gray infrastructure network. The projected avoided gray infrastructure investments reduce, but do not eliminate, needed gray infrastructure improvements. The overall approach that Lancaster has proposed presents a combined green and gray infrastructure system projected to cost less than a gray only plan and intended to enhance the environmental performance and benefits provided by their investment.
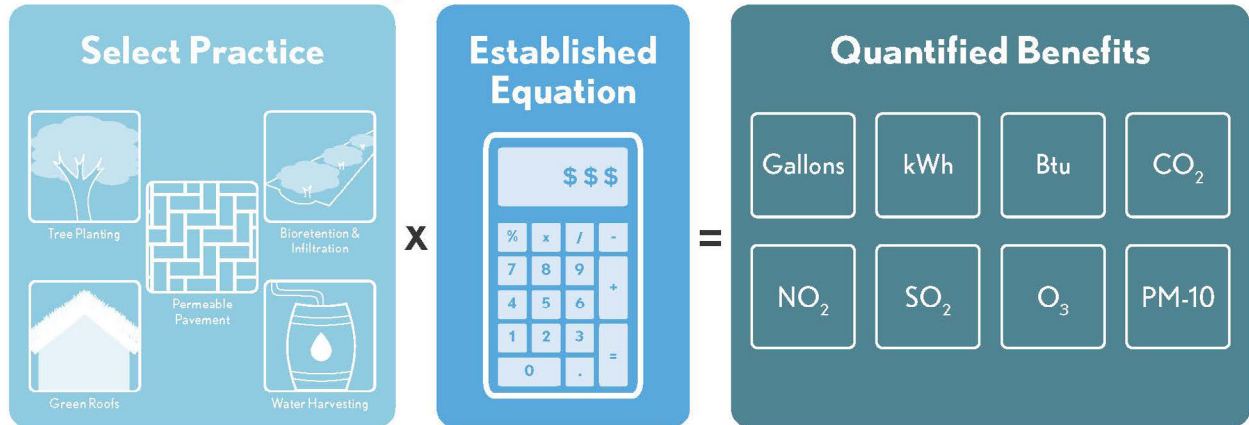
This analysis also highlights the importance of incorporating green infrastructure into planned capital improvement projects. While the estimated capital cost of the 25-year implementation scenario for the entire city is $141 million, the estimated marginal cost of including green infrastructure that is built at the same time as other capital improvements is $77 million, approximately 45% lower than implementing green infrastructure projects in a stand-alone manner. The opportunity to integrate green infrastructure broadly across a number of infrastructure improvements provides an opportunity to reduce overall implementation costs and promote more cost effective stormwater management solutions.
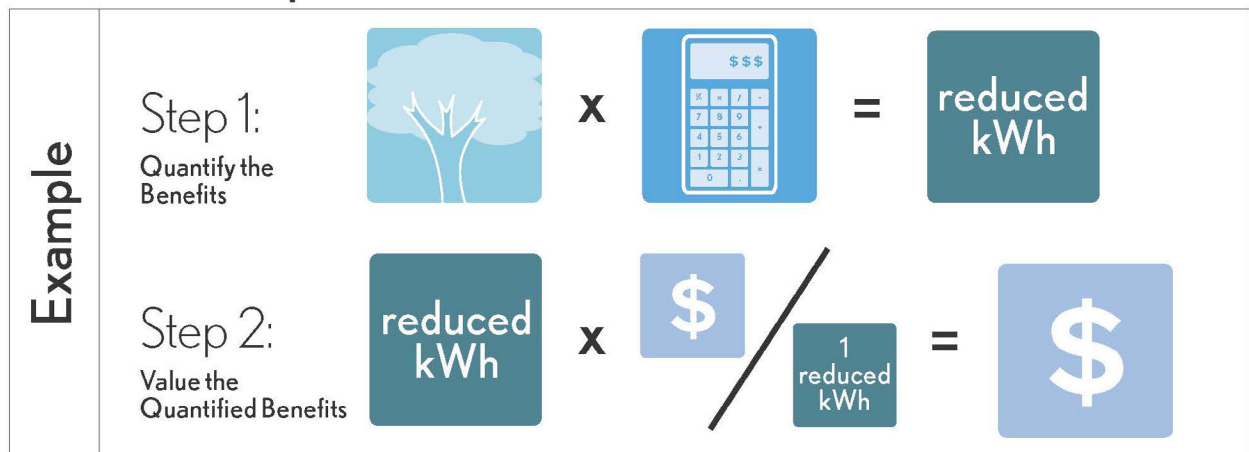
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Appendix A: Graphical Representation of Methodology[5]

Method for Valuing the Benefits of Green Infrastructure

Select Practice	Established Equation	Quantified Benefits			
Tree Planting, Bioretention & Infiltration, Permeable Pavement, Green Roofs, Water Harvesting	$$$	Gallons	kWh	Btu	CO_2
		NO_2	SO_2	O_3	PM-10

Valuation Steps in Action

Example

Step 1: Quantify the Benefits

(tree) x (calculator $$$) = reduced kWh

Step 2: Value the Quantified Benefits

reduced kWh x $\frac{\$}{1 \text{ reduced kWh}}$ = $

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[5] This image is based-on methodology developed and outlined in The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits: http://www.cnt.org/media/CNT_Value-of-Green-Infrastructure.pdf

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Appendix B: Data Requirements List

DATA NEEDED FOR WORKING THROUGH A VALUATION WITHIN THE WATER, ENERGY, AIR QUALITY AND CLIMATE CHANGE SECTIONS OF THE GUIDE

- **Data needs for existing green infrastructure projects/installations**
  - Project-specific   green infrastructure data:
    - Square foot area of green infrastructure feature
    - Type of green infrastructure installed along with details of these features (e.g., number and type of trees being planted, etc.)
    - Drainage area for the green infrastructure feature
    - Amount of stormwater being retained by the green infrastructure feature (estimated or results from monitoring)
- **Data needs for future planned green infrastructure projects**
  - Site design specs for the anticipated green infrastructure project(s)
  - Square foot area of green infrastructure feature
  - Type of green infrastructure being installed along with details about the anticipated features (e.g., number and type of trees being planted, etc.)
  - Drainage area for the green infrastructure feature
  - Estimated amount of stormwater that will be retained by the green infrastructure feature
- **Average annual precipitation in your region (inches)**
- **Average water treatment costs to customers ($/gallon)**
- **Average capital costs for additional grey infrastructure capacity ($/gallon)**
- **Annual number of cooling degree days (°F days) in your region**
- **Annual number of heating degree days (°F days) in your region**
- **R values for conventional and green roofs in your region (can use Guides range for this if not available)**
- **Type of wastewater treatment used (trickling filter, activated sludge, advanced WW treatment, advanced WW treatment nitrification) and how many million gallons per day the plant produces**
- **Average cost of electricity for your utility ($/kWh)**
- **Average cost of natural gas for your utility ($/Btu)**
- **Average annual pollutant uptake (lbs/SF) for NO_2, O_3, SO_2, and PM-10 within your region (Guide provides source for reference)**
- **Average value ($/lbs) of reduced NO_2, O_3, SO_2, and PM-10 within your region (Guide provides source for reference)**