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Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure

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Prepared by:

Janet Clements
Corona Environmental Consulting

Jim Henderson
Corona Environmental Consulting

Alan Flemming
Kennedy Jenks

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For more information, contact:
The Water Research Foundation

1199 North Fairfax Street, Suite 900
Alexandria, VA 22314-1445
P 571-384-2100

6666 West Quincy Avenue
Denver, Colorado 80235-3098
P 303-347-6100

www.waterrf.org
info@waterrf.org

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Prepared By Corona Environmental Consulting and Kennedy Jenks

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Research Team

Principal Investigators:
Janet Clements
Corona Environmental Consulting

Jim Henderson
Corona Environmental Consulting

Project Team:
Alan Flemming
Kennedy Jenks

Shonnie Cline
Corona Environmental Consulting

Claire Sheridan
Coronal Environmental Consulting

Robert Raucher, PhD
Raucher, LLC

Karen Raucher
Raucher, LLC

Carolyn Wagner
CW Research and Consulting

WRF Project Advisory Committee

Michael E. Barrett, PhD, PE, D WRE
University of Texas

Gary Belan
American Rivers

Melissa Enoch
New York City Department of Environmental Protection

Gregory E. Granato
U.S. Geological Survey

Mark Jaeger
Seattle Public Utilities

Howard Neukrug, PE
University of Pennsylvania

Wing Tam, PE
City of Los Angeles - Bureau of Sanitation

WRF Staff

John Albert, MPA
Chief Research Officer

Harry Zhang, PhD, PE
Research Program Manager – Integrated Water and Stormwater

Abstract and Benefits

Abstract:
The Green Stormwater Infrastructure (GSI) Triple Bottom Line (TBL) Benefit Cost Framework and Tool (Tool) provides stormwater practitioners with a systematic approach for quantifying and monetizing the financial, social, and environmental benefits of GSI at the community, watershed, or neighborhood scale. The Tool leads users through each step of TBL-based benefit cost analysis, from establishing a baseline, to applying appropriate economic valuation methods, and comparing benefits and costs over time. The resources developed for this project include a research-based report that documents the key economic principles upon which the Tool is based and provides detailed methods and considerations for assessing 12 different categories of GSI co-benefits. The report is accompanied by an Excel-based Tool and guidance document that provide data, information, and calculations that allow users to assess the TBL benefits and costs of alternative GSI stormwater management options. The Tool also provides summary and graphic representations of results.

Benefits:
The resources developed for this research:

- Provide an objective and comprehensive basis for quantifying and monetizing the benefits of GSI.
- Allow stormwater managers, governing officials, and other stakeholders to better understand and communicate the implications of alternative stormwater management options.
- Address current research gaps and information needs; the Tool is based on extensive research and incorporates economic valuation methods that allow users to quantify and monetize a wide range of TBL benefits.
- Strike an appropriate balance between providing enough information and data to allow practitioners to quantify relevant benefits while requiring enough user input to ensure the process is transparent and community specific.
- Provide a foundation for developing a systematic approach for evaluating the costs and benefits of gray and green infrastructure options for stormwater management. It is our hope that The Water Research Foundation and other researchers continue to build on this initial research to best meet the needs of the stormwater sector.

Keywords: Co-benefits; Triple Bottom Line; green stormwater infrastructure; economic analysis monetization.

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Acronyms and Abbreviations

ACOE	Army Corps of Engineers
ACS	American Community Survey
AF	Acre feet
AVERT	AVoided Emissions and geneRation Tool
BenMAP-CE	Benefits Mapping and Analysis Program – Community Edition
BMP	Best management practice
Btu	British thermal unit
CBP3	Community-based public private partnership
CIRA	Climate change impacts and risk analysis
CNT	Center for Neighborhood Technology
CLASIC	Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
CSO	Combined sewer overflow
eGrid	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
GHG	Greenhouse gas
GIS	Geographic Information Systems
GSI	Green stormwater infrastructure
IAM	Integrated Assessment Model
kWh	Kilowatt hour
LAI	Leaf area index
MG	Million gallons
MHI	Median household income
MMT	Minimum mortality temperature
MS4	Municipal separate storm sewer system
MT	Metric ton
NEORSD	Northeast Ohio Regional Sewer District
NO_x	Nitrogen oxides
NPV	Net present value
NRCS	Natural Resources Conservation Service
NRDC	Natural Resources Defense Council
NRPA	National Recreation and Parks Association
NTBC	National Tree Benefit Calculator
O_3	Ozone
O&M	Operations and maintenance
PM	Particulate matter

PV	Present value
SO_2	Sulfur dioxide
SCC	Social cost of carbon
SPU	Seattle Public Utilities
TBL	Triple bottom line
TMDL	Total maximum daily load
Tool	Green Stormwater Infrastructure Cost Benefit Framework and Tool
UHI	Urban heat island
USD	United States dollars
USFS	United States Forest Service
UDVM	Unit day value method
VSL	Value of statistical life
WRF	The Water Research Foundation
WTP	Willingness-to-pay
WQL	Water quality ladder
WWTP	Wastewater treatment plant

Executive Summary

ES.1 Background and Objectives

In addition to proven effectiveness for stormwater management goals, green stormwater infrastructure (GSI) can yield many important co-benefits, including beautifying neighborhoods, avoiding flood damages, improving air quality, reducing respiratory and heat-related illnesses, creating green jobs, and more. As communities continue to consider how to best integrate GSI into stormwater management planning efforts and/or expand existing GSI programs, stormwater practitioners have expressed a need for information to help them better quantify and monetize these benefits using a triple bottom line (TBL) approach. Information on the TBL benefits and costs of GSI can help stormwater practitioners and utility managers:

- Identify stormwater management alternatives that maximize community value
- Build support for GSI internally
- Compete for scarce funding
- Leverage private capital and alternative funding sources
- Support alternative project delivery and/or financing models, such as community-based public-private partnerships and/or environmental impact bonds
- Gain community support for and raise awareness of stormwater management programs

The GSI TBL Benefit Cost Framework and Tool (Tool) provides a systematic approach that allows practitioners to use location- and region-specific data to quantify and monetize the full suite of TBL benefits applicable to their community and GSI-related goals. It also provides a comprehensive framework for appropriately comparing the benefits and costs of GSI projects or programs over time.

The Tool aims to address current research gaps and information needs. Specifically, the Tool incorporates market and non-market economic valuation methods that allow users to understand and value a wide range of TBL benefits, including several harder to quantify benefits that have not been incorporated into existing tools or studies. The Tool also aims to strike an appropriate balance between providing enough information and data to allow practitioners to quantify relevant benefits, while requiring enough user input to ensure the process is transparent and community specific.

The Tool is intended for use by utility and municipal staff or other interested stormwater practitioners. The Tool does require some level of expertise and familiarity with GSI implementation and planning; however, users do not need to have an advanced knowledge of economics.

An important caveat to consider is that the Tool is not intended to supplement a detailed/customized site- or city-specific analysis. The economic benefits that are realized through GSI depend on several factors that cannot be captured within the scope of this research, including site-specific parameters, intentional design, location of GSI practices within the urban or suburban landscape, surrounding land uses, and more. GSI practices must also be maintained to continue to support and provide the multiple benefits included in the Tool. The Tool does provide reasonable estimates for potential economic benefits, assuming intentional design and siting of GSI practices.

The Tool was developed in coordination with The Water Research Foundation's (WRF) Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) project. The Tool leverages data and information from CLASIC to allow users to not only assess the benefits of alternative GSI scenarios, but to also compare them appropriately to costs. While users can bring inputs to the tool from CLASIC, the Tool is a stand-alone product.

ES.2 Project Resources

The resources developed for this research include:

- An Excel-based Tool and associated guidance document that allow users to quantify and monetize the TBL costs and benefits of a defined GSI scenario at the city-, watershed-, or neighborhood-scale. The Tool and guidance are organized around 12 benefit categories represented by a series of benefit modules. They are available on the 4852 project page of the WRF website. Figure ES-1 provides a snapshot of the introduction page of the Tool.
- A report that provides background on key steps, considerations, and valuation methods, as well as an overall economic framework for assessing the benefits and costs of GSI.
- Four case study applications of the Tool for GSI projects/scenarios in Saint Paul, MN; Lancaster, PA; Seattle, WA; and Cleveland, OH. The case studies represent a wide geographic range as well as different scales of GSI implementation. They are contained in the main report for this research.
- A detailed technical paper for each of thirteen GSI benefit categories. These papers provide comprehensive reviews of relevant literature and detail the methodology and considerations for quantifying and monetizing the respective benefit within the Tool. The technical papers are incorporated in the main report as Appendices A–L.

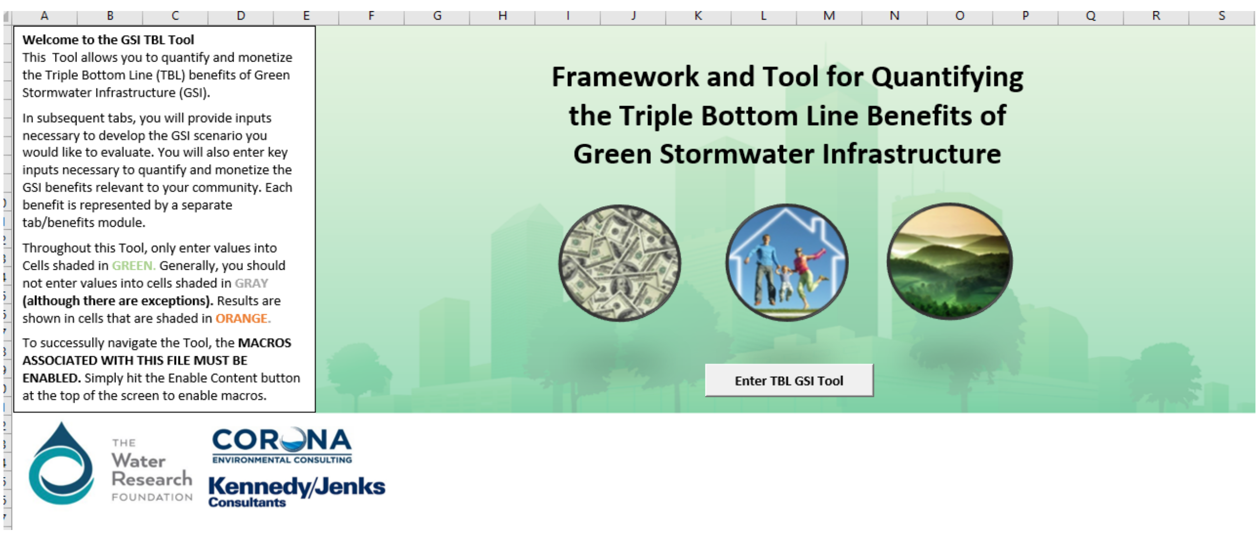


Figure ES-1. Introduction Page for the GSI TBL Benefit Cost Framework and Tool.

ES.3 Economic Framework for Triple Bottom Line Analysis

The term triple bottom line analysis reflects what economists might refer to as a comprehensive benefit-cost analysis that attempts to account for all benefits and costs of a potential project or program over time, regardless of who bears the impact or whether the impact can be easily valued using observed market prices.

The Tool leads users through each step of TBL-based benefit-cost analysis, from establishing a baseline, to applying appropriate economic valuation methods, and comparing benefits and costs over time. Figure ES-2 provides an overview of the economic framework upon which the Tool is based.

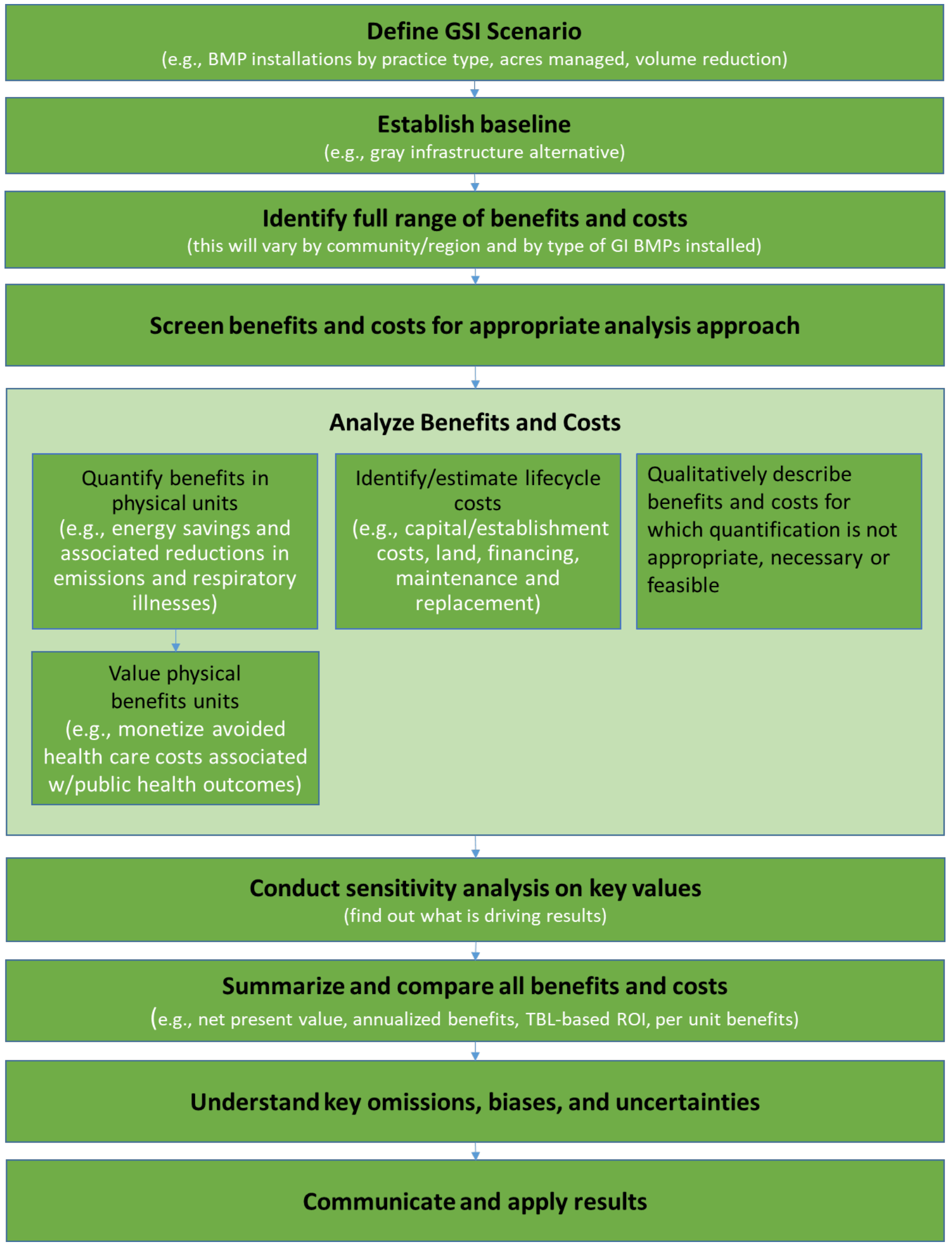


Figure ES-2. Economic Framework for Conducting TBL-Based Benefit Cost Analysis of GSI.

The TBL approach also provides an organizing framework within which the broad array of benefits and costs can be portrayed. It consists of:

A **financial** bottom line that reflects benefits that accrue directly to the utility, municipality, and/or the implementor of GSI projects in the form of cost savings.

A **social** bottom line that reflects the benefits and costs that accrue directly to households and residents (e.g., improved health outcomes or enhanced community aesthetics).

An **environmental** bottom line that reflects direct environmental benefits (e.g., improved water quality, carbon reduction, and sequestration benefits).

Figure ES-3 shows how the authors of this research have categorized GSI benefits within this TBL accounting framework.

Financial	Social	Environmental
• Avoided infrastructure and/or treatment costs • Avoided maintenance and replacement of non-stormwater assets • Energy savings	• Improved air quality and related health benefits • Water supply benefits • Improved aesthetics and community sustainability/livability • Reduced urban heat stress and related public health benefits • Increased recreational opportunities • Green job creation • Flood risk reduction [a]	• Water quality and associated aquatic habitat improvements • Carbon emissions reduction and sequestration • Terrestrial and wetland ecosystem benefits

Figure ES-3. Categorization of GSI Benefits Within a TBL Framework.

a. Flood risk reduction benefits are not included as a module in the Tool due to site-specific nature of this benefit. The Tool allows the user to enter flood reduction benefits directly so they can be included in overall benefit cost analysis

ES.4 Economic Valuation Methods

The Tool applies various approaches to quantify and monetize the different TBL benefits of GSI. In some cases, market prices are used to directly value benefits. For example, the Tool applies local energy prices to estimate the value of building energy savings associated with trees and green roofs. However, many of the benefits of GSI do not have direct market prices (e.g., recreational trips to parks, improvements in water quality and habitat, and health benefits associated with air quality improvements). Economists have established different methods for valuing these "non-market goods and services:"

- *Stated preference methods* rely on survey questions that ask individuals to make a choice, describe behavior, or state directly what they would be willing to pay for the non-market good or service being evaluated.
- *Revealed preference methods* infer willingness-to-pay (WTP) based on choices people make in related markets. For example, the aesthetic value of GSI may be measured based on the additional amount that individuals are willing to pay for a home that is located close to GSI.
- *Avoided cost approache*s estimate benefits based on the marginal cost of providing an equivalent service in another way. For example, areas where GSI is used to recharge groundwater for water supply purposes can offset the need to draw upon or develop alternative sources of supply. The avoided costs associated with securing the alternative supply source can be counted as a benefit of the GSI project.
- *Benefits transfer methods* involve transferring value estimates from a "study site" (i.e., for which an original valuation study has been performed) to a "policy site." Researchers often use benefits

transfer to estimate non-market values because original stated preference or revealed preference studies typically require a significant amount of time, expertise, and resources.

It is not within the scope of this research to conduct original stated preference or revealed preference studies. The Tool therefore relies on market price, avoided cost, and benefit transfer methods to value GSI benefits. Figure ES-4 shows the valuation methods applied for each benefit category. In cases when benefits transfer is used, the original methodology upon which it is based is also shown. When more than one original valuation approach is indicated, this means that the Tool incorporates a range of values from various approaches or that different valuation methods are available in the Tool.

	Market price	**Stated preference**	**Revealed preference**	**Avoided costs**	**Benefits transfer**
Avoided infrastructure/treatment costs				●	
Asset life extension		●		●	
Energy savings	●			●	
Water supply benefits	●			●	
Improved air quality and related health benefits				●	●
Improved aesthetics and community sustainability/livability			●		●
Flood risk reduction				●	
Reduced urban heat stress				●	●
Increased recreational opportunities		●			●
Green job creation	●				
Improved water quality		●			●
Carbon emissions reduction and sequestration				●	●
Terrestrial ecosystem and biodiversity benefits		●	●		●

Figure ES-4. Economic Valuation Methods for GSI Benefits.

ES.5 Case Study Applications

The case study applications of the Tool represent a wide geographic range as well as a range in the scale of GSI implementation. Overall, the case studies demonstrate significant potential for GSI to provide important community benefits. They also serve as valuable resources for practitioners interested in applying the Tool. The case studies include:

- Saint Paul, MN – This case study compares the costs and benefits of two stormwater management alternatives – a more conventional approach and a GSI-based approach – for a planned mixed-use redevelopment site spanning 134 acres. Results are compared to an analysis of the same site using Autocase, a proprietary software designed to assess the TBL benefits and costs of GSI.
- Lancaster, PA – This case study evaluates the benefits of a citywide GSI-based stormwater management plan implemented over 25 years. Results are compared to a similar analysis developed using *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits,* which was developed by CNT and American Rivers in 2010.
- Seattle, WA – This case study quantifies the benefits and costs of a series of planned GSI projects in Seattle's Longfellow Creek Watershed. The primary objective of these projects is to improve water quality in Longfellow Creek, which is one of the only streams within the city that supports spawning

habitat for important salmon species. This case study also highlights a multiple objective decision analysis (MODA) methodology that Seattle Public Utilities (SPU) uses to incorporate (non-quantifiable) values that are not typically included in benefit-cost methodology.
- Cleveland, OH – This case study evaluates the TBL benefits and costs of the GSI projects implemented through the Northeast Ohio Regional Sewer District's (NEORSD) Green Infrastructure Grant Program. This analysis focuses on projects funded in 2020, the 7th year of the grant program.

Table ES-1 provides a summary of the case studies, including key highlights and results. It is important to note that in many cases the benefit-cost ratio for the GSI scenario being analyzed may not always be greater than one. However, this does not mean that they are not worthwhile. This Tool is intended to measure co-benefits of GSI projects and often the full value of water quality improvements or other benefits (e.g., those not included in the Tool) is not reflected. It can be more telling to measure incremental benefits and costs of GSI. For example, if GSI projects cost more than a gray infrastructure alternative, measuring the additional costs compared to additional benefits can be particularly informative. As demonstrated in the SPU case study, qualitative assessment can also be used to demonstrate non-quantifiable benefits.

ES.6 Conclusions and Future Updates

The GSI TBL Benefit Cost Framework and Tool represents the most up-to-date methodologies and advancements in quantifying and monetizing the full range of TBL benefits associated with GSI. It also provides practitioners with a consistent and sound methodology for assessing benefits and costs. In addition to the Tool itself, this research provides the most comprehensive documentation of available literature and methods for assessing GSI co-benefits through a series of technical appendices. The case studies incorporated into this report demonstrate the potential for GSI projects to provide important community benefits that exceed project costs.

While the Tool represents a step forward in the economic evaluation of the benefits and cost of GSI, the authors have identified several areas for future research that could not be accommodated within the scope of this work. These include further exploring potential methodologies that could be incorporated into the Tool to quantify and value flood risk reduction benefits associated with GSI, further developing methodology for assessing heat stress reduction and terrestrial ecosystem benefits and developing additional methodologies and/or frameworks for incorporating the benefits associated with GSI that cannot be quantified (e.g., such as through multi-criteria decision-making).

In addition, while the Tool documentation highlights important equity issues, it assumes that GSI is distributed in such a way as to minimize adverse equity outcomes. The valuation methodology included in the Tool does not specifically address distributional impacts and/or equity concerns. This is an important research topic and continues to be explored by leaders in the water sector.

Given the significant resources invested and potential for the Tool to evolve, it is important to think about how future updates and iterations might be accommodated. Ideally, the Tool could be adapted to a web-based platform so that future iterations can be easily updated and accessed by users. It could also be further integrated with the CLASIC tool to allow users to easily compare alternatives and to better understand the water quality benefits associated with green and gray infrastructure alternatives.

Table ES-1. Summary of Tool Application Case Studies.

a. The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefit (CNT/American Rivers 2010); b. Multiple objective decision analysis (MODA); c. Indicates percent of total volume managed by GSI practice; d. Lancaster case study includes significant number of trees

	Saint Paul, MN	**Lancaster, PA**	**Seattle, WA**	**Cleveland, OH**
Description	Compares benefits and costs of two alternatives – gray- and GSI-based approaches – for mixed-use, 134-acre redevelopment site.	Evaluates benefits and costs of a citywide GSI-based stormwater management plan implemented over 25-years.	Examines benefits and costs of three ROW bioretention projects in high priority watershed.	Evaluates benefits and costs of multiple grant funded GSI projects in combined sewer are of District.
Project proponents	Capitol Region Watershed District/City of Saint Paul	City of Lancaster	Seattle Public Utilities	Northeast Ohio Regional Sewer District.
Key highlights	Results compared to similar analysis using Autocase tool. Compares incremental costs / benefits of gray and GSI scenario.	Results compared to a similar analysis developed using *CNT/American Rivers Guide.*[a].	Incorporates MODA[b] framework that SPU uses to assess GSI project priorities / benefits.	Includes customized property value analysis and analyzes distributed projects.
GSI scenario	Centralized GSI corridor; 4.8 acres of bioretention; 300 trees, large retention pond / wetland system; 10-acres of green space. Stream restoration links development site to recreation/natural area.	Manages 1,265 IA / 1,060 MG of runoff/year through GSI: bioretention (56%)[c]; permeable pavement (26%); trees (13%)[d]; green roofs (4.5%); RWH (1%).	ROW bioretention projects managing 6 impervious acres; includes 89 trees, pedestrian/safety improvements, and community gathering space.	Nine distributed projects including bioretention, permeable pavement, and underground systems.
Avoided infrastructure		★		★
Avoided maint. /replace		★		★
Energy savings	★	★	★	★
Water supply		★		★
Air quality	★	★	★	★
Heat stress	★	★		
Recreation	★	★	★	
Enhanced aesthetics	★	★	★	★
Green job creation	★	★	★	★
Water quality/habitat	★		★	
Carbon reduction	★	★	★	★
Terrestrial ecosystem	★	★	★	★
Flood risk reduction	★			
Total PV benefits ($M)	$27.9 (GSI); $15.1 (gray); (28-year PV)	$521.8 (50-year PV)	$8.98 (50-year PV)	$3.49 (40-year PV)
Total PV costs ($M)	$21.5 (GSI); 18.8 (gray) (28-year PV)	$241.5	$5.87	2.40
Benefit-cost ratio	1.3 (GSI); 0.8 (gray)	2.16	1.53	1.455

CHAPTER 1

Introduction

1.1 Background

Many cities throughout the United States and Canada have adopted ambitious green stormwater infrastructure (GSI) programs to reduce polluted stormwater runoff and meet water quality standards related to combined sewer overflows (CSOs), pollutant runoff from municipal separate storm sewer systems (MS4s), and total maximum daily load (TMDL) targets. GSI practices include green roofs, rain gardens, permeable pavement, trees, cisterns, and other natural approaches that infiltrate, evapotranspirate, or reuse stormwater onsite. These approaches can help reduce the need for large-scale gray infrastructure systems and can serve as an important component of a community's stormwater management portfolio.

In addition to proven effectiveness in meeting water quality goals, GSI practices can yield many important co-benefits, including beautifying neighborhoods, avoiding flood damages, improving air quality, reducing respiratory and heat-related illnesses, creating "green-collar" jobs, and more. As more communities consider how to best integrate GSI into stormwater management planning efforts and/or expand existing GSI programs, stormwater practitioners have expressed a need for information to help them better quantify and monetize these benefits using a triple bottom line (TBL) approach. Information on the TBL benefits and costs of GSI can help stormwater practitioners and utility managers:

- *Identify stormwater management alternatives that maximize community value.* When feasible, it is important to assess the types and levels of benefits associated with alternative stormwater management approaches in both physical units and monetary terms. This allows for an apples-to-apples comparison of benefits and costs and helps community leaders discern which approach (or combination of approaches) will yield the largest value (net benefit) to the community.
- *Build support for GSI internally.* At the outset of this research, the project team held an in-person workshop with utility representatives from across the U.S. and Canada to obtain feedback on the proposed Framework and Tool. A key finding of the workshop was that many utility practitioners want quantitative (rather than qualitative) information on the benefits of GSI in order to demonstrate the merits of green approaches to their colleagues, who are not as familiar with GSI.
- *Compete for scarce funding.* Approximately 1,500 communities in the U.S. currently have a stormwater fee. This provides a dedicated source of revenue that these communities can use to implement stormwater projects and leverage additional funds. Without the benefit of having fees in place, many stormwater departments must compete for funding with water, wastewater, and potentially, other community programs. This makes it important to demonstrate the full value of proposed stormwater management programs.
- *Leverage private capital and alternative funding sources.* Information on the benefits of GSI can be used to leverage alternative funding streams from both public and private sources. For example, information on public health and economic development benefits may leverage funding from public agencies that might not otherwise think about funding stormwater projects. Similarly, research related to private sector implementation of GI (Clements and Henderson 2015) shows that property owners and developers would be willing to implement GI on their property if they knew it would improve their bottom line (e.g., through increased property values, retail sales, and/or rents).

- *Support alternative project delivery models.* Many communities are considering alternative GI project delivery or financing models, such as community-based public-private partnerships (CBP3s) and environmental impact bonds, to achieve water quality targets and meet other community goals (e.g., creation of green jobs). These approaches require quantitative, performance-based metrics to ensure program success. Information on GI benefits can inform CBP3 contracting, helping communities achieve stated goals.
- *Gain community support and buy-in*. Utilities and municipalities can use objective information on the benefits of GI to gain buy-in and communicate with stakeholders. This can increase support for rate increases and other programs and raise awareness of stormwater and water quality issues.

An increasing number of studies, guidance documents, and tools are now available to support the quantification and monetization of GSI benefits. However, many of these resources are focused on specific geographies, benefits, or GSI practices; others require significant investments and/or economic expertise (Wildish and Schmidt 2019). In addition, the benefits of GSI are location- and program-specific. There is a need for a more systematic approach that allows practitioners to use location- and region-specific data to understand and value the full suite of TBL benefits applicable to their community and GSI-related goals.

1.2 Objectives and Overall Approach

The GSI TBL Benefit Cost Framework and Tool (Tool) provides a practical, user-friendly, yet robust economic framework and tool that municipalities and utilities can use to identify and assess the TBL benefits associated with GSI program alternatives. The resources developed for this research offer an objective and comprehensive basis for quantifying and monetizing GSI benefits so that stormwater managers, governing officials, and other stakeholders can better understand and communicate the implications of alternative stormwater management options.

The Tool aims to address current research gaps and information needs. Specifically, the Tool incorporates economic valuation methods that allow users to quantify and monetize a wide range of TBL benefits, including several harder to quantify benefits that have not been incorporated into existing tools or studies. The Tool also aims to strike an appropriate balance between providing enough information and data to allow practitioners to quantify relevant benefits, while requiring enough user input to ensure the process is transparent and community specific.

The Tool is intended for use by utility and municipal staff, or other interested stormwater practitioners. The Tool does require some level of expertise and familiarity with GSI implementation and planning; however, users do not need to have an advanced knowledge of economics. For some benefit calculations, the Tool requires the collection of local or site-specific data; the Tool guidance provides detail on how to access key information and provides default values when possible and appropriate.

The Tool is not intended to supplement a detailed/customized site- or city-specific analysis. The economic benefits fully realized by a GSI program depend on several factors that cannot be captured within the scope of this research, including site-specific parameters, intentional design, location of GSI practices within the urban or suburban landscape, surrounding land uses, and more. In short, GSI must be designed and sited in ways that allow municipalities to fully realize its benefits. GSI practices must also be maintained to continue to support and provide the multiple benefits included in the Tool. The Tool does provide reasonable estimates for potential economic benefits, assuming intentional-design and siting of GSI practices.

In addition, while the Tool and associated documentation highlight important equity issues (e.g., effects of locating GSI in lower-income neighborhoods, see Appendices G and H), it assumes that GSI is distributed in such a way as to minimize adverse equity outcomes. The valuation methodology included in the Tool does not specifically address distributional impacts and/or equity concerns.

The Tool was developed in coordination with WRF's Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) project. The Tool leverages data and information from CLASIC to allow users not only to assess the benefits of alternative GSI scenarios but to appropriately compare them to costs. While users can bring inputs to the tool from CLASIC, the Tool is a stand-alone product.

Finally, in developing the Tool, the project team benefitted from the input provided by 15 participating utility representatives, starting with an in-person meeting at the outset of the project to obtain input on objectives and methods for the Tool. Our utility representatives also provided feedback and beta-tested the Tool in its draft form.

1.3 Report and Tool Organization

The remainder of this report is organized as follows:

- Chapter 2 provides background on key concepts related to the GSI TBL Benefit Cost Framework and Tool, including an overview of the GSI practices and benefit categories included in the Tool, TBL-based benefit cost analysis, and economic valuation methods.
- Chapter 3 presents key steps and considerations for assessing the benefits and costs of GSI
- Chapter 4 provides an overview and describes the methods incorporated in the Tool for quantifying and monetizing each GSI benefit.
- Chapter 5 contains case studies demonstrating the application of the Tool in four different locations, including in Saint Paul (MN), Lancaster (PA), Seattle (WA), and Cleveland (OH).
- Chapter 6 provides a summary of our conclusions and ideas and needs for future research.

This report is accompanied by an Excel-based Tool and associated guidance document that allows users to assess the TBL costs and benefits of GSI project alternatives at the city, watershed, and/or neighborhood scale. The Tool and guidance are organized by benefit category. For each benefit, the Tool includes a module that contains the following information:

- A brief description of the relevant benefit, including the link to specific GSI practices and the approach(es) included in the Tool for quantifying and monetizing the benefit
- Key considerations that influence whether the benefit is applicable, as well as factors that influence the level or magnitude of benefit provided
- Step-by-step guidance for quantifying and monetizing each benefit

In addition to a separate module for each benefit, the Tool includes a series of Excel worksheets in which users must enter key inputs and define their GSI scenario for evaluation. It also includes an output/results worksheet that presents the results of the user's analysis and compares total benefits to costs. The Tool and guidance are available the 4852 project page of the WRF website.

In addition to the primary report and Tool, the project team developed a detailed technical document for each GSI benefit category; these papers provide a comprehensive review of relevant literature and detail the methodology and considerations for quantifying and monetizing the respective benefit in the Tool. These technical papers are incorporated as Appendices A –L:

- A: Avoided infrastructure costs

- B: Building and utility energy savings
- C: Water supply benefits
- D: Air quality improvements and related health effects
- E: Aesthetic improvements and associated increases in property values
- F: Reduced urban heat stress and related health benefits
- G: Increased recreational opportunities and enjoyment of greened areas
- H: Green job creation
- I: Water quality
- J: Carbon reduction and sequestration
- K: Terrestrial habitat benefits
- L: Flood risk reduction benefits

CHAPTER 2

Background and Key Concepts

This chapter describes the GSI practices and benefits included in the Tool and provides an overview of TBL-based economic analysis and relevant valuation methods.

2.1 Economic Benefits of GSI Practices

GSI encompasses a range of approaches that use vegetation, soils, permeable surfaces, and rainwater harvesting systems to capture, treat, or infiltrate rain where it falls, thus reducing stormwater runoff and related flows to sewer systems and surface waters. The GSI Benefits Valuation Framework and Tool focuses on GSI practices that are typically implemented in urban and suburban settings. It does not include large-scale land preservation efforts. Figure 2-1 contains a brief description of the GSI practices included in the Tool, including:

- Rain gardens
- Bioretention facilities and vegetated infiltration practices
- Biofiltration and vegetated swales
- Green roofs
- Tree planting
- Permeable pavement
- Wet ponds
- Constructed wetlands
- Rainwater harvesting systems

These practices can yield significant economic benefits that go beyond improving water quality. For this research, the project team was able to develop methodologies for quantifying and monetizing the following categories of GSI benefits:

- Avoided costs for conventional stormwater management (e.g., gray infrastructure practices)
- Avoided replacement and maintenance of non-stormwater assets
- Energy savings
- Improved air quality and related health benefits
- Water supply benefits (including through stormwater reuse and groundwater recharge)
- Improved aesthetics and community livability (as measured through increased property values)
- Reduced urban heat stress and related public health benefits
- Increased recreational opportunities and enjoyment of green space
- Green job creation
- Water quality and associated aquatic habitat improvements
- Carbon emissions reduction and sequestration
- Terrestrial and wetland ecosystem and biodiversity benefits.

Rain gardens are hallowed depressions filled with an engineered soil mix that supports vegetative growth, including grasses, flowers, and other plants. They are commonly used on individual home lots to capture and infiltrate runoff from roofs, driveways, and streets. More complex rain gardens are often referred to as bioretention areas/cells (see below).

Bioretention and biofiltration practices come in a variety of types and scales. In general, they can be described as depressions filled with grass or other natural vegetation in engineered soils that provide storage, treatment, infiltration, and/or evaporation of both direct rainfall and runoff captured from surrounding areas. They can be used to capture or mange runoff from adjacent roads, sidewalks, and/or parking lots, as well as from much larger drainage areas. A key difference between bioretention and biofiltration is that bioretention is specifically designed to retain stormwater, while the primary objective of biofiltration practices (e.g., bioswales, grass swales) is treatment. Stormwater may be routed through biofiltration practices before it enters sewer or stormwater collections systems, or local streams.

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

Trees reduce stormwater runoff by capturing and storing rainfall in the canopy and releasing water into the atmosphere through evapotranspiration. In addition, tree roots and leaf litter create soil conditions that promote infiltration of rainwater into the soil. Trees also help to slow down and temporarily store runoff, which further promotes infiltration, and decreases flooding and erosion downstream.

Permeable pavement allows rainfall to pass through the pavement into the gravel storage layer below, where it can infiltrate at natural rates into the site's native soils. In block paver systems, rainfall is captured in the open spaces between the blocks and conveyed to the storage zone and native soil below. There are several different types of permeable pavement, including pervious or porous concrete, porous asphalt, and interlocking permeable pavers.

Wet ponds (or retention basins) are constructed basins or ponds that provide both permanent and temporary storage of stormwater runoff. Wet ponds have an outlet structure that creates a permanent pool and detains and attenuates runoff inflows. This allows for sediment and pollutants associated with that sediment to settle and remain in the wet pond, where they can later be removed and properly disposed.

Constructed stormwater wetlands are wetland systems designed to maximize the removal of pollutants from stormwater runoff through settling and both uptake and filtering by vegetation. Constructed stormwater wetlands temporarily store runoff in relatively shallow pools that support conditions suitable for the growth of wetland plants. Standard constructed wetlands direct flow through an open vegetated marsh system. Subsurface gravel wetlands, also direct flow through a surface marsh which then discharges to a permanently ponded subsurface gravel bed.

Rainwater harvesting systems, including rain barrels and cisterns, collect roof runoff during storm events. The captured stormwater can either be released or reused for outdoor irrigation during dry periods. Cisterns may be located above or below ground and can also be used for some non-potable indoor uses (e.g., toilet flushing). Rain barrels are typically used at the household level.

Figure 2-1. GSI Practices Included in the GSI TBL Benefit Cost Framework and Tool.
Source: Data from EPA, n.d.; EPA 2021; NJ DEP 2011; Center for Watershed Protection, n.d.

Importantly, not all GSI practices will result in the same level or type of benefits. Figure 2-2 highlights the potential economic benefits associated with different GSI practices, although the actual realization of these benefits depends on several factors. To the extent feasible, the valuation methodology included in the Tool accounts for the different level of benefits afforded by each GSI practice, as well as for key design parameters and other considerations that affect the level of benefits provided (e.g., local climate, population, and other study area characteristics).

There are potential benefits of GSI that are not included in the Tool because the authors could not find sufficient evidence in the literature to support the quantification and/or monetization of these benefits within the scope of this research effort. Most notably, this includes benefits associated with flood risk reduction. While this benefit can be quantified and monetized in various ways (e.g., based on avoided property damage, averting behavior, or willingness to pay to avoid flood damage), the flood risk reduction benefits of GSI are site-specific; reductions in flood depth associated with GSI are difficult to generalize without hydrologic modeling, particularly in urban settings. The authors researched potential methods for quantifying this benefit, including approaches applied in other tools; however, it was determined that available approaches accurately capture this benefit with a desired order-of-magnitude. Chapter 4 of this report includes a description of the different methods available for quantifying and monetizing flood risk reduction benefits, with additional detail in Appendix L. Users can calculate these benefits outside of the Tool and manually enter them for inclusion in the overall benefit cost analysis. The authors of the Tool hope to include this benefit in future updates.

2.2 Economic Analysis and TBL Accounting

The GSI TBL Benefit Cost Framework and Tool allows stormwater practitioners to conduct a “full social accounting”-based assessment of the benefits and costs of GSI implementation at the city-, watershed- or neighborhood-scale. “Full social accounting” refers to the economic perspective of trying to identify and account for all the benefits and costs of a potential project or program, regardless of who bears the impact, or whether the impact can be easily valued using observed market prices.

The term “triple bottom line analysis” has become somewhat synonymous with the basic principles of full social- accounting or what economists might refer to as a comprehensive benefit-cost analysis that attempts to account for the full range of financial, environmental, and social benefits and costs of a project or program over time. This includes benefits and costs borne “internally” by a municipality or stormwater agency, as well as those that are borne “externally” by other parties (e.g., households, businesses, special interest groups).

Many of the potential benefits of GSI, such as improved air and water quality, urban heat stress reduction, and increased recreational opportunities, are not bought and sold in a market and therefore do not have a directly observable market price or value. As described in more detail below, economists have developed several methods for valuing these and other “non-market” goods and services. The inclusion of both market and non-market values in TBL-based assessments provides for a more comprehensive accounting and direct comparison of the benefits and costs of alternative program options.

Economic benefit	Rain gardens	Bioretention	Green roofs	Tree planting	Permeable pavement	Wet ponds	Wetlands	Rainwater harvesting
Avoided infrastructure/treatment costs	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Asset life extension			🟢		🟢			
Energy savings (buildings)			🟢	🟢				🟡
Energy savings (utility)	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟢
Improved air quality and related health benefits	🟡	🟡	🟢	🟢	🟡	🟡	🟡	🟢
Water supply benefits	🟡	🟡		🟡	🟡	🟡	🟡	🟢
Improved aesthetics and community sustainability/livability	🟢	🟢	🟢	🟢	🟡	🟡	🟢	🟢
Flood risk reduction	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Reduced urban heat stress and related public health benefits	🟢	🟢	🟢	🟢		🟢	🟢	
Increased recreational opportunities and enjoyment of green space		🟢	🟢	🟢		🟢	🟢	
Green job creation	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡
Improved water quality	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Carbon emissions reduction and sequestration	🟢	🟢	🟢	🟢	🟡	🟡	🟢	🟢
Terrestrial and wetland ecosystem benefits	🟢	🟢	🟢	🟢		🟢	🟢	

🟢 High likelihood of providing benefit 🟡 Medium likelihood of providing benefit

Figure 2-2. GSI Practices and Associated Benefits.

Once all benefits and costs are accounted for (and quantified and monetized to the extent feasible), the TBL approach provides an organizing framework within which the broad array of benefits and costs can be portrayed. It consists of:

- A **financial** bottom line that reflects benefits that accrue directly to the utility, municipality, and/or the implementor of GSI projects in the form of cost savings.
- A second bottom line to reflect **social** impacts of an agency action, or the benefits and costs that accrue directly to households and residents (e.g., improved health outcomes or enhanced community aesthetics associated with GSI).
- A third **environmental** bottom line that reflects direct environmental benefits (e.g., improved water quality, carbon emissions reduction and sequestration benefits associated with GSI).

Figure 2-3 shows how the authors of this research have categorized the GSI benefits included in the Tool within this TBL accounting framework. In some cases, users of the Tool may wish to classify these benefits differently. For example, the authors classified benefits based on how they are monetized rather than their quantitative or physical value; air quality benefits are classified under the "social" bottom line because they are valued based on the avoided illnesses and associated health care costs that result from these improvements. However, the Tool also calculates pounds of air pollutant removal. Users may wish to communicate the physical values associated with different benefits, and to classify them within different TBL categories.

Financial	**Social**	**Environmental**
• Avoided infrastructure and/or treatment costs • Avoided maintenance and replacement of non-stormwater assets • Energy savings	• Improved air quality and related health benefits • Water supply benefits • Improved aesthetics and community sustainability/livability • Reduced urban heat stress and related public health benefits • Increased recreational opportunities • Green job creation • Flood risk reduction[a]	• Water quality and associated aquatic habitat improvements • Carbon emissions reduction and sequestration • Terrestrial and wetland ecosystem benefits.

Figure 2-3. Categorization of GSI Benefits Within a TBL Framework.

a. Flood risk reduction benefits are not included as a module in the Tool due to site-specific nature of this benefit. The Tool allows the user to enter flood reduction benefits directly so they can be included in overall benefit cost analysis

2.3 Economic Valuation Methods

The GSI TBL Benefit Cost Framework and Tool applies various approaches to monetize the different TBL benefits of GSI, including both market and non-market valuation techniques. Market prices can be used to value benefits that are directly traded in markets. For example, the Tool estimates the value of energy savings based on the local price for electricity and natural gas (i.e., $/kWh or $/Btu). However, many of the benefits of GSI need to be estimated using non-market valuation techniques (e.g., value of recreational trips). The following sections describe the non-market valuation methods the Tool relies upon to estimate the value of nonmarket goods and services related to GSI, including:

- Stated preference methods
- Revealed preference methods
- Avoided costs
- Benefits transfer

2.3.1 Stated Preference Methods

Stated preference methods rely on survey questions that ask individuals to make a choice, describe behavior, or state directly what they would be willing to pay for the non-market good or service being evaluated. Stated preference methods are based on the notion that there is some amount of market goods and services that people would be willing to trade off so they can benefit from a non-market good. This is often measured in terms of willingness to pay (WTP); stated preference studies typically yield average per-person or per-household WTP estimates for survey respondents. These estimates can be extrapolated to the wider study population to provide an indication of total non-market benefits or costs.

An advantage of stated preference methods is that they include the ability to estimate both use values and non-use values. For example, stated preference methods have been used to estimate WTP by recreationalists for water quality improvements that enhance water-based recreational activities (i.e., use values). They have also been used to estimate WTP for water quality improvements by individuals who do not necessarily participate in water-based recreation but who intrinsically value these improvements for the ecosystem or biodiversity benefits they provide (i.e., non-use values).

2.3.2 Revealed Preference Methods

WTP can also be inferred from choices people make in related markets. Methods that employ this general approach are referred to as revealed preference methods because values are estimated using data gathered from observed choices that reveal the preferences (i.e., WTP) of individuals for non-market goods and services.

The most common revealed preference methods are the hedonic pricing, travel cost, and averting behavior methods. Hedonic methods use statistical analysis to estimate the influence of different factors on observed market prices. For example, researchers often cite hedonic studies that infer the value of GSI by comparing price differences between properties that have incorporated GSI improvements (or that are located close to such improvements) and those that have not. These studies use hedonic models to isolate the effect of GSI on a property's market value while controlling for all other factors.

The travel cost method develops economic demand functions for recreation based on the choices people make to travel to a specific location. The essence of the method is recognition that users pay an implicit price by giving up time and money to take trips to specific areas to recreate. In relation to GSI, travel cost methods could be used to estimate how much more people are willing to pay to take recreational trips to areas that have better water quality or that have benefitted from stream restoration improvements.

The averting behavior method infers values from defensive or averting expenditures (e.g., expenditures made to avoid flood-related property damage or to reduce the potential for illness during extreme heat events). To the extent that averting behaviors are available, this method assumes that a person will continue to take protective action as long as the expected benefit exceeds the cost of doing so. If there is a continuous relationship between defensive actions and reductions in risks, then the individual will continue to avert until the marginal cost just equals his or her marginal WTP (or marginal benefits) for these reductions. The averting behavior method typically generates values that may be interpreted as lower bound estimates because averting expenditures only capture a portion of an individual's WTP to avoid harm and generally does not account for the loss of utility from pain and suffering.

2.3.3 Avoided Cost Methods

Avoided cost analysis determines the marginal cost of providing an equivalent service in another way. For example, retaining stormwater runoff through GSI practices can offset a utility's cost to capture, transport, treat and return runoff through gray infrastructure systems. Similarly, in areas where GSI is used to recharge groundwater for water supply purposes, this can offset (or delay) the need to draw upon or develop alternative sources of supply. When using avoided costs as a proxy for benefit values, analysts must carefully define a baseline scenario; this scenario must be consistently applied across benefit categories. Avoided costs should only be used to measure benefits when they would actually be incurred in absence of the planned GSI scenario.

2.3.4 Benefits Transfer Methods

An original stated preference or revealed preference study typically requires a significant amount of time, expertise, and financial resources. For this reason, researchers often use the *benefits transfer* approach to estimate non-market values. Bergstrom and De Civita (1999) offer the following definition of benefits transfer:

> *Benefits transfer can be defined practically as the transfer of existing economic values estimated in one context to estimate economic values in a different context …. In the case of natural resource and environmental policies and projects, benefits transfer involves transferring value estimates from a "study site" to a "policy site" where sites can vary across geographic space and or time.*

There are numerous challenges and cautions to consider when using benefits transfer (see EPA 2010). However, when implemented correctly, with the recognition that the estimates are not intended to be precise, benefits transfer is accepted as a suitable method for estimating non-market benefits in various contexts. Benefits transfer is commonly used in economics, and there is a well-developed literature on how to correctly apply this method (e.g., Rosenberger and Loomis, 2003; U.S. OMB, 2003).

2.3.5 Application of Economic Valuation Methods in Tool

It is not within the scope of this research to conduct original stated preference or revealed preference studies. The Tool therefore relies on market price, avoided cost, and benefit transfer methods to estimate the monetary value of GSI benefits. Figure 2-4 shows the methods applied in the valuation of each benefit category. In cases when benefits transfer is used, the original methodology upon which it is based is also shown. When more than one original valuation approach is indicated, this means that the Tool incorporates a range of values from various approaches or that different valuation methods are available in the Tool.

	Market price	Stated preference	Revealed preference	Avoided costs	Benefits transfer
Avoided infrastructure/treatment costs				●	
Asset life extension		●		●	
Energy savings	●			●	
Water supply benefits	●			●	
Improved air quality and related health benefits				●	●
Improved aesthetics and community sustainability/livability			●		●
Flood risk reduction				●	
Reduced urban heat stress and related public health benefits				●	●
Increased recreational opportunities		●			●
Green job creation	●				
Improved water quality		●			●
Carbon emissions reduction and sequestration				●	●
Terrestrial ecosystem and biodiversity benefits		●	●		●

Figure 2-4. Economic Valuation Methods for GSI Benefits.

CHAPTER 3

Key Steps and Considerations for Conducting TBL-Based Economic Analysis of GSI

There are several essential steps and considerations for conducting TBL-based benefit cost analyses of GSI programs. The GSI TBL Benefit Cost Framework and Tool focuses on quantifying and monetizing the benefits of GSI and appropriately comparing them to costs over a defined analysis period. This section describes the key economic principles upon which the Tool is based, as well as how principles are incorporated into the Tool.

3.1 Establishing the Baseline

Defining the baseline scenario is a critical first step to conducting a comprehensive economic analysis; it is often the key to revealing the benefits of a project or program. To define the baseline, the user must ask what steps would be taken to meet the same objectives if the planned GSI program is not implemented. For communities planning to use GSI to meet TMDLs, the without-project baseline may include installing additional wastewater treatment capacity to meet water quality goals. For communities aiming to reduce combined sewer overflows, the without project baseline may include installing greater amounts of “gray” infrastructure. In these instances, avoided costs from the without project baseline become benefits of the project.

An important aspect of defining the baseline is that it must reflect the future. The baseline is not the same thing as the “current” situation. Defining the baseline means looking into the years ahead, and since the useful lifetime of most water quality/stormwater investments typically is 20 or more years, a matching long-term timeframe needs to be applied for the baseline and GSI options. In addition, the baseline scenario has implications, and must be applied consistently, across benefits categories. In the simplified example of a baseline scenario that includes the use of gray infrastructure to meet water quality or quantity goals, the cost savings from foregoing the baseline gray infrastructure option can and should be included as a benefit of the GSI option.

There may also be a need to consider several aspects of the baseline scenario, beyond the primary water quality or quantity objectives. For example, in some cases, communities may use GSI to recharge local groundwater for water supply purposes. This can reduce or delay the need to develop alternative water supplies (e.g., more expensive surface water options). The user needs to clearly articulate what would happen if the additional recharged groundwater was not available (i.e., in absence of GSI) in order to understand and quantify GSI-related water supply benefits.

For each benefit category (as relevant), the Tool includes key questions and/or assumptions regarding the baseline or “without GSI” scenario. This starts with an understanding of the alternative stormwater infrastructure and/or water quality management actions that a municipality or utility would take in absence of the GSI option, which filters through to other benefit categories. For example, the Tool automatically calculates energy savings and related air quality improvements associated with implementing GSI over the baseline scenario. In some cases, such as with the water supply scenario presented above, the Tool includes questions related to the “without GSI option” to ensure that the user correctly accounts for any relevant avoided costs.

3.2 Developing a "GSI Scenario"

The next step is to establish a GSI Scenario for evaluation. As described earlier, different types of GSI practices result in different types and levels of benefits, as does the scale of implementation. Additional factors, such as study area population, climate, and other community characteristics also affect the types and level of benefits provided. The user's GSI Scenario must define several key components that serve as inputs into subsequent benefit calculations. This includes information related to the following:

- **Stormwater management goal.** Data requirements related to the user's stormwater management goals includes the total annual rainfall that results in runoff, the percentile storm that GSI is generally designed to capture, and the rainfall depth associated with that storm event. This information is necessary to calculate the annual volume of stormwater managed through the user's GSI Scenario, as well as the size/capacity of GSI practices.
- **The GSI management area.** The management area is the area over which GSI will be implemented. Key data requirements include the size and population of the management area, as well as the climate zone in which it is located. The size of the management area can be as large as a watershed or city, or as small as a neighborhood area. It does not need to consist only of the GSI drainage area; for example, it may consist of a watershed or neighborhood where multiple GSI installations will manage some portion of impervious area.
- **GSI practices and scale of implementation**. At a minimum, users must enter the effective impervious area managed by GSI practice type (as relevant) or the number of practices installed (for trees and stormwater harvesting systems only). The Tool uses default design specifications to estimate additional information by practice type, including total volume capacity, footprint/size, and annual runoff volume managed. Users can change the design specifications and/or overwrite these calculations using site-specific data or information obtained through stormwater models (e.g., EPA's Stormwater Management Model [EPA, n.d.] or CLASIC). Importantly, the Tool can be used to analyze the benefits of a GSI at the neighborhood, watershed, or citywide scale. If a user wishes to analyze benefits associated with multiple projects across a watershed or neighborhood, they must simply aggregate the effective impervious acres managed by practice type across all projects. If a user desires to compare benefits and costs of multiple alternatives, he or she would need to run the Tool separately for each alternative.

3.3 Identifying Relevant Benefits and Costs to Include in the Analysis

The Tool identifies the range of GSI benefits applicable to the user's GSI Scenario based on the type of GSI practices they plan to implement (Figure 3-1), the scale of the program, and other factors defined as part of the user's GSI Scenario. However, the user has the option to exclude benefits from the analysis, as desired. For example, the user may not want to include benefits that may have a large degree of uncertainty associated with them, are small and somewhat insignificant (i.e., they may not be worth quantifying), or that are politically or culturally sensitive. In these cases, it is important to recognize potential impacts or benefits through qualitative characterization.

In addition, the user may have additional benefits and/or costs of GSI that he or she may want to include in the analysis. For example, the Tool does not include methods for quantifying and/or monetizing benefits associated with flood risk reduction, crime reduction, noise attenuation, or educational value, although evidence from the literature suggests these benefits can be achieved with GSI. In addition, the Tool does not quantify or monetize any disservices of GSI, such as any construction-related disruption that may occur due to the distributed nature of GSI. While it may not be possible to value these benefits/costs, the user may characterize them qualitatively, as discussed below.

Finally, the Tool includes lifecycle cost data (based on data and information from CLASIC) that it applies to the user's GSI scenario. This includes upfront capital costs (e.g., planning, design, construction, and establishment costs), as well as ongoing maintenance and replacement costs. The user can also input their own cost data.

The Tool identifies the economic benefits associated with a user's GSI scenario based on the "benefits pathway" for different GSI practices. The example below shows how a specific GSI practice (e.g., tree planting) results in physical benefits, such as improved air and water quality, increased shade and cooling, and enhanced aesthetics, among others. Following the "cooling" pathway, the multiple outcomes associated with tree planting can be examined. For example, trees in urban settings can reduce temperatures and provide shade. This in turn can result in decreased energy use for cooling in buildings (when located appropriately) and can reduce heat-related illnesses (including fatalities associated with extreme heat events). Energy savings reduce costs for building owners, and reduce emissions associated with energy use. Reduced emissions improve air quality, resulting in health benefits, which can be monetized based on avoided health costs. And so on. Tracing these pathways allows the user to identify how the benefits of GSI are linked, as well as where they overlap. For example, while tree planting improves urban aesthetics, which can result in enhanced property values, the other benefits of trees can also result in increased property values. The Tool accounts for these linkages and overlaps.

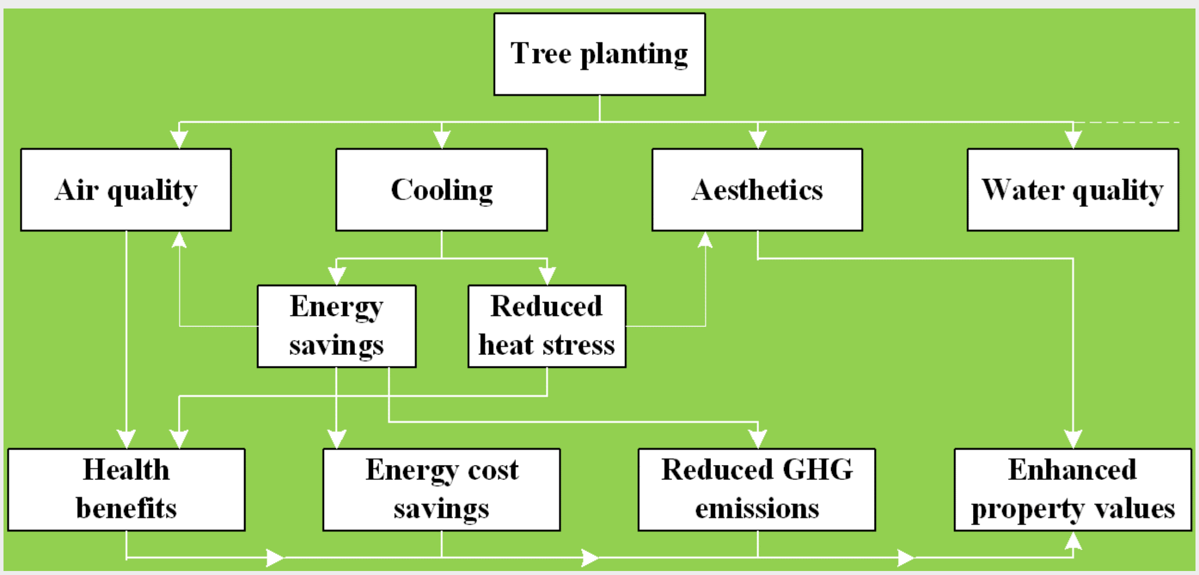


Figure 3-1. Benefits Pathway for GSI Practices.

3.4 Quantifying and Monetizing Benefits and Costs

The first step to valuing a benefit or cost is to establish the physical quantities or outcomes associated with it. Physical outcomes associated with the benefits of GSI may include, for example, tons of carbon sequestered, pounds of pollutants removed from the air, or the number of recreational user outings enabled by enhanced instream flows or water quality. These metrics serve as the initial step in the valuation process; it is therefore important to match the quantity units of measurement to whatever metric is available for the corresponding dollar values. Figure 3-2 shows the physical outcomes associated with each GSI benefit category included in the Tool; in some cases, these outcomes may resonate better with stakeholders compared to compared to casting everything in monetary terms.

Benefit category	Quantification unit
Avoided infrastructure/treatment costs	No quantity outcomes; valued in dollars only
Asset life extension	No quantity outcomes; valued in dollars only
Energy savings	Electricity savings (kWh) Natural gas savings (kBtu)
Improved air quality and related health benefits	Sulfur dioxide (SO_2) emissions reductions (metric tons) Nitrogen oxides (NOx) emissions reductions (metric tons)
Water supply benefits	Potable water supply offsets (gallons or acre-feet) Groundwater recharged (gallons or acre-feet)
Improved aesthetics and community sustainability/livability	Properties located adjacent to GSI improvements Percentage increase in property values
Flood risk reduction	Forthcoming
Reduced urban heat stress and related public health benefits	Change in minimum mortality temperature associated with increase in vegetation Avoided heat-related fatalities Avoided heat-related illnesses
Increased recreational opportunities and enjoyment of green space	Number of additional recreational trips taken (user days)
Green job creation	Number of GSI-related jobs created
Improved water quality	Incremental improvement on 10-point water quality ladder WTP per household
Carbon emissions reduction and sequestration	CO_2 emissions reductions (metric tons) CO_2 sequestered (metric tons)
Terrestrial and wetland ecosystem and biodiversity benefits	Area of terrestrial habitat created (acres)

Figure 3-2. Physical Outcomes Associated with GSI Economic Benefits.

Once the physical benefits have been estimated, a per unit dollar value often can be assigned to the benefit or cost to reach a total value (quantity times per unit value). The Tool (and associated guidance and documentation) present the user with appropriate literature, methodologies, and data for quantifying and monetizing each GSI benefit. The Tool provides advice and guidance on how to approach each benefit, recognizing that the valuation approaches differ across benefit categories and that each GSI scenario will have location-specific elements that must be considered. For each benefit category, and as detailed in the accompanying technical appendices, the authors have attempted to be explicit and reasonable about the assumptions and approaches incorporated into the Tool.

3.5 Qualitatively Describing Key Benefits and Costs

As noted above, it may not be feasible or desirable to express some types of benefits or costs in quantitative or monetary terms. However, it is always important to describe these non-quantified benefits and costs in a meaningful, qualitative manner. Benefits and costs may be described qualitatively, in part, by using a simple scale indicating the likely impact on net project benefits. For example, impacts can be qualitatively ranked on a 5-point scale, ranging from -2 to +2, to reflect unquantified relative outcomes that span from very negative to very positive (e.g., a "-1" may signify an outcome with moderate unquantified costs, and a "+2" may represent a high unquantified benefit). More complex or sophisticated rankings or methods, such as multi-criteria decision analysis, can also be applied (but may not be necessary). In any case, qualitative ratings should be accompanied by descriptions of the impact and should be explicitly carried through the analysis.

Because the focus of the GSI TBL Benefit Cost Tool and Framework is to provide methodologies for quantifying and monetizing GSI benefits, it does not include extensive guidance on incorporating qualitative benefits into economic analysis. Future iterations of the Tool could include additional resources on this topic, such as applying multi-criteria decision making into the assessment of GSI projects to account for non-quantified benefits.

3.6 Comparing Benefits and Costs Over Time

The benefits and costs of GSI programs will occur as a stream of values that change over time. On the cost side, GSI programs may have larger upfront capital costs that are expended in the earlier years of the program, depending on the implementation schedule; in some cases, these costs may be spread over an amortization period. Benefits typically accrue over the life of project, and in the case of some GSI practices, continue to grow over time as vegetation becomes established and continues to grow. As with costs, benefits will also vary based on the planned implementation schedule (e.g., as more projects come online).

Values that occur in different time periods need to be adjusted to comparable "present values". There are two interrelated factors to consider when comparing values from different times – inflation and the "time value of money." When inflation is included in projecting values over time, the values are said to be in "nominal" terms. Many financial analyses are conducted in nominal dollars. However, for economic analyses, benefits and costs are normally not entered in nominal dollars. The use of "real" dollars (i.e., where no inflation rate is applied) makes analyses easier and keeps inflation-related projections from clouding the analysis.

The second factor to account for in comparing values over time is the fact most people prefer a dollar today more than an inflation-adjusted dollar available in the future. This is because they can use that dollar to consume today, or they can invest that dollar today to yield a higher return. This preference for near-term consumption over deferred consumption is referred to as the "social rate of time preference" or the "time value of money." This social rate of time preference is the real (i.e., inflation free), net of tax, and risk-free rate of interest that would need to be paid to a person to entice them to consider delayed receipt of a real dollar. The annual rate at which present values are preferred to deferred values is known as the discount rate (and is similar to an interest rate). The greater the preference for immediate benefits (time preference), or the greater expected rate of return on other investments today, the greater the discount rate.

To compare streams of value over time from different projects, the stream of values for each project is discounted to "present value" using the discount rate. If both benefits and costs are involved, the present value of the costs is subtracted from the present value of the benefits to get the net present value (NPV) of the project. If the NPV of a project is greater than zero, then the present value of the benefits is greater than the present value of the costs. The NPV of different projects can be compared if they are adjusted to be in the same year's dollars. Comparison of NPV of projects allows apples-to-apples comparisons of project values regardless of possible differences in the timing of benefits and costs for each project.

The Water Resources Planning Act of 1965 and the Water Resources Development Act of 1974 require an annual determination of a discount rate for Federal water resources planning. This discount rate is based on the average yield during the preceding fiscal year on interest-bearing marketable securities of the U.S. that have terms of 15 years or more remaining to maturity at the time the computation is made.[1] For fiscal year 2020, the discount rate for Federal water resources planning is 2.75% (USBR 2019).

The Tool uses 2.7% as the real discount rate (although this can easily be changed by the user) and automatically calculates present value benefits and costs based on several key inputs from the user, including the year in which the project is initiated, the length of the project planning/construction period, and the desired analysis period (e.g., in years).

In addition to the present value of monetized benefits and costs, when assessing benefits and costs of GSI, it is important to consider the timeline over which benefits accrue. This is particularly important for trees, which provide increased levels of benefits as they grow and mature. The Tool accounts for tree growth and other changes in GSI practices over time, as relevant, when calculating benefits and costs. This methodology is described in detail in the relevant appendices and the Tool guidance (to some extent).

3.7 Conducting Sensitivity Analysis

Analyses of social and environmental benefits invariably require the use of assumptions and approaches that interject uncertainty about the accuracy or comprehensiveness of the empirical results. In an ideal situation, data would be available to statistically estimate confidence intervals for benefit or cost estimates. However, statistically estimated confidence intervals are most often not possible. When it is possible with available data, ranges should be developed for an estimate by stating the upper and lower bounds. When bounding of an estimate is not possible, one can at least characterize uncertainty qualitatively by describing the sources of uncertainty and stating whether an estimate developed is likely to over- or under-estimate the true value.

In many cases it will be useful to explore the impact of uncertainties or key assumptions through sensitivity analysis or scenario analysis. Sensitivity analysis involves systematically changing the value of a key input to see how it affects the outcome of the analysis. The change in results associated with the change in inputs can illuminate how important the impact of uncertainty in a particular variable is to the outcome. Sensitivity analysis is often performed by varying an input by equal amounts greater to and less than the current value. For example, if a discount rate of 6% has been chosen for the main analysis, that value might be varied in increments of 3 percentage points from 3% to 9% for the sensitivity analysis. Scenario analysis is similar to sensitivity analysis; however, rather than focusing on a single input at a time, scenario analysis examines the effect of changing several input variables on the outcome of the analysis.

For each benefit category, as relevant, the Tool includes key input variables and uncertainties that the user may want to consider for sensitivity analysis. In addition, the user can change most of the required inputs in the Tool, including inputs that have default values associated with them.

3.8 Additivity and Double Counting

The benefits calculated within the Tool are generally additive, meaning they can be added together to generate a total value. However, as noted above, many of the GSI benefit categories, and associated valuation methods, are interconnected (and to some extent may overlap) and must be carefully accounted for. For example, the anticipated energy savings enjoyed at tree-shaded properties and enhanced opportunities for GSI-related recreation may be capitalized into the property values for those residences. At the same time, the property value analysis does reflect some unique values that are not

[1] The rate is also not allowed to change by more than one-quarter of 1% in any year

embodied in the other estimated categories (e.g., enhanced aesthetics). Thus, the interpretation of the property value estimates must be carefully considered. The Tool includes a scaling factor so that only a portion of property value benefits are counted in the overall benefit-cost analysis.

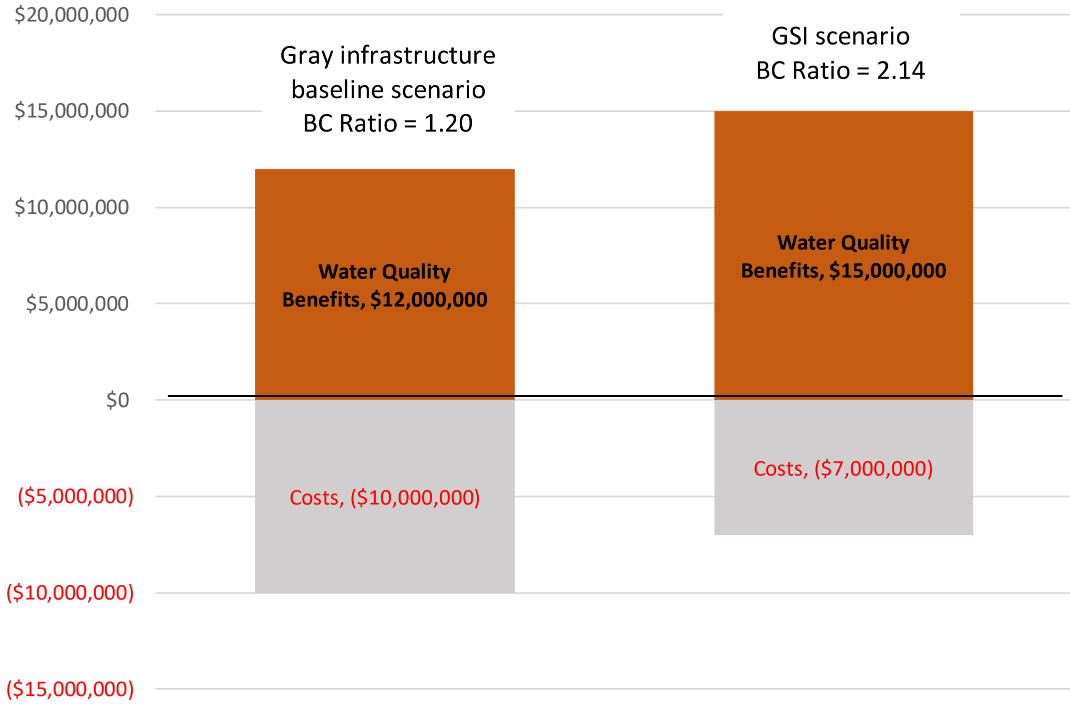
Proper accounting of benefits is also necessary to ensure against double counting. For example, any avoided gray infrastructure costs associated with a GSI scenario should include cost savings associated with reduced energy use (e.g., from reduced pumping and treatment of wastewater in CSO communities). However, reductions in energy use also result in avoided emissions from power plants. Thus, it is necessary to quantify these energy savings in the energy savings benefits module (and to ultimately translate them into air quality benefits), but to make sure that the associated financial savings are only accounted for in one place (i.e., the avoided infrastructure and treatment costs benefits module).

In addition, there are different ways to account for avoided gray infrastructure costs associated with a GSI scenario. Specifically, it depends on whether the user is comparing two alternatives (i.e., a gray infrastructure and GSI scenario) or evaluating the benefits of a GSI alternative on its own. When directly comparing two alternatives, this benefit is accounted for by comparing the costs of each alternative. When evaluating a GSI alternative on its own, avoided costs can be accounted for on the benefits side of the ledger. If the user plans to compare the results of the Tool to the benefits and costs associated with a gray infrastructure alternative, avoided gray infrastructure costs should not be included as a benefit of the GSI scenario.

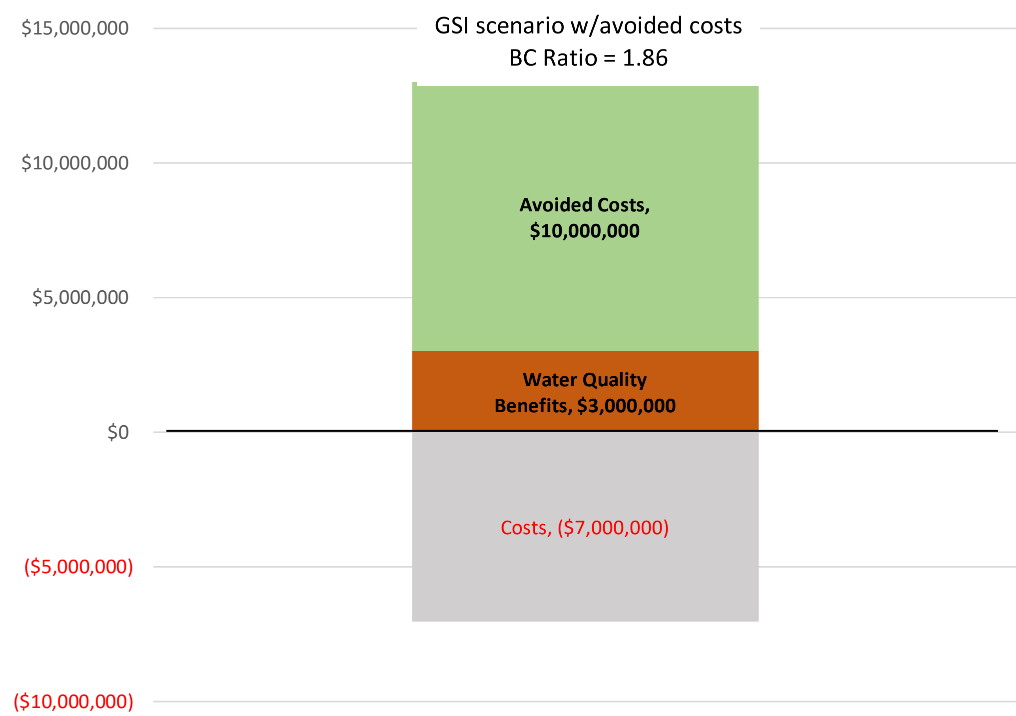
Similarly, if avoided gray infrastructure costs are included as a benefit of a GSI scenario, then the full amount of water quality benefits associated with the GSI scenario cannot be included on the benefits side of the ledger. Presumably, any avoided stormwater management scenario (e.g., a gray infrastructure scenario) would also result in water quality benefits. If avoided gray infrastructure costs are included in the assessment of GSI benefits, then only the *difference* in water quality benefits between the GSI scenario and the avoided gray infrastructure alternatives should be included in the GSI benefit cost analysis. Another way to handle this is to compare the two alternatives directly, accounting for the full costs and benefits of each alternative. Figure 3-3 presents a simple depiction of this concept, with both methods correctly accounting for benefits and costs.

3.9 Benefits and Scale of GSI Implementation

Many of the co-benefits associated with GSI depend on the scale of implementation. For example, to realize benefits associated with urban heat stress reduction, municipalities or utilities must implement enough GSI to result in a measurable cooling effect. Several studies that have analyzed urban heat reduction strategies have found that a 10-percentage point increase in urban surface reflectivity (e.g., increase in vegetation) within a study area can reduce peak temperatures, resulting in fewer excessive heat events. To address this issue for urban heat stress reduction, the Tool allows the user to indicate whether they are concentrating GSI within a specific portion of their management area such that it would result in at least a five-percentage point increase in surface reflectivity in the relevant area, before benefits are counted. Benefits are then scaled up to the 10-perecentage point increases.



(a) Direct comparison of two stormwater management alternatives



(b) Benefits and costs of GSI scenario only (avoided costs included on "benefits side of ledger")

Figure 3-3. Proper Accounting of GSI Benefits and Comparison of Alternative Stormwater Management Scenarios.

However, it is important to note that the user may be analyzing a project that is part of a larger GSI-based plan. In this case, the total benefits associated with the larger plan can be allocated across the projects that make up the plan, when they are being analyzed on an individual basis. In addition to urban heat stress, this is the case for the valuation methodology included in the Tool for water quality improvements. This methodology is based on household WTP for larger scale (e.g., citywide) water quality improvements. The Tool guidance provides users with guidance for assigning water quality benefits to an individual projects or projects that contribute to larger city- or watershed-wide water quality goals.

There are also several benefits that require a significant number of GSI installations before they become significantly measurable as part of a benefit-cost analysis but that scale linearly as more GSI projects come online. For example, the building energy savings associated with trees can seem relatively insignificant on an individual tree basis (e.g., on the order of 15 to 35 per year per tree). Thus, adding one tree to a bioretention cell will not result in significant energy saving benefits; however, the addition of 100 trees across a project site or within the public ROW can begin to add up. Other benefits that scale relatively linearly include air quality, green jobs, carbon reduction, and water supply benefits.

CHAPTER 4

Background and Methods for Quantifying and Monetizing Benefits

This section provides background and describes the methods for quantifying and monetizing the TBL benefits of GSI, as follows:

FINANCIAL

- Avoided stormwater or wastewater infrastructure and treatment costs
- Asset life extension
- Energy savings

SOCIAL

- Water supply benefits (including through stormwater reuse and groundwater recharge)
- Improved air quality and related health benefits
- Improved aesthetics and community sustainability/livability (as measured through increased property values)
- Reduced urban heat stress and related public health benefits
- Increased recreational opportunities and enjoyment of green space
- Green job creation
- Flood risk reduction

ENVIRONMENTAL

- Water quality and associated aquatic habitat improvements
- Carbon emissions reduction and sequestration
- Terrestrial and wetland ecosystem and biodiversity benefits

The following sections describe the link between GSI and each benefit category, identify relevant GSI practices (i.e., the practices that provide each benefit), and describe the methods and data incorporated into the Tool for quantifying and monetizing each benefit.

4.1 Avoided Costs for Conventional Stormwater Management

GSI reduces the amount of stormwater entering sewer systems and local waterways. This in turn can reduce the need (and associated costs) for traditional or gray infrastructure practices that would otherwise be necessary to meet municipal water quality and/or quantity goals. In communities with combined sewers, GSI practices can also reduce costs associated with pumping and treating stormwater at wastewater treatment plants (WWTPs). The key to quantifying these avoided costs is to clearly define the baseline “without GSI project scenario.” To define the baseline, the user must ask what steps would be taken to meet the same objectives or stormwater management goal if the planned GSI program is not implemented.

4.1.1 Relevant GSI Practices

All GSI practices

4.1.2 Benefits Quantification

The type of gray infrastructure that GSI offsets will vary based on the size of the user's management area and total stormwater volume managed. In addition, the sizing of many traditional infrastructure practices (i.e., conveyance pipes and detention basins) is determined based on peak flow rates rather than storage capacity for an estimated volume of runoff. Thus, some level of hydrologic modeling or calculation is needed to accurately determine the type and level of stormwater infrastructure that will be avoided through GSI implementation. It is beyond the scope of this research to incorporate these methods into the Tool; instead, the Tool applies simple assumptions based on impervious area and total volume of stormwater managed to help users estimate baseline stormwater management needs. For CSO communities, the Tool allows users to indicate the percentage of impervious area or stormwater volume that would otherwise be managed through large-scale CSO reduction projects (e.g., deep tunnels or sewer separation). It also calculates avoided pumping and treatment based on the annual volume of stormwater managed through GSI.

4.1.3 Monetary Value

The costs of a "without GSI project scenario" vary depending on site- and community-specific factors. Thus, the ideal situation is for users to directly enter the costs associated with their baseline scenario into the Tool using community-specific data. For users who do not have this data available, the Tool provides default values for avoided CSO reduction projects and applies national average costs for other conventional stormwater management approaches based on impervious area managed (i.e., $/sq ft). The Tool incorporates avoided capital and annual O&M costs over the study period to estimate this benefit.

4.1.4 Additional Considerations

There are different ways to account for the gray infrastructure costs that GSI projects avoid. When directly comparing a gray infrastructure alternative to a GSI alternative, this benefit is accounted for by comparing the costs of each alternative. When evaluating a GSI alternative on its own, avoided costs can be accounted for on the benefits side of the ledger. If the user plans to compare the results of the Tool to the benefits and costs associated with a gray infrastructure alternative, avoided gray infrastructure costs should not be included as a benefit of the GSI scenario. This would result in a double counting of benefits/costs. Similarly, as described above, if a user includes avoided costs as a benefit of a GSI scenario, then only the difference in water quality benefits between the two alternatives should be included as a benefit of the GSI scenario.

$ 4.2 Avoided Maintenance and Replacement Costs for Non-stormwater Assets

For most GSI practices, avoided replacement and maintenance costs are captured through the assessment of avoided costs associated with a baseline or "without GSI project" scenario, as described in the previous section. Green roofs and permeable pavement are an exception because their traditional alternatives are not related to stormwater management - i.e., traditional roofs and regular pavement or asphalt would not be included as an avoided stormwater management practice in a gray infrastructure baseline alternative.

4.2.1 Relevant GSI Practices

- Green roofs
- Permeable pavement

4.2.2 Benefits Quantification and Monetization

Evidence suggests that both green roofs and permeable pavement (in some cases) can last longer than their traditional alternatives. For example, several studies report that green roofs can last 40 years or more, while the life span of a traditional roof is typically less than 20 years (David Evans and Associates 2008, U.S. GSA 2011, CNT 2009). Based on this assumption, a conventional roof would need to be replaced or significantly repaired once over the period of a green roof's expected life. A study of the benefits of extensive green roofs in Portland (David Evans and Associates 2008) estimated that for a 40,000-square-foot roof, the avoided present value cost of not having to replace a conventional roof after 20 years would amount to about $667,000 (2019 USD).

The Tool includes replacement costs for traditional roofs an avoided cost associated with the user's GSI scenario. It assumes that green roofs are implemented at the time a traditional roof would have been replaced or rehabilitated. Thus, initial avoided capital costs are not included in the calculation. The Tool provides default values for the useful life of traditional roofs and green roofs, as well as for avoided replacement costs (per sq. ft.). The user can change these values based on local and site-specific data.

While some estimates show that permeable pavement (particularly permeable asphalt) can last longer than its traditional alternative, others have shown that permeable pavement (particularly permeable concrete) has a shorter useful life. There are few sources available that document the useful life of permeable pavement alternatives. The Tool therefore does not include avoided replacement costs associated with permeable pavement because additional research is needed to accurately assess these benefits.

In addition to avoided replacement costs, green roofs and permeable pavement offset costs associated with traditional roof and pavement maintenance. The Tool applies annual avoided maintenance costs for traditional roofs, concrete, asphalt streets, and asphalt parking lots (per sq. ft.) based on estimates from the literature. The user can change these assumptions based on local cost data and site-specific conditions, including the type of pavement that permeable pavement would be replacing.

4.2.3 Additional Considerations

In some cases, green roofs and permeable pavement may be more expensive to maintain than their more traditional alternatives. However, the cost of maintaining traditional roofs and pavement will still be avoided when alternative GSI practices are implemented. They therefore should be included as a benefit under the GSI scenario. In combination with other benefits, these avoided costs can contribute to a greater benefit cost ratio.

$ 4.3 Building and Utility Energy Savings

Green roofs and trees can help shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. In cities with combined sewers, diverting stormwater from wastewater collection, conveyance, and treatment systems reduces the amount of energy needed to pump and treat the water. Rainwater harvesting systems that offset potable water use reduce energy demand for drinking water treatment and distribution.

4.3.1 Relevant GSI Practices

- Trees and green roofs (building energy savings)
- All GSI practices (avoided stormwater/wastewater treatment and pumping)
- Rainwater harvesting systems (avoided energy use for drinking water treatment and distribution)

4.3.2 Benefits Quantification: Building Energy Savings

To quantify tree-related energy savings, the Tool relies on extensive research conducted by the U.S. Forest Service (USFS) on the energy savings associated with trees by climate region. The data included in the Tool represents averages across different types and sizes of trees, the location of trees relative to buildings, and building characteristics. For green roofs, the Tool uses data from the Green Roof Energy Calculator (ASU, n.d.), which is based on extensive modeling that accounts for differences in local climate and building and roof characteristics.

4.3.3 Benefits Quantification: Utility Energy Savings

Energy use associated with stormwater and wastewater pumping and treatment can vary significantly based on local topography, level of treatment required, and other site-specific factors. Energy demands for drinking water treatment also vary by supply source (i.e., groundwater, surface water). The Tool quantifies utility energy savings associated with avoided pumping and treatment using published energy intensity estimates that vary by WWTP size/capacity. For drinking water, the Tool applies average intensity estimates based on the source of supply avoided. In both cases, the user can enter community-specific data to estimate energy savings.

4.3.4 Monetary Value

The value of GSI-related energy savings is reflected in the direct financial savings associated with reduced energy use. The Tool calculates financial savings from reduced building energy use based on average retail and commercial energy prices by state (EIA 2019). The monetary value of utility energy savings is accounted for in the calculation of avoided infrastructure/treatment costs and water supply benefits. Thus, utility energy savings are not monetized in the energy savings module. However, the reduction in utility energy use provides air quality and associated health benefits; it is therefore necessary to quantify this reduced energy demand.

4.3.5 Additional Considerations

In areas where GSI is used to recharge groundwater for water supply purposes, energy savings may result if the groundwater recharge results in a less-energy intensive source of water supply. The Tool does not account for this benefit; however, it can be calculated by the user if information on comparative energy use is available. In addition, reductions in energy use result in decreased greenhouse gases and other air pollutant emissions from power plants. These benefits are accounted for in the calculation of CO_2 reduction and air quality benefits.

4.4 Water Supply Benefits

GSI practices can provide important water supply benefits. For example, water collected in rainwater harvesting systems (rain barrels and cisterns) can be used for outdoor irrigation, as well as for several (non-potable) indoor uses. This can significantly reduce potable water demand for households, businesses, and other water users. In addition, water infiltrated into the soil through GSI practices can augment local groundwater, which serves as an important source of water supply in many communities.

4.4.1 Relevant GSI Practices

- Rainwater harvesting systems (potable water supply offsets)
- GSI practices that recharge groundwater (bioretention, rain gardens, wet ponds, and wetlands)

4.4.2 Benefits Quantification: Potable Water Supply Offsets

The water supply benefits of rainwater harvesting systems depend on the quantity and timing of on-site water demand relative to the quantity and timing of stormwater runoff available for capture. These factors are influenced by local climate, total rainfall, distribution of rainfall depths, system storage capacity, and system operation. To account for these factors, the Tool incorporates data from a study of the benefits of rainwater harvesting systems in more than 70 cities across the U.S. This data translates the volume of stormwater captured by rainwater harvesting systems into potable water supply offsets based on local conditions.

4.4.3 Benefits Quantification: Groundwater Recharge for Water Supply Purposes

The extent to which groundwater recharge augments local water supplies depends on the degree to which the recharge area is hydrologically connected to aquifers used for water supply. In aquifers connected to local streams, groundwater recharge can increase base flow, making additional water available for downstream users. Annual rainfall and land use patterns also affect the amount of runoff available for groundwater recharge. The Tool approximates groundwater recharge based on the volume of stormwater managed by relevant GSI practices and applies efficiency factors to account for different infiltration capacities by soil type.

4.4.4 Monetary Value

Offsetting potable water use and/or recharging groundwater can increase water supply reliability, reduce the need for additional water infrastructure, and/or avoid the development of alternative water supplies. The value of these benefits can be monetized based on the market price of water, the avoided cost of alternative water supplies, and/or estimates of household WTP to avoid water shortages. The appropriate valuation method depends on the level of water scarcity in the region, local water and infrastructure costs, and other factors. The Tool incorporates different methods and considerations for valuing water supply benefits.

4.4.5 Additional Considerations

As noted above, groundwater recharge benefits depend on the extent to which the recharge area is hydrologically connected to aquifers used for water supply. This cannot be estimated in a national level tool and requires input and judgement from the user. Further, the Tool does not incorporate values associated with groundwater recharge and related to increases in stream flow. However, the user can incorporate the percentage of stormwater volume that they expect to result in off stream uses into the groundwater recharge estimation.

4.5 Air Quality Improvements and Related Health Benefits

Trees and other vegetation can improve air quality in several ways, including:

- Reducing emissions (e.g., SO_2 and NO_x) from power plants by reducing energy consumption for heating and cooling and stormwater collection and treatment
- Absorbing gaseous pollutants [e.g., ozone (O_3), carbon monoxide (CO), NO_2, SO_2] through leaf/vegetated surfaces
- Intercepting particulate matter (PM, e.g., dust, ash, dirt, pollen, smoke)

The public health and environmental impacts of specific air pollutants are well-documented. NO_x and SO_x contribute to adverse respiratory and cardiovascular effects; ground-level O_3 and PM are linked to premature deaths, chronic bronchitis, asthma, respiratory infections, and other illnesses. O_3 can also damage crops and increase the vulnerability of some tree species to various diseases; PM can reduce visibility in urban areas.

4.5.1 Relevant GSI Practices

- All GSI practices that reduce energy use (as calculated in Benefits Module 3: Energy Savings)
- Trees and vegetated GSI practices (green roofs, rain gardens, bioretention, and wetlands)

4.5.2 Benefits Quantification: Energy-Related Emissions Reductions

Emissions associated with power generation can vary significantly based on fuel resource mix and other power plant characteristics. The U.S. EPA and EIA track pollutant emission rates (i.e., pounds of pollutant emitted per MWh or MMBtu generated) for almost all power generation in the U.S. These agencies publish emission rates at various geographic scales. The Tool applies this data (by power grid region) to estimate emission reductions associated with GSI-related energy savings.

4.5.3 Benefits Quantification: Pollutant Removal from Trees & Other Vegetation

Extensive research by the USFS shows that pollutant removal from trees and other vegetation varies based on local climate, ambient pollution concentrations, and other factors. USFS researchers have used computer simulations and local environmental data to estimate tree pollutant removal rates (g/m^2 of tree canopy) for every county in the co-terminus U.S. The Tool applies this data to the average canopy size for common tree species in different climate regions. To estimate air quality improvements for other vegetated GSI practices, the Tool applies findings from a limited number of studies.

4.5.4 Monetary Value

Reductions in NO_x, SO_x, $PM_{2.5}$, and O_3 can directly reduce the risk of adverse human health effects. The benefit of reducing these pollutants can therefore be valued based on associated reductions in health-related costs and/or WTP to avoid specific health outcomes. The Tool relies on data from the U.S. EPA to translate pollutant reductions into specific health outcomes and associated monetary values. This data is serves as the basis for U.S. EPA's Environmental Benefits Mapping and Analysis Program – Community Edition, a model that calculates the number and economic value of air pollution-related deaths and illnesses.

4.5.5 Additional Considerations

The monetary value of air quality benefits is based on associated reductions in adverse health outcomes. This methodology does not include the value of environmental damages caused by pollutants (e.g., crop damage). Finally, GSI-related energy savings also reduce CO_2 and other greenhouse gas (GHG) emissions from power plants; CO_{2e} emissions reductions are included in the carbon reduction benefits calculation.

4.6 Enhanced Aesthetics

Trees and plants improve urban aesthetics and community livability, which can result in increased sale prices and rental rates for homes and commercial spaces. Simply put, people are willing to pay more to live and work in places with more greenery. The Tool applies findings from hedonic studies to estimate the aggregate potential increase in property values associated with GSI improvements.

4.6.1 Relevant GSI Practices

Trees, bioretention, rain gardens, green roofs, wet ponds, and wetlands

4.6.2 Benefits Quantification

To quantify the total (aggregate) value associated with property value increases, it is necessary to determine the number of properties affected by different types of GSI improvements. The Tool helps the user estimate the number of properties affected based on the increase in greened acreage, treed area, and/or number of green roofs added. The Tool allows the user to identify two tiers of properties – a percentage located directly adjacent to GSI improvements, as well as those located a bit further away. In addition, users may opt to exclude certain areas where GSI improvements will not likely result in additional property value benefits (e.g., higher income, well-vegetated neighborhoods).

4.6.3 Monetary Value

To calculate property value increases associated with GSI, the Tool provides guidance to help users estimate baseline property values for single family and multi-family properties. Next, the Tool applies relevant percentage increases to the percentage of properties affected by GSI improvements. The range of values applied in the Tool depends on a series of inputs from the user, as well as the characteristics of the user's GSI scenario. For example, the Tool applies a weighted average percentage increase based on the mix of GSI practices included in the GSI scenario (e.g., trees and green roofs realize a higher percentage increase as compared to bioretention). The Tool allows the user to apply a slightly lower increase to the percentage of properties located outside directly affected areas. This is consistent with literature findings showing a "decay" of benefits the further the property is from an amenity.

4.6.4 Additional Considerations

Property value increases can reflect a WTP for a range of benefits associated with GSI, including many of the benefits incorporated elsewhere in the Tool. For example, changes in property values linked to GSI can reflect associated differences in neighborhood aesthetics, air quality, energy usage, recreation opportunities, and other benefits. Thus, to simply add property value benefits to the other GSI benefits would be double counting. Property value increase are intended to measure benefits not already captured in the Tool, such as those stemming from aesthetic improvements, reduced crime, or other characteristics. To reduce the potential for double counting, the Tool includes 70% of property value benefits in the final GSI benefit-cost ratio, although this can be adjusted by the user.

Increased property taxes will result in increased revenues for local governments. Property taxes do not represent additional benefits of GSI, but rather a transfer or redistribution. However, based on local milling rates, the user can determine associated increases in tax revenues, if desired.

Finally, analysis of property values may bring up important concerns regarding equity and potential gentrification. As noted previously, the valuation methodology included in the Tool does not specifically address distributional impacts and/or equity concerns. This is an important research topic and continues to be explored by leaders in the water sector.

4.7 Urban Heat Stress Reduction

Many GSI practices create shade, reduce the amount of heat absorbing materials, and emit water vapor, all of which cool hot air and reduce the urban heat island (UHI) effect. In many areas, this cooling effect is enough to reduce heat stress-related fatalities and illnesses during extreme heat events (EHEs).

4.7.1 Relevant GSI Practices

Trees, rain gardens, bioretention, wetlands, green roofs

4.7.2 Benefits Quantification

To estimate avoided fatalities associated with GSI implementation, the Tool relies on data provided by the U.S. EPA on the baseline (and projected) relationship between extreme heat and fatalities in 49 U.S. municipalities (reference municipalities). The Tool also applies data from existing studies to establish a link between planned increases in vegetation and surface reflectivity under the user's GSI Scenario and reductions in urban temperatures, by climate region. The Tool uses this data to calculate the change in extremely hot days each year within the user's reference municipality (compared to the baseline) and the associated change in annual heat-related fatalities.

To estimate the reduction in heat-related illnesses, the Tool uses state-level data from the Center for Disease Control to calculate the ratio of heat-related fatalities to heat-related emergency room visits and hospitalizations. The Tool applies this ratio to the estimated number of heat-related fatalities, as calculated in the previous step.

4.7.3 Monetary Value

To monetize avoided fatalities, the U.S. EPA applies estimates of how much people are willing to pay for small reductions in mortality risks; this is often referred to as the "value of a statistical life" (VSL). This is not an estimate of how much money any single individual or group would be willing to pay to prevent the certain death of any particular person. Rather, VSL represents an aggregate dollar amount that a large group of people would be willing to pay for a reduction in their individual risks of dying in a year, such that one fewer death among the group during that year would be expected (on average, U.S. EPA 2019). To estimate the value of avoided heat-related fatalities, the Tool applies the current VSL dollar value of $10.2 million per avoided death. The monetary value of avoided heat-related emergency room visits and hospitalizations is based on U.S. EPA data on associated reductions in health-related costs and/or WTP to avoid specific health outcomes.

4.7.4 Additional Considerations

The data and analyses upon which the quantification and monetization of UHI reduction benefits is based is subject to several limitations. First is a lack available data for many municipalities and regions. Further, the Tool assumes that GSI would be located in areas where it will result in UHI benefits (e.g., locating GSI in highly affluent, well-vegetated areas will not make much of a difference). In addition, this methodology does not account for changes in sensitivity over time as humans adapt to a changing climate, whether due to increased availability of air conditioning or how the human body can become accustomed to high temperatures over time. Finally, the number of heat-related illnesses (and associated monetary values) are likely underestimated, as heat-related illnesses are often misclassified or not identified as being related to extreme temperatures. Despite these limitations, the authors feel that the methodology included in the Tool provides reasonable, ballpark estimates that help practitioners understand the value of well-located and well-designed GSI implemented at the city- or neighborhood-scale.

4.8 Recreation and Enjoyment of Urban Green Space

Implementation of GSI at the city- or neighborhood-scale can increase recreational opportunities for local residents in different ways. For example, substantial increases in vegetated acreage, tree canopy, and enhanced urban aesthetics can increase enjoyment and participation in neighborhood activities such as walking, biking, or jogging on sidewalks, bench sitting, and/or other general outdoor recreation. In addition, some GSI projects are specifically designed to include recreational amenities. For example, several cities across the U.S. have created stormwater parks; others have developed large infiltration areas, such as wetlands, that provide active and passive recreation opportunities.

4.8.1 Relevant GSI Practices

Vegetated GSI practices, including bioretention, rain gardens, trees, wetlands, and wet ponds, have the potential to contribute to recreational benefits.

4.8.2 Benefits Quantification

Total recreational benefits associated with GSI depend on the number of additional recreational trips (often referred to as “user days”) taken as a result of the GSI improvements. However, these benefits can range significantly depending on the availability of existing (i.e., baseline) outdoor recreation opportunities within the study area, the type of recreational activities facilitated by GSI improvements, the amount and quality of the recreational space, and other local conditions. The Tool includes a series of questions to help guide the user toward some basic assumptions for estimating the increase in user days associated with their GSI Scenario. The Tool calculates additional recreational trips associated with pocket parks, neighborhood parks, and general urban greening, as relevant. These assumptions are based on available data regarding visitation to local parks in cities throughout the country.

4.8.3 Monetary Value

Because recreational activities associated with GSI projects are not traded in the market (i.e., there is no fee for participation), it can be difficult to establish the values associated with them. However, many researchers have conducted stated preference surveys to estimate the value of a recreational experience across a range of activities. These studies yield what economists refer to as *direct use values*. Direct use values reflect the amount that individuals would be willing to spend to participate in a recreational activity if they had to pay for it. The Tool relies on the U.S. Army Corps of Engineers Unit Day Value Method (UDVM) to estimate direct use values. This method relies on a series of inputs from the user regarding the quality and characteristics of the recreational activities/experiences that their planned GSI improvements will support.

Rather than relying on increased visitation and direct use values associated with recreational activities at wetlands (if applicable to a user’s GSI Scenario), the Tool relies on meta-analyses of wetland valuation studies that isolate the marginal value (WTP per acre) of recreational services provided by wetlands.

4.8.4 Additional Considerations

The benefits associated with projects that result in increased opportunities for water-based recreation are not valued within the recreation module of the Tool because these benefits are included in the methodology for valuing water quality improvements (at least to some extent). In addition, the value of recreational benefits included in the Tool (i.e., direct use values) reflect benefits for individuals who participate in passive and active recreation activities; they do not reflect benefits associated with having views of green space or living in green environments. These benefits are captured in the calculation of property value increases associated with GSI improvements.

4.9 Green Job Creation

The construction, operations, and maintenance of GSI projects have the potential to create entry-level job opportunities for low income, low-skilled workers (JFF 2017). When GSI jobs are targeted to individuals who are currently unemployed or underemployed, this creates a net social welfare gain that should be reflected in benefit-cost analysis. Further, the nature of GSI jobs creates opportunities to hire workers from the available local labor pool. To the extent that under a baseline "gray infrastructure" scenario, a city or utility would have hired contractors from outside the local community (e.g., large construction firms specialized in tunneling/boring), GSI-based alternatives can result in positive local economic impacts.

4.9.1 Relevant GSI Practices

All GSI practices

4.9.2 Benefits Quantification

A limited number of studies have quantified the direct construction and maintenance jobs created by GSI programs or projects. To estimate the construction jobs associated with a user's GSI scenario, the Tool applies average estimates from available studies for jobs created per million dollars of construction spending. To estimate O&M-related jobs, the Tool relies on WRF's Whole Life Cost Models, which estimate O&M labor requirements for individual GSI practices. The Tool includes baseline assumptions (but also allows for user input) regarding the percentage of GSI-related jobs that would likely be filled by local, unemployed individuals.

4.9.3 Monetary Value

Economists have developed various approaches for valuing job creation benefits associated with hiring individuals who would otherwise be unemployed and incorporating them into project evaluation. These approaches include the calculation and application of shadow wages (also known as the social opportunity cost of labor or the value of labor in its next best use), as well as the estimation of avoided social costs that local, state, and federal governments would otherwise incur to support an individual who is not gainfully employed. The Tool incorporates simplified versions of both approaches to assess green job creation benefits.

4.9.4 Additional Considerations

American Rivers and the Alliance for Water Efficiency note the potential for GSI-related work to take place in "low-road work environments," represented by low wages and poor benefits. To fully realize green job creation benefits, utilities and municipalities must design programs that intentionally target specific groups or individuals. Further benefits can be realized by providing career development pathways through workforce development initiatives and other partnerships.

Finally, the employment effects of GSI (and other policies and programs that create or reduce employment) are often evaluated using economic impact analysis (EIA). EIA focuses on the effects of a project or policy on the amount and type of economic activity in a region, including direct, indirect, and induced effects. In contrast, benefit-cost and TBL analyses include market and non-market values to reflect overall societal well-being (consumer surplus). Consistent with sound economic methodology, the TBL Tool focuses only on the direct effects associated with job creation. It does not include the indirect and induced effects associated with an EIA.

4.10 Flood Risk Reduction

GSI can provide significant benefits by reducing the risk of localized flooding in urban and semi-urban areas. Localized flooding occurs when rain overwhelms drainage systems and waterways; GSI is particularly effective at reducing peak flood flows associated with smaller storm events that often cause localized flooding (i.e., the 2-year to 10-year storm event). As documented by CNT (2014), the impacts of localized flooding can be significant, resulting in "street flooding, sewage pipe backup into buildings, seepage of water through building walls and floors, and the accumulation of stormwater on property and in public rights-of-way."

4.10.1 Relevant GSI Practices

All GSI practices

4.10.2 Benefits Quantification

Quantification of flood risk reduction depends on a variety of local factors, including the effectiveness of GSI in reducing peak flood flows/runoff, and the assets (buildings, infrastructure) and population that is exposed to potential flooding. The key is to understand the locations of urban flooding and the potential reduction in flood depth that can be achieved through GSI. Rainfall to runoff models can be used to quantify the amount of runoff generated from different storm events, while hydrologic and hydraulic (H&H) models can be used to investigate the flow of runoff into a stormwater system and through an urban setting under baseline conditions. When GSI is added to the scenario, the modeling can help determine reductions in flood depths at the various locations where urban flooding might be occurring. An inventory of buildings and infrastructure can be used to understand the potential flood damage that can be avoided because of green infrastructure.

4.10.3 Monetary Value

Monetization of flood risk reduction benefit depends on available data and resources. A direct way to monetize flood risk reduction is to use the results of H&H modeling to determine the reduction in flood depth at locations where urban flooding would otherwise occur (i.e., without the GSI intervention). Reduction in flood depth can be used to estimate associated reductions in damage to buildings and property using standard methods and models, such as FEMA's HAZUS model or USACOE's HEC-RAS model or depth to damage functions.

Other approaches may also give a rough indication of the value of a potential reduction in flood risk, including transferring values estimated in other locations about local WTP to avoid flood damage, estimating the value of shifting the 100-year floodplain boundary due to GSI flood risk reduction projects, and/or applying other research reflecting local values. For example, CNT (2014) examined flood damage claims and sewer- and drain-backup claims data, and conducted a survey of property owners, to understand the impact of localized flooding in Cook County, IL (Chicago area). The study found that total claims amounted to $773 million over the five years examined, with an average payout per claim of $4,272; the authors note that insurance claims represent a significant understatement of total flood damage; many damages are not reported and cleanup costs, time off work, illnesses, and other costs associated with flooding are not reported.

4.10.4 Additional Considerations

Each valuation method has potential limitations and drawbacks, and any method that does not include an understanding of the locations of urban flooding and the change in flood depth in those locations will only achieve a rough approximation of value.

4.11 Water Quality Improvements and Stream Habitat Benefits

Stormwater runoff from developed areas delivers pollutants— including pathogens, nutrients, sediment, and heavy metals—to nearby streams, lakes, and beaches. High stormwater flows can also result in streambank erosion, and in cities with combined sewers, can cause overflows that discharge untreated sewage into local waterways. GSI projects that retain rainfall from small storms, or that treat stormwater runoff prior to discharge, reduce the amount of untreated stormwater runoff entering local water systems. This in turn can result in substantial water quality and related aquatic habitat improvements.

4.11.1 Relevant GSI Practices

All GSI practices

4.11.2 Benefits Quantification

It is not within the scope of this research to develop estimates of the physical unit improvements in water quality (i.e., pounds of pollutant removal) associated with GSI scenarios. While the water quality benefits of GSI have been well documented, quantifying water quality improvements typically requires extensive modeling of site-specific circumstances. The methodology for estimating the value of water quality benefits assumes that the user can provide a general estimate of expected changes in water quality in the target area based on a 10-point water quality scale. The guidance accompanying the Tool provides suggestions and recommendations for estimating expected water quality changes. The Tool translates the expected change in water quality to an estimate of household WTP (see below) based on inputs from the user related to the GSI scenario and associated management area.

4.11.3 Monetary Value

Individual's value clean water for several reasons, including for recreation, economic development, public health, water supply reliability, and other ecosystem services. To estimate the value of water quality improvements associated with GSI investments, the Tool relies on findings from nonmarket valuation studies that estimate household WTP for water quality improvements across a range of locations and water resource types. Specifically, the tool incorporates a WTP function from a meta-analysis of water quality-related stated preference studies. The WTP function allows users to estimate WTP for water quality improvements associated with their GSI scenario based on site-specific characteristics, such as household median income, baseline water quality, recreational use of affected water bodies, and more. Household WTP is then multiplied by the number of households in the management area to estimate the total value of improvements.

4.11.4 Additional Considerations

There are inherent limitations and uncertainties associated with stated preference studies, as well as the use of a meta-analysis regression model as a benefits-transfer tool. For example, the meta-regression does not measure how WTP varies with respect to the proportion or amount of water that is improved, or the distance of the water quality changes from populations. This lack of specificity imposes limitations on the precision of resulting WTP estimates. However, the range of WTP estimates that the Tool provides (based on user input) are consistent with findings from the literature. They provide a reasonable approximation of the value that individuals place on clean water and water quality improvements.

4.12 Carbon Reduction Benefits

Carbon dioxide (CO_2) is widely recognized as a significant greenhouse gas (GHG) that contributes to rising atmospheric temperatures and associated climate change. Trees and vegetation associated with GSI remove CO_2 from the atmosphere (sequestration) and acts as a sink by storing carbon in the form of biomass. In addition, GSI-related energy savings reduce CO_2 emissions and other GHGs (which can be translated to CO_2 equivalents or CO_{2e}) from power plants.

4.12.1 Relevant GSI Practices

- Trees, green roofs, bioretention, rain gardens, and wetlands (carbon sequestration and storage)
- All GSI practices that reduce energy use (avoided CO_2 emissions)

4.12.2 Benefits Quantification: Carbon Sequestration and Storage

Trees and vegetation can play a significant role in mitigating the impacts of climate change by sequestering and storing carbon. Most of the carbon sequestered by trees becomes fixed and is stored as woody biomass. Carbon sequestered by other types of vegetation (e.g., herbaceous cover, grasses, wetlands) is stored in biomass and soils; however, dead and decaying vegetation can re-release carbon into the atmosphere. USFS has developed models and methods to estimate net carbon sequestration and storage for various tree species at different stages of growth. The Tool applies this data to common tree species in different climate regions to estimate related CO_2 reductions. To estimate CO_2 reductions for other vegetated GSI practices, the Tool applies findings from a limited number of studies.

4.12.3 Benefits Quantification: Avoided CO_2 Emissions

The U.S. EPA and EIA track emission rates for different pollutants, including CO_{2e}, for almost all power generation in the U.S. These agencies publish emission rates at various geographic scales. The Tool applies this data (by grid region) to estimate CO_{2e} emission reductions associated with GSI-related energy savings.

4.12.4 Monetary Value

Economists typically value the benefits of CO_{2e} reductions using the “social cost of carbon” (SCC), which represents the aggregate net economic value of damages from climate change across the globe. In 2016, the U.S. Government’s Interagency Working Group on Social Cost of Carbon issued updated guidance (IWG, 2016) on recommended SCC values (per ton of CO_2) for regulatory benefit-cost analysis. The Working Group’s mean SCC estimate reflects the worldwide net benefit of reducing one ton of atmospheric CO_2.

4.12.5 Additional Considerations

The carbon sequestration and storage of trees has been well-studied; for other types of GSI, less data is available. The Tool applies a range of values for carbon sequestration from various studies to estimate carbon reduction benefits for these practices. However, these estimates are not region specific (as are the estimates for trees). In addition, the net carbon sequestration rates associated with different GSI practices depend on management of the associated landscapes (e.g., if decaying plant biomass is removed from the site, it will not be sequestered into the soils, which substantially reduces the net carbon sequestration rate).

4.13 Urban Habitat Enhancement

Urban and suburban areas generally consist of a network of green spaces – including parks, yards, street plantings, greenways, commercial landscaping, and vacant lots - that offer important ecosystem and biodiversity benefits, as follows:

- Providing food and refuge for birds, amphibians, bees, butterflies, and other species
- Promoting functional groups of insects that enhance pollination and bird communities
- Providing landscape connectivity/encouraging the movement of organisms between habitat patches

GSI practices, can contribute to the network of green spaces that support terrestrial ecosystems and biodiversity in urban and suburban settings. This is particularly true in areas where development and impervious cover have degraded habitat for native species and/or where green spaces are isolated within the built environment.

4.13.1 Relevant Practices

Trees, rain gardens, bioretention, wetlands, wet ponds, green roofs

4.13.2 Benefits Quantification

The Tool calculates the total area of GSI that has the potential to provide habitat value based on the design parameters assumed in the GSI scenario. Ecological studies have identified the various factors that influence the ability of different GSI practices to provide ecosystem and biodiversity benefits, including GSI design parameters, ecological conditions, and surrounding landscape characteristics. It is likely that site-specific conditions and/or competing objectives may not allow for the full realization of ecosystem and biodiversity benefits. Thus, the Tool allows the user to apply an adjustment factor to account for the percentage of GSI area that will likely provide habitat value. This methodology is intended to provide a ballpark estimate of potential benefits.

4.13.3 Monetary Value

The Tool incorporates findings from a meta-analysis of economic studies that yields annual, per-acre estimates of the marginal value of terrestrial habitat benefits associated with wetlands. Based on available research, it is evident that not all GSI practices are considered equal in terms of ecosystem and biodiversity value. For example, wetlands seem to have greater richness and abundance of flora and fauna compared to many other GSI practices, green roofs generally provide fewer benefits compared to ground-level practices, while some practices can be designed to support specific species of interest (e.g., to enhance pollination). To account for these differences, the Tool scales the monetary value of habitat for wetlands the suite of GSI practices that provide ecosystem and biodiversity benefits.

4.13.4 Additional Considerations

Additional research is needed to better understand how GSI practices can be designed, located, and managed to maximize terrestrial ecosystem and biodiversity benefits in different settings. In addition, very few economic studies have estimated the marginal value of terrestrial habitat in urban settings, where it can be relatively scarce (e.g., compared to rural areas). Given these uncertainties, the Tool incorporates a methodology that allows the user to develop a ballpark estimate.

CHAPTER 5

Framework and Tool Application - Four Case Studies

This chapter presents results from four case study applications of the Tool, as follows:

- Saint Paul, MN – This case study compares the costs and benefits of two stormwater management alternatives – a more conventional approach and a GSI-based approach – for a planned mixed-use redevelopment site spanning 134 acres. Results are compared to an analysis of the same site using Autocase, a proprietary software designed to assess the TBL benefits and costs of GSI.
- Lancaster, PA – This case study evaluates the benefits of a citywide GSI-based stormwater management plan implemented over 25-years. Results are compared to a similar analysis developed using *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits,* which was developed by CNT and American Rivers (CNT and American Rivers, 2010).
- Seattle, WA – This case study quantifies the benefits and costs of a series of planned GSI projects in Seattle's Longfellow Creek Watershed. The primary objective of these projects is to improve water quality in Longfellow Creek, which is one of the only streams within the city that supports spawning habitat for important salmon species. This case study also incorporates a multiple objective decision analysis (MODA) evaluation that incorporates additional SPU values that are not typically included in benefit-cost methodology.
- Cleveland, OH – This case study evaluates the TBL benefits and costs of the GSI projects implemented through the Northeast Ohio Regional Sewer District's (NEORSD's) Green Infrastructure Grant Program. This analysis focuses on projects funded in 2020.

The case studies provide valuable examples and highlight key considerations for applying the methods and assumptions incorporated in the Tool. The project team selected these studies to reflect a wide geographic range, as well as a range in different types of projects and scale of implementation. For example, the Lancaster, PA case study covers a comprehensive citywide plan for GSI, while the Cleveland, OH case study incorporates several distinct projects located throughout the city. Two of the case studies, Saint Paul, MN and Lancaster, PA, provide a comparison of results from similar tools or analyses, while the Seattle case study incorporates a SPU's method for qualitatively evaluating project benefits that cannot be easily quantified or monetized. Table 5-1 provides a summary of the case studies; subsequent sections provide additional detail on the GSI scenarios analyzed, methods for assessing benefits and costs, and overall results.

Table 5-1. Summary of Tool Application Case Studies.

	Saint Paul, MN	Lancaster, PA	Seattle, WA	Cleveland, OH
Description	Compares benefits and costs of two alternatives – gray- and GSI-based approaches – for mixed-use, 134-acre redevelopment site.	Evaluates benefits and costs of a citywide GSI-based stormwater management plan implemented over 25-years.	Examines benefits and costs of three ROW bioretention projects in high priority watershed.	Evaluates benefits and costs of multiple grant funded GSI projects in combined sewer are of District.
Project proponents	Capitol Region Watershed District/City of Saint Paul	City of Lancaster	Seattle Public Utilities	Northeast Ohio Regional Sewer District.
Key highlights	Results compared to similar analysis using Autocase tool. Compares incremental costs / benefits of gray and GSI scenario.	Results compared to a similar analysis developed using *CNT/American Rivers Guide.*[a].	Incorporates MODA[b] framework that SPU uses to assess GSI project priorities / benefits.	Includes customized property value analysis and analyzes distributed projects.
GSI scenario	Centralized GSI corridor; 4.8 acres of bioretention; 300 trees, large retention pond / wetland system; 10-acres of green space. Stream restoration links development site to recreation/natural area.	Manages 1,265 IA / 1,060 MG of runoff/year through GSI: bioretention (56%); permeable pavement (26%); trees (13%); green roofs (4.5%); RWH (1%).	ROW bioretention projects managing 6 impervious acres; includes 89 trees, pedestrian/safety improvements, and community gathering space.	Nine distributed projects including bioretention, permeable pavement, and underground systems.
Avoided infrastructure		★		★
Avoided maint./replace.		★		★
Energy savings	★	★	★	★
Water supply		★		★
Air quality	★	★	★	★
Heat stress	★	★		
Recreation	★	★	★	
Enhanced aesthetics	★	★	★	★
Green job creation	★	★	★	★
Water quality/habitat	★		★	
Carbon reduction	★	★	★	★
Terrestrial ecosystem	★	★	★	★
Flood risk reduction	★			
Total PV benefits ($M)	$27.9 (GSI); $15.1 (gray); (28-year PV)	$521.8 (50-year PV)	$8.98 (50-year PV)	$5.20 (40-year PV)
Total PV costs ($M)	$21.5 (GSI); 18.8 (gray) (28-year PV)	$241.5	$5.87	3.49
Benefit-cost ratio	1.3 (GSI); 0.8 (gray)	2.16	1.53	1.455

(a) CNT and American Rivers 2010
(b) MODA = Multiple Objective Decision Analysis

5.1 Case Study 1: Ford Redevelopment Site, Saint Paul Minnesota

5.1.1 Background

The Ford redevelopment site consists of 134 acres of land along the Mississippi River; it is the former home of Ford Motor Companies' Twin Cities Assembly Plant. Since Ford announced the closure of the plant in 2006, the City of Saint Paul has been engaging with various partners and the community to create a sustainable redevelopment plan. When complete, the development will include approximately 3,800 housing units, mixed use commercial and retail stores, public open spaces and GSI, and other sustainability elements.

Case study highlights

- Comparison of two stormwater management alternatives.
- Analysis for a relatively small new development site (134 acres).
- Comparison to results from similar study using AutoCase.

Stormwater runoff from the former Ford site (now known as the Highland Bridge Development) primarily drains to Hidden Falls Creek, which flows into the Mississippi River via Hidden Falls. Historic maps indicate the creek once meandered across the Ford site but that it was buried prior to the construction of the assembly plant. Since then, impervious surfaces at the Ford site have sent uncontrolled runoff downstream without treatment, destabilizing the creek and carrying pollutants into the river (Barr Engineering 2016).

In 2015 the City of Saint Paul and Capitol Region Watershed District (CRWD), a local agency responsible for regulating stormwater management at the site, retained Barr Engineering to assess two conceptual stormwater management alternatives: a conventional stormwater management approach (Baseline Alternative) and a centralized, GSI-based approach (Hidden Falls Headwaters Alternative).

The original analysis included an assessment of financial, social, and environmental costs and benefits of each alternative using the Autocase proprietary software tool. Barr Engineering, CRWD, and the City of Saint Paul shared the inputs and results of their assessment, allowing us to conduct a similar analysis with this Tool. As described in more detail below, this case study is not intended to be an exact replica of the Autocase analysis due to differences in study methodology and assumptions. In addition, in some cases, inputs from the Autocase analysis were not explicitly documented in ways that directly translate for use in the Tool. The authors therefore made several assumptions regarding key inputs. Results from this case study are therefore not directly compared to the results from the Autocase analysis; however, key differences are highlighted.

As an important note, the gray infrastructure-based alternative included in this analysis is referred to as the Baseline Alternative because this is how it is characterized in the Barr Engineering (2016) report. All of the case studies in this report include a baseline scenario against which the GSI Scenario is compared. However, this case study is unique because it provides a full comparison of benefits and costs of both the Baseline and GSI-based Alternatives. The other case studies incorporate baseline conditions by including avoided costs (i.e., costs that would be incurred under the baseline) as a benefit of the GSI Scenario being analyzed.

5.1.2 Key Inputs

According to the CNT National Stormwater Calculator (CNT 2009), Saint Paul receives 23.2 inches of rain per year that results in runoff. The proposed stormwater management alternatives are both designed to capture runoff associated with a 1.375-inch storm event.

The management area is the 134-acre[2] Ford redevelopment site. The population of the neighborhood will amount to 8,550 when construction is complete. Saint Paul falls within the Midwest climate zone.

5.1.3 GSI Scenarios

The two stormwater management alternatives analyzed are as follows:

- The Baseline Alternative is representative of a "business-as-usual" approach. Under this alternative, runoff from individual parcels would be managed through underground storage systems. This alternative includes 2.1 acres of bioretention to help manage runoff from impervious area within the public right-of-way and the addition of 200 trees.
- The "Hidden Falls Headwaters" Alternative reflects enhanced stormwater management goals. Under this alternative, runoff from the entire site would be managed through a centralized GSI corridor that would re-create the buried Hidden Falls Creek. This alternative includes 4.83 acres of bioretention, the addition of 300 trees, and a large retention pond (2.4 acres) / wetland (2 acres) system. Hidden Falls would be restored downstream and associated recreation/natural areas would be linked to the development through an improved recreation trail connection.

Both alternatives include close to 10 acres of additional green space that will provide stormwater management and recreational benefits; the Hidden Falls Headwater Alternative will manage runoff from an additional 35 acres from a nearby development site through the centralized GSI system. Figures 5-1 and 5-2 present conceptual designs for the Hidden Falls and Baseline Alternatives.

To develop the GSI Scenario, the authors entered data into the GSI Scenario worksheet in the Tool. Figure 5-3 shows how data on the GSI practices associated with the Hidden Falls Headwaters Alternative were entered. First, the authors entered the effective impervious acres managed by each GSI practice, including 79.5 effective impervious acres managed through bioretention and 77 managed through the retention pond/wetland system (combined). The 10 acres of green space included in this alternative were incorporated as biofiltration, assuming it only manages/captures runoff associated with the rain that falls on it (design specifications were changed accordingly).

The Tool calculated the volume capacity of each GSI practice entered; however, the authors directly entered the footprint (i.e., surface area) of each GSI practice, overwriting the gray cells in Column I (rather than relying on the Tool calculations) because this data was readily available.

Data for the baseline alternative was entered similarly for bioretention, trees, and the open space area.

5.1.4 Costs and Timeline

Consistent with the Autocase analysis, the authors assumed a 4% real discount rate, a 2-year construction period (starting in 2020), 25-years of O&M, and replacement of key infrastructure components after the 25-year O&M period (overall analysis period of 28 years). The total costs of each scenario include those associated with gray infrastructure components.

Table 5-2 shows the capital, annual O&M, and replacement costs for each alternative. Figure 5-4 provides a snapshot of how these costs and assumptions were entered into the Tool for the Hidden Falls Alternative (Costs.Timeline worksheet).

[2] The final redevelopment site encompasses 122 acres; for this case study, the authors have kept the 134-acre assumption to be able to directly compare results to the Autocase analysis.

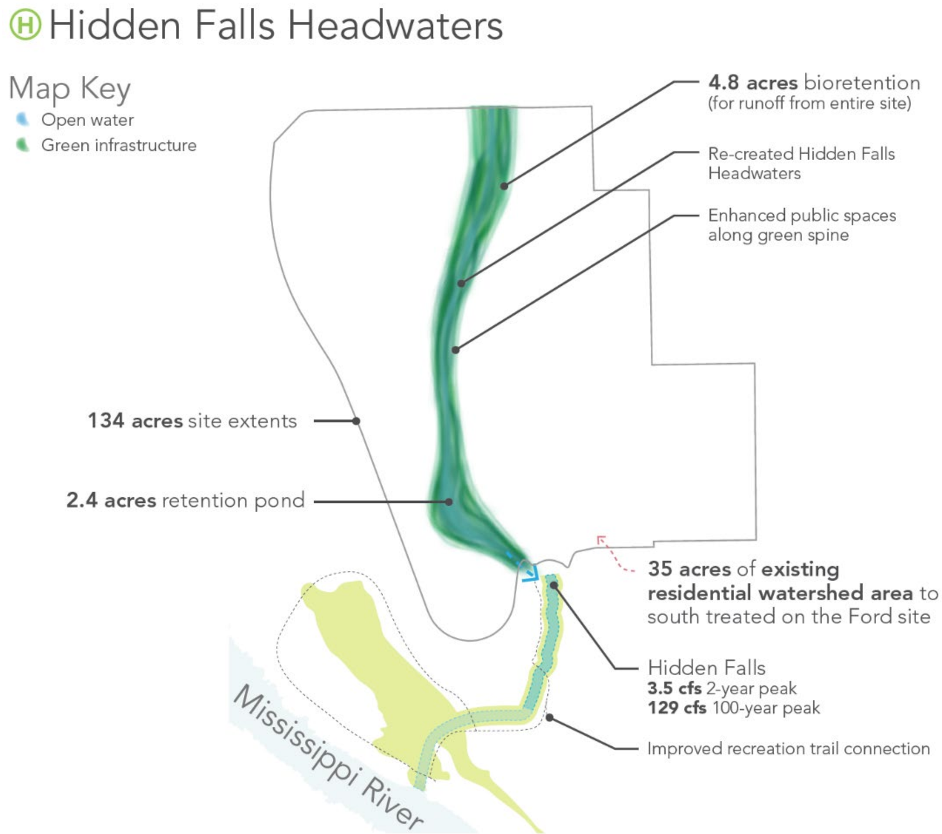


Figure 5-1. Conceptual Design for Centralized GSI-Based Hidden Creek Falls Alternative at Ford Site.
Source: Barr Engineering 2016; Reprinted with permission from Barr Engineering.

Table 5-2. Capital, O&M, and Replacement Costs for Baseline and Hidden Falls Alternatives.
(2019 USD)

	Baseline Alternative		Hidden Falls Alternative	
Cost category	**Costs[a] ($M)**	**Present value costs over analysis period ($M)**	**Costs[a] ($M)**	**Present value costs over analysis period ($M)**
Capital (2-year implementation)	$14.78	$13.94	$13.38	$12.61
O&M	$0.18 (annual)[b]	$2.79	$0.38 (annual)	$5.75
Replacement[b]	$ 6.38	$2.04	$9.87	$3.17
Total[c,d]		$18.8		$21.5

a. Updated from 2015 USD from AutoCase analysis
b. PV analysis is conducted in "real" terms, meaning that O&M costs are not inflated over time and a real discount rate is applied (discount rate net of inflation). See Chapter 3 (Section 3.5) for more information.
c. Replacement costs estimated based on PV replacement costs reported by Barr Engineering
d. The authors could not recreate exact costs as reported by Barr Engineering based on inputs provided. Particularly, the present value O&M costs calculated using a 4% real discount rate are lower.

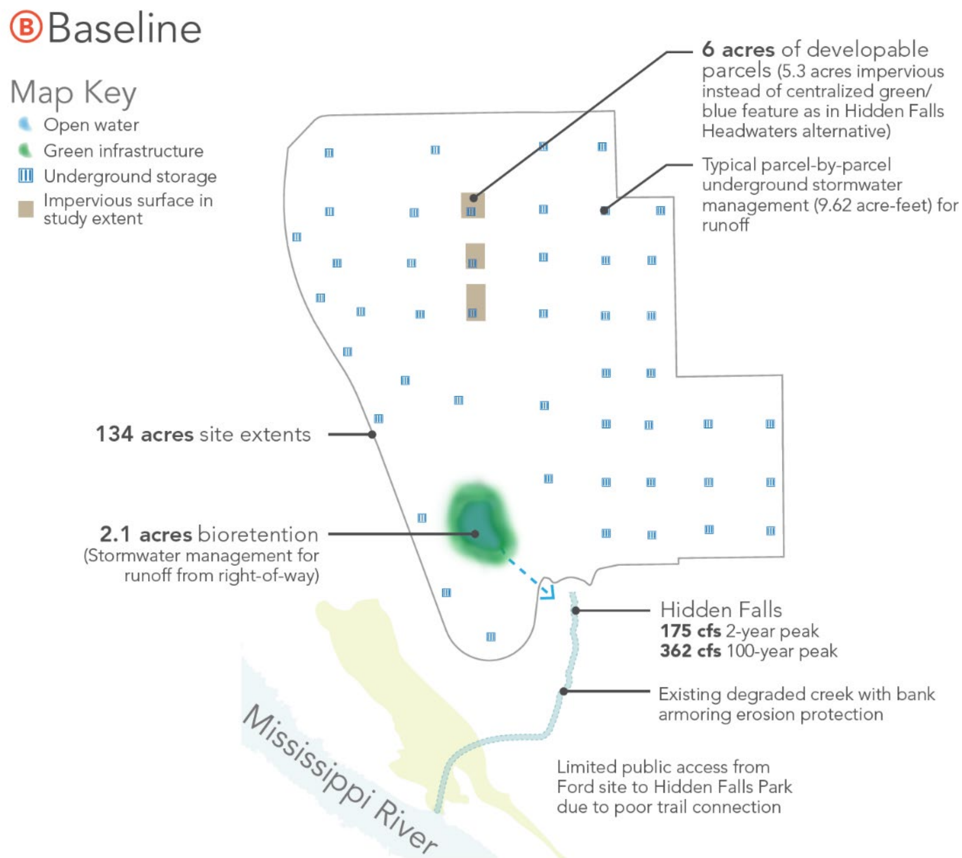


Figure 5-2. Conceptual Design for Baseline Alternative at Ford Site.
Source: Barr Engineering 2016; Reprinted with permission from Barr Engineering.

5.1.5 Benefits

5.1.5.1 Avoided Infrastructure Costs

Because this analysis compares two alternatives, it is not appropriate to include avoided infrastructure costs as a benefit under either alternative. Instead, costs of each alternative can be compared directly. However, the initial design for the Headwaters Falls Alternative included the management of runoff from an adjacent 35-acre residential development. To the extent that this runoff would have been managed in another way (e.g., additional detention or underground storage), the avoided costs should be reflected in the overall benefit cost analysis for the Hidden Falls alternative. Barr Engineering reports that the 35-acre site had an effective impervious area of 49%. Based on the Tool methodology, which assumes a cost for traditional stormwater management of $3 per square foot of impervious area, total avoided capital costs could amount to as much as $2.24 million. Barr Engineering reports that this aspect of the Hidden Falls alternative was not included in the final design; however, several offsite parcels will be treated by the site. The authors did not include any avoided gray infrastructure costs in the analysis of alternatives

GSI Practices - Enter Acres Managed or Number of BMPs

GSI Practice (BMP)	CLASIC BMP Name	Effective Impervious Acres Managed (acres)	Number of BMPs	Volume Capacity by BMP type (cft)	Calculated BMP Area (Footprint) (square feet)	Annual Runoff Volume (cft)
Rain gardens	Rain gardens		-	-	-	-
Bioretention facilities	Infiltration trenches	79.5	39	388,868	214,726	6,233,205
Green roofs	Green roofs		-	-	-	-
Tree planting/street trees	*	3.2	300	16,043	192,038	252,008
Permeable pavement	Permeable pavement		-	-	-	-
Cisterns - rainwater harvesting	Rainwater harvesting	-		-		-
Rain barrels - rainwater harvesting	Rainwater harvesting	-		-		-
Constructed wetland	*	17.5	4	85,600	87,120	1,372,089
Wet ponds	Wet pond	59.5	5	291,040	104,544	4,665,103
Biofiltration/grass or vegetated swale	Grass swale	10.0	44	48,914	435,600	784,051
		170		830,465		13,306,457

* CLASIC does not address "Tree planting/street trees" or "constructed wetland"

Figure 5-3. Tool Snapshot - GSI Scenario Data Entry for Hidden Falls Headwaters Alternative.

Total Cost for GSI Scenario (Manual entry)

Total capital	13,375,188
Annual O&M (at full implementation)	377,525
Enter replacement costs manually below (Row 63)	

Construction Begin Year (2020 = 1)	Construction Period (yrs)
1	2

Discount rate	4.0%
Analysis period	28

	Year	2019	2020	2021	2022	2023	2024	2025
		0	1	2	3	4	5	6
Total costs	**Sum**							
Capital Costs	**13,375,188**	-	6,687,594	6,687,594	-	-	-	-
Maintenance Costs	**10,004,413**		-	188,763	377,525	377,525	377,525	377,525
Replacements Costs	**9,873,550**							
Total	**33,253,151**	-	6,687,594	6,876,357	377,525	377,525	377,525	377,525
Present Value	**Sum**							
Capital Costs	**12,613,435**	-	6,430,379	6,183,057	-	-	-	-
Maintenance Costs	**5,753,197**		-	174,522	335,618	322,710	310,298	298,363
Replacement Costs	**3,165,968**		-	-	-	-	-	-
Total	**21,532,600**	-	6,430,379	6,357,578	335,618	322,710	310,298	298,363

Figure 5-4. Tool Snapshot – Cost and Timeline Data Entry for Hidden Falls Headwaters Alternative.

Note: Replacement costs are included in year 28 of analysis period

5.1.5.2 Energy Savings

The Baseline and Hidden Falls alternatives include the addition of 200 and 300 trees, respectively; this results in energy savings for heating and cooling in buildings. Under both alternatives, each tree will save $33.21 per year in electricity and $33.79 per year in natural gas once it is fully mature (the Tool assumes full maturity at year 30). Over the 28-year analysis period, this amounts to $93,193 (Baseline) and $139,790 (Hidden Falls) in present value terms.

Table 5-3. Air Quality Improvements and Associated Health Benefits, Ford Redevelopment Site Analysis, Saint Paul, MN.

	Baseline Alternative		Hidden Falls Alternative	
	Pollutant reduction (MT/year)[a]	PV benefit (2019 USD)	Pollutant reduction (MT/year)	PV benefit (2019 USD)
NO_x	0.1	$9,338	0.14	$13,178
SO_2	0.05	$22,438	0.08	$33,629
O_3	0.49	$301,279	0.7	$412,717
$PM_{2.5}$	0.02	$419,160	0.03	$575,209
Total Present Value[b]		$727,248		$1,034,733

a. Reflects average annual value with trees at full maturity
b. Accounts for tree growth over time

5.1.5.3 Air Quality Improvements and Associated Health Benefits

Both alternatives will result in reduced emissions due to energy savings; added vegetation (e.g., trees, shrubs, wetlands) will also remove air pollutants from the surrounding environment. Table 5-3 shows the pollutant reduction (MT/year) under each alternative and the associated present value benefits. The monetized benefits reflect avoided health effects and related healthcare costs.

5.1.5.4 Property Value Benefits

Under the Hidden Falls alternative, property value benefits will be greater because: 1) there will be more GSI improvements, and 2) the nature of these improvements will result in greater increases. Specifically, the GSI corridor and stream enhancement/daylighting will have a larger impact than improvements planned under the Baseline.

To estimate property value benefits, the authors made several assumptions based on a zoning map for the development (Figure 5-5). This map and related assumptions are intended to provide a demonstration of potential benefits due to data limitations.

For both alternatives, the authors assume the redevelopment site will include 950 single family units and 285 multi-family buildings, with an average of 10 units per building. Property values for single family homes average $340,000, while the average value of multi-family buildings is $2,000,000 ($200,000 per unit).

For the Hidden Falls Alternative, the authors assume an increase in value of 5% associated with the bioretention and green space. For the Baseline, an increase of 3.5% is assumed for these practices because they are not located/sited with the enhanced stream corridor. The authors assume a 7% increase associated with trees under both alternatives and 5.7% increase associated with wetlands/wet ponds, which are only included in the Hidden Falls Alternative.

Figure 5-5. Planned Zoning Map for Ford Redevelopment Site.
Source: City of Saint Paul 2019.

Based on the literature, properties within up to 0.5 miles can realize increases associated with significant GSI improvements, although this depends on several factors (see Appendix E). Within the Ford development site, all housing units will be located within 0.25 miles of the GSI corridor under the Hidden Falls Alternative. While this is also true for the bioretention area installed under the baseline, it does not offer the same level of aesthetic and therefore will likely not have an impact on as many properties within the study area (i.e., it will not have as far-reaching effects). Under both alternatives, the authors assume the 10-acres of open space are distributed across the 134 acres (i.e., as a few large parks) so that many properties are located even closer to planned GSI improvements.

At the same time, some percentage of housing units will be located along the Mississippi River corridor. The authors assume that these properties will not experience additional increases from GSI because they are already adjacent to significant areas of green space. These properties were excluded from the analysis.

The authors also assume that properties located further away from the GSI corridor (Headwaters Falls Alternative) and the green space areas will experience a lower increase compared to those directly adjacent. We use the percentage of area covered by GSI practices as a proxy for the percentage of parcels located directly adjacent.

Table 5-4 shows how these different factors are incorporated into the property value analysis. Under both alternatives, the authors assume that 70% of property value benefits apply to avoid double counting.

Table 5-4. Assumptions for Property Value Analysis, Ford Redevelopment Site, Saint Paul, MN.

Assumption	Baseline Alternative	Hidden Falls Alternative
Property value increases from GSI	4.25%	5.77%
Percent of housing units in study area *potentially* affected by GSI improvements	63% (based on ratio of green area under Baseline to green area under Headwaters Alternative)	100%
Properties excluded from analysis because they are along Mississippi river corridor	60% of single-family properties 13% of multi-family properties	60% of single-family properties 13% of multi-family properties
Percent of properties that will realize a lower increase because they are not directly adjacent to GSI improvement	89%	83%

Based on these assumptions, total property value benefits under the Hidden Falls Alternative will amount to $8.2 million in present value terms. This compares to $4.0 million under the Baseline. These calculations distribute the one time increase across the analysis period.

5.1.5.5 Recreation

The Hidden Falls Alternative includes 10 acres of recreational green space; the GSI corridor included in this alternative encompasses 9.3 acres. For estimating recreation benefits, the authors model these as two distinct “stormwater parks” – larger recreation areas created as part of the stormwater management. The authors treated the 10 acres as one park because it will not likely make a significant difference in visitation whether this green space is distributed across the study area (e.g., creating a few smaller parks) or concentrated in one area, if they are at least two acres in size (the minimum size for a stormwater park). For the Baseline Alternative, the authors estimate benefits associated with the 10 acres of recreational space and the 2-acre bioretention area, assuming it is designed to support some level of recreation activity.

Table 5-5 shows the assumptions used to estimate recreation benefits under the baseline scenario. Based on these assumptions, the Tool estimates that the Hidden Falls and Baseline Alternatives will result in 68,642 and 41,405 additional recreational visits per year, respectively. Corresponding present value benefits amount to $9.4 million and $4.0 million over the 28-year analysis period.

Table 5-5. Assumptions for Recreational Analysis, Ford Redevelopment Site, Saint Paul, MN.

Assumption	Baseline Alternative	Hidden Falls Alternative
Number of parks	1	2
Average size	12 acres	9.9 acres
Number of residents within 1 square mile	12,650[a]	12,650
Poverty rate[b]	5.8%	5.8%
Months out year for outdoor recreation	7	7
Direct use value inputs ($/trip)		
Capacity for fishing and hunting	No	No
Availability of general recreation activities	Few	Several
Availability of similar recreation opportunities located nearby	Many	Many
Carrying capacity	Adequate	Adequate
Accessibility	High	High
Quality	Average	High
Resulting direct use value	$6.21 per person per trip	$8.80 per person per trip

a. This estimate is based on Census data for the Census tract in which the site is located, as well as the estimated population of the immediate study area.
b. Poverty rate based on data for Census tract in which the site is located

5.1.5.6 Heat Stress

Data from the U.S. EPA Climate Change Impacts and Risk Analysis (CIRA) study indicates that in Minneapolis (which is selected as the reference city for Saint Paul in the Tool), extreme heat days (defined as days on which temperatures do not drop below an established minimum mortality threshold, MMT) result in an increase in daily mortality of 5.9%, after controlling for other factors. In the year 2000, which serves as the reference year for the CIRA data, EPA estimates that extreme heat days were responsible for 11.7 deaths.

At the same time, based on estimates from the literature, an increase in vegetative or reflective cover of ten percentage points would reduce average temperatures by 0.25 degrees Fahrenheit in Minneapolis. In 2050, this is enough to reduce the number of days when the city is over the MMT by 4.7.

The Headwater Falls and Baseline alternatives result in an increase in vegetative cover of 19% and 13%, respectively (including coverage from tree canopy at full growth) – enough to realize urban heat stress benefits. As detailed earlier in this report, the heat stress module associated with the Tool only estimates benefits associated with a 10% change in surface cover because there is not sufficient evidence from the literature to support a linear increase in benefits as the percentage change in surface cover increases beyond this amount.

To estimate heat stress reduction benefits, the Tool begins to count heat stress-related benefits in the year of the analysis period in which the change in reflective or vegetative cover reaches 5%. This is based on the GSI implementation period and the tree growth model built into the Tool. The Tool scales the population of the reference city to the population of the study area. In this case, the authors subtracted out the estimated percentage of the study area population living along the river corridor because these homes are located near significant vegetation (this change was made in Cell L28 of the Tool's Heat Stress benefits worksheet). Based on this method, the Tool estimates that the Headwater Falls alternative will reduce the number of extreme heat days in the study area by 4.7 in 2050, saving

0.03 lives and reducing heat-related emergency room visits and hospitalizations by 1.4 and 0.2, respectively. Over the analysis period, total present value benefits associated with heat stress reduction amount to $2.24 million under the Headwater Falls Alternative. The Baseline Alterative has slightly lower benefits because it takes longer to reach 5% vegetative cover due to fewer trees. The Headwater Falls Alternative will likely result in additional benefits than estimated because it has a greater change in vegetative cover (19% at full tree growth); these additional benefits are not quantified in the Tool.

5.1.5.7 Green Jobs

The Tool estimates that the Headwater Falls Alternative will create 74 construction job-years and requires 0.31 full time employees per year. Under the baseline, construction job-years amount to 81 and annual maintenance requires 0.22 full time employees. The authors assume that under the Headwater Falls Alternative, 25% of construction jobs and 100% of maintenance jobs are filled by individuals who would otherwise be unemployed. Under the Baseline it is assumed that 10% of construction jobs and 100% of maintenance jobs are filled by individuals who would otherwise be unemployed.

Based on these assumptions, and using the “reservation wage approach,” the Tool estimates present value green job benefits of $385,119 and $189,400 under the Hidden Falls and Baseline Alternatives, respectively.

5.1.5.8 Water Quality

Both the Baseline and Hidden Falls Alternative will result in water quality improvements. However, the Hidden Falls Alternative will realize greater improvements and enhanced downstream protection. For the original analysis, the authors estimated that the Hidden Falls Alternative would result in a change from 1 to 2 on the water quality ladder, while the Baseline Alternative would only result in a 0.1 unit increase. The authors use these same assumptions to estimate WTP for water quality improvements in the Tool. Further, it is assumed that 30% of affected population are “users” of the creek under the Hidden Falls Alternative, and 10% are users under the Baseline. Figure 5-6 shows the inputs to the Tool Water Quality module for the Hidden Falls Alternative.

Based on these assumptions, the Tool estimates an annual average household WTP for water quality improvements of $31.47 and $4.42 under the Hidden Falls and Baseline Alternatives, respectively. The next step is to determine the number or percentage of households to which this should apply. As noted in the guidance for the Tool, this can be determined in different ways. For the purposes of this case study, the authors use the number of households within the Census tract, which is approximately one square mile, plus the estimated new number of housing units that will be constructed within the study area. This yields a total present value water quality benefit of $2.72 million under the Hidden Falls Alternative and $0.38 million under the Baseline.

5.1.5.9 Carbon Reduction

Both alternatives will result in reduced emissions of CO_2 and other GHGs due to energy savings; added vegetation (e.g., trees, shrubs, wetlands) will also sequester carbon from the surrounding environment. Under the Baseline Alternative, carbon reduction benefits amount to $97,505 over the 28-year analysis (present value). Benefits under the Hidden Falls alternative are greater because of the increased energy savings and greater amount of vegetation available for sequestration. Over the analysis period, total present value benefits for this alternative amount to $136,548. Total CO_{2eq} sequestered or avoided through reduced emissions amount to 154 and 221 per year (one trees reach full maturity, 30 years, in this case, the end of the analysis period).

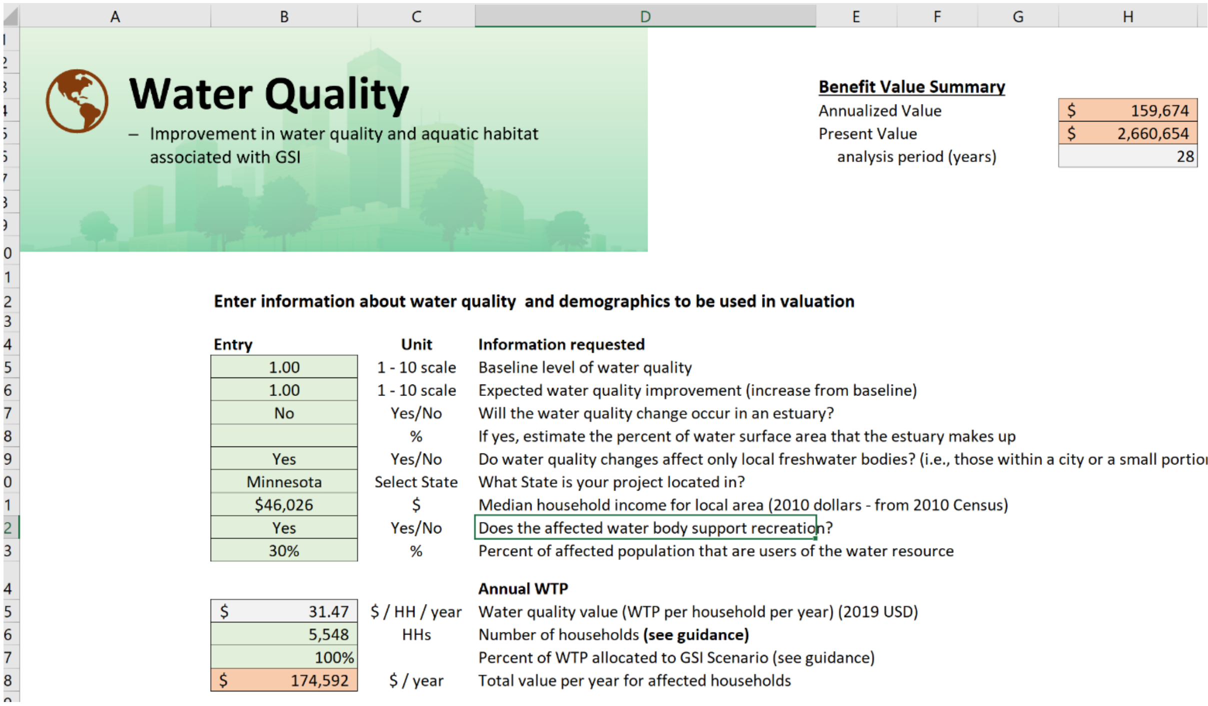


Figure 5-6. Water Quality Module Inputs, Ford Redevelopment Site, Saint Paul, MN.

5.1.5.10 Terrestrial Habitat and Ecosystem Benefits

The Hidden Falls Alternative results adds more than 1 million square feet of potential habitat area, while the Baseline adds approximately 660,000. For this case study, the authors assume that 80% of this area (across all practices) is designed to provide habitat benefits. This results in $716,543 and $390,189 in present value benefits under the Hidden Falls and Baseline Alternatives, respectively.

5.1.5.11 Additional Benefits

The original analysis includes $2.93 and $2.97 in present value flood risk reduction benefits under the Hidden Falls and Baseline Alternatives, respectively. It is not clear how these benefits were determined. However, the authors included these benefits in the “other” benefits category on the Results Dashboard so that they are reflected in the overall benefit cost analysis.

5.1.6 Results Summary

Figure 5-7 and Table 5-6 provide a summary of the results of this analysis. As shown, the benefits of the Hidden Falls Alternative significantly outweigh those realized under the Baseline Alternative, which includes some GSI but mostly reflects conventional stormwater management approaches. Both alternatives realize significant benefits associated with large areas of green space that provide both recreational and stormwater management benefits. The overall benefit cost ratio for the Hidden Falls Alternative is equal to 1.30 this compares to 0.80 under the Baseline.

It is important to remember that these benefits reflect those that can be quantified. The Hidden Falls Alternative will likely result in additional heat stress benefits, and potentially avoid additional infrastructure costs associated with the management of 35 impervious acres from a nearby residential development.

In addition, our estimate of household WTP for water quality improvements is likely conservative, particularly for the Hidden Falls alternative, which will see substantial instream improvements at Hidden Falls Creek. Hidden Falls appears to be a resource of local importance, which provides some justification for increasing the number of households included in the WTP analysis. The total value represents a conservative estimate.

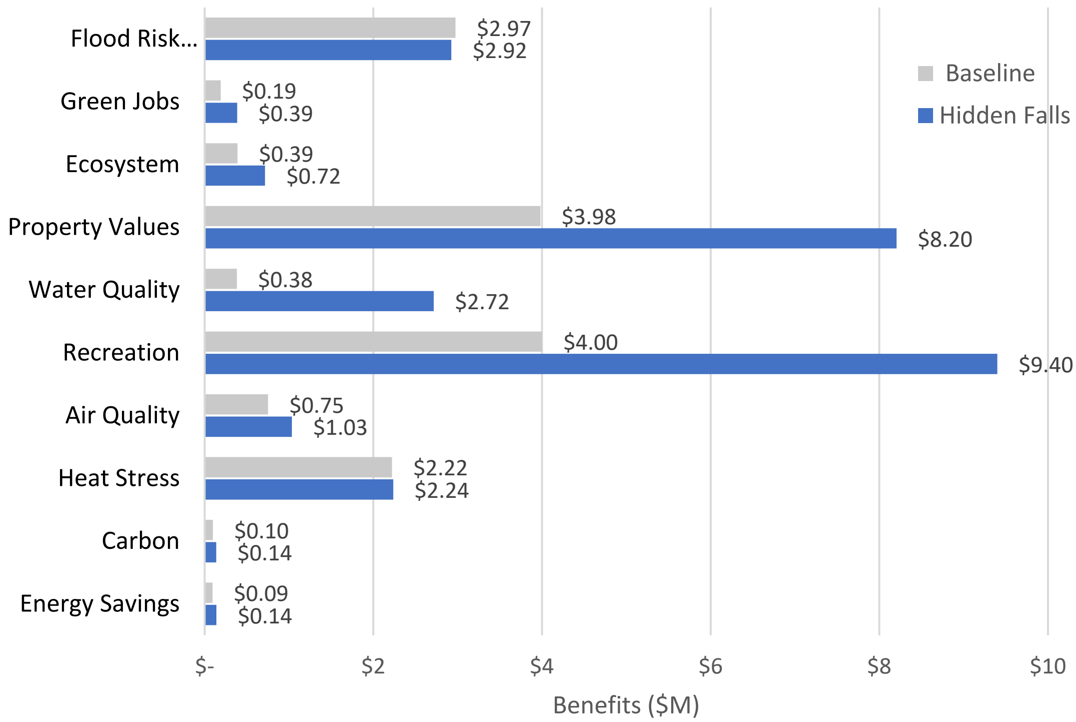


Figure 5-7. Present Value Benefits Over 28-Year Analysis Period: Hidden Falls and Baseline Alternatives.
(2019 USD)

Table 5-6. Present Value Benefits and Costs Over 28-Year Analysis Period: Hidden Falls and Baseline Alternative.
(2019 USD)

Benefit Category	Hidden Falls	Baseline
Energy Savings	$133,615	$89,077
Carbon	$131,087	$93,693
Heat Stress	$3,747,801	$3,608,696
Air Quality	$999,211	$727,248
Recreation	$9,205,273	$3,918,420
Water Quality	$2,660,654	$373,632
Property Values	$8,035,257	$3,899,119
Ecosystem	$774,358	$420,954
Green Jobs	$383,616	$188,340
Flood Risk Reduction	$2,924,368	$2,974,690
Total benefits	**$27,893,556**	**$15,082,478**
Total costs	**$21,532,600**	**$18,775,026**
Benefit cost ratio	**1.30**	**0.80**

Finally, as noted above, the Saint Paul case study is unique in that it compares the full costs and benefits of two stormwater management alternatives – the "business-as-usual" approach (the baseline alternative) and a GSI-based alternative (i.e., the Hidden Falls alternative). The results of the case study analysis indicate that the initial capital costs of the GSI-based alternative will likely be a bit less than those associated with the baseline scenario. However, the maintenance and rehabilitation/replacement costs (i.e., the life cycle costs) associated with GSI alternative will be much greater. Over the 28-year analysis period, the present value costs of the GSI alternative will amount to $21.5 M; this compares to $18.8 M for the baseline alternative – a difference of approximately $2.8 M.

However, the PV benefits of the GSI-based alternative are much greater than those estimated for the baseline alternative. Specifically, over the 28-year analysis period, the difference in benefits between the two alternatives amounts to approximately $12.8 M. Thus, every additional $1 spent under the Hidden Falls Alternative (compared to the baseline alternative) yields an additional $4.6 dollars in benefits. This incremental cost to benefit ratio may be useful in communicating the benefits of GSI-based alternatives.

5.1.7 Comparison to Autocase Analysis

It is difficult to exactly compare the results from the Tool to the results of the analysis of costs and benefits using Autocase. However, there are major differences in results related to water quality, property values, urban heat stress, and recreation.

First, the Autocase analysis estimates significantly higher water quality benefits associated with both alternatives. Both the Tool and Autocase rely on the same meta-analysis model to estimate water quality benefits (this methodology was first applied by the Tool authors in a 2008 study of the TBL benefits of GSI for the City of Philadelphia). The difference in benefits appears to be because the Autocase analysis multiplies annual average household WTP for water quality improvements by a much larger number of households. The authors acknowledge that this estimate is conservative; however, the underlying meta-analysis model draws on studies of large-scale water quality improvements (e.g., city- and state-wide) and/or for large/regional waterbodies. Thus, it is not appropriate to multiply household WTP by the number of households in a city to estimate the value associated with individual projects that contribute to citywide water quality improvements. Benefits must be allocated in some way. For this analysis, the authors scaled the number of households to include only those within one square mile of the improvement (roughly the number of households within the Census tract in which Hidden Falls is located).

The Tool's estimates for property value and urban heat stress reduction benefits are much higher than estimated in the Autocase analysis. To estimate property values and urban heat stress reduction benefits, this case study analysis includes the entire 134-acre site; however, as detailed above, the authors exclude some portions of the study area because they will not likely realize additional property value or heat stress reduction benefits. It appears that the Autocase analysis may have limited these benefits to a 16-acre study area where the GSI will be implemented (although this reflects our best guess based on model inputs). This results in fewer benefits. However, the purpose of the Autocase analysis was to compare the relative benefits and costs of the alternatives; it was not necessarily as concerned with identifying all potential benefits (pers. comm. N. Campeau, Vice President, Senior Water Resources Engineer, Barr Engineering, August 9, 2020).

The Tool methodology for estimating recreational benefits also seems to be quite different in terms of what was included in the analysis. The Autocase analysis includes benefits associated with restoring access to the 123-acre Hidden Falls regional park, which is located along the Mississippi River. This park seems to have several additional access points. The authors did not have data available on how the Ford redevelopment/rehabilitation of Hidden Falls Creek would increase visitation to the park beyond current levels. The recreational benefits associated with the park are therefore not included in this analysis.

Alternatively, the Autocase analysis does not seem to include recreational benefits associated with the 10 acres of green space under either alternative or with the GSI corridor/stream restoration associated with the Hidden Falls Alternative. Based on site renderings these assets will provide significant recreational opportunity. As detailed above, the authors treated these areas as "stormwater parks" to estimate benefits within the Tool.

Finally, Autocase calculates increased emissions (CO_2 and other pollutants) associated with energy used during construction. The Tool does not include these costs. For the analysis of the Ford site, increased emissions associated with energy use were minimal compared to overall benefits.

5.2 Case Study 2: Citywide Green Infrastructure Plan, Lancaster, Pennsylvania

5.2.1 Background

The city of Lancaster is located in Lancaster County in southcentral Pennsylvania. The city has a population of nearly 60,000 and spans approximately 4,700 acres; it is one of more than 770 cities nationwide with a combined sewer system (CSS). In 2011, the City developed a Green Infrastructure Plan (Plan; City of Lancaster 2011) that focused on integrating GSI into its approach for reducing CSOs into the Conestoga River, which flows into the Chesapeake Bay.

Case study highlights

- Comparison to results of similar study conducted using *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits* (CNT and American Rivers, 2010).
- Analysis of a citywide GSI Plan over 25-year implementation period.

The 2011 Plan identified opportunities for adding GSI throughout the city and estimated the water quality benefits associated with different levels of GSI implementation, including over a 5- and 25-year timeline. The Plan estimated that long-term implementation of GSI (i.e., over 25-years) on public and private property could reduce average annual stormwater runoff (and associated pollutants) by 1.053 billion gallons per year. Further, the GSI-based approach would result in significant cost savings compared to managing CSOs through gray infrastructure alone.

In developing the Plan, the City recognized the potential to provide significant TBL benefits through GSI implementation. In 2013 and 2014, the City worked with the U.S. EPA and a team of consultants to quantify these benefits using the framework developed by CNT and American Rivers (2010): *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits*. The findings of this analysis are documented in EPA report: The Economic Benefits of Green Infrastructure, A Case Study of Lancaster, PA (Mittman et al. 2014).

This case study relies on inputs from the City's Green Infrastructure Plan (Plan) and Mittman et al. (2014) to provide an updated TBL-based benefit-cost analysis of the 25-year GSI scenario included in the Plan. Note that the authors of this Tool regard the CNT and American Rivers (2010) Guide very highly. In addition, the authors recognize that conditions/estimates (including engineering and cost estimates) have likely changed in Lancaster since the initial development of the Plan, as more information on the cost and performance of GSI has become available, and the industry has continued to innovate. Further, many of the GSI projects included in the Plan may have already been implemented and/or may no longer be part of the City's vision. The objectives of this case study are simply to apply updated methodology to the Lancaster context, expand upon the categories of benefits quantified in the original case study, and to demonstrate the application of the Tool.

5.2.2 Key Inputs

Based on information in the Plan related to impervious area managed and annual runoff reduction under the 25-year implementation scenario, the authors estimate that Lancaster receives 37 inches of rain per year that results in runoff and that GSI improvements will capture runoff associated with a 1-inch storm event.

The management area consists of the City of Lancaster (approximately 4,700 acres) plus an additional 135 acres that fall within the CSS but outside of the city boundaries. In 2018, the population of Lancaster was 59,420. The city is located within the Northeast climate zone.

5.2.3 GSI Scenario

The Plan's 25-year GSI implementation scenario includes the management of 1,059 MG of stormwater runoff per year from 1,265 impervious acres throughout the city. The 1,265 impervious acres managed is achieved in year 25, with incremental GSI implementation over this timeframe. The Plan does not include detailed information on the types of GSI practices that will be installed over the long-term implementation period; however, it does provide data for 20 GSI demonstration projects. Mittman et al. (2014) extrapolated future GSI implementation by practice type based on characteristics of the 20 demonstration projects. These estimates, shown in Table 5-7, serve as the basis for the 25-year GSI scenario developed for the Tool.

Table 5-7. Assumptions for Recreational Analysis, Lancaster, PA.

GSI Practice type	% annual runoff reduction by practice type	GSI Practice area/number (total)
Bioretention/infiltration practices	56%	100 acres (4.36 million sq. ft.)
Permeable pavement	26%	Not reported
Trees	13%	118,000
Green roofs	4.5%	69 acres (3 million sq. ft.)[a]
Rainwater harvesting	1%	Not reported

a. Study also reported an average roof size of 5,000 sq. ft., which amounts to 600 green roofs.

The authors input the above data into the Tool on using the GSI.Scenario worksheet. It was necessary to change the run-on-ratio and other default design specifications for several practices to match the inputs reported by Mittman et al. (2014). Specifically:

- The bioretention footprint of 100 acres is relatively large for the volume of stormwater managed. The default run-on-ratio (i.e., impervious area managed / BMP footprint) included in the Tool for bioretention is 14.1, which is based on standard design specifications. It was necessary to change the run-on-ratio to 7 to match the inputs shown in Table 5-7.
- The Plan includes the planting of a total of 6,250 trees within the public right-of-way for the 25-year scenario (approximately 250 plantings per year) but notes that additional tree plantings will be incorporated into most GSI projects. Mittman et al. (2014) included a total of 118,000 trees, which the authors state is inclusive of existing trees within the City. For this case study, the authors also included 118,000 trees. To match the 13% of stormwater managed assigned to trees, it was necessary to lower the per tree volume management capacity to approximately 5 cubic feet.
- The authors lowered the run-on-ratio for green roofs to 0.83 in order to match the 3 million square feet of green roof estimate reported in Table 5-7. This indicates that green roofs are not managing

the full design storm and that additional green roof area is needed to capture the total annual volume of stormwater runoff assigned to green roofs (4.5%). This assumption means that green roofs likely will not have the same CSO-reduction benefits as other practices.

Figure 5-8 shows GSI Scenario Tool input page for this case study (GSI.Scenario worksheet).

5.2.4 Costs and Timeline

For this case study, the authors assume a 2.8% real discount rate, a 25-year construction period (starting in 2020), and an overall analysis period of 50 years.

The Plan estimates the total capital cost of the 25-year GSI scenario to amount to up to $184.8 million (including 15% continency and updated to 2019 from 2011 USD). The Plan also identifies the potential for a 45% cost savings if GSI projects are incorporated into other capital improvements (e.g.., transportation projects); if this potential is realized capital costs could be as low as $101.1 million (2019 USD). For this analysis, the authors assume that half of these savings are realized (i.e., capital costs amount to $142.9 million).

Mittman et al. (2014) evaluates annual benefits once full GSI implementation is achieved; the study also only includes capital costs and does not address O&M and/or replacement costs. To estimate O&M costs, the authors relied on the “mid-point” default values included in the Tool. It is assumed that replacement costs amount to 70% of capital costs, with replacement of initial capital beginning in year 25, such that in year 25 of the analysis period, year 1 installations are replaced, in year 26, year 2 installations are replaced, and so on.

In present value terms, total capital costs amount to $104.6 million, while total O&M and replacement costs amount to $100.2 and 36.7 million, respectively. Total present value lifecycle costs for the 25-year GSI scenario are more than $241.5 million (2019 USD).

5.2.5 Benefits

5.2.5.1 Avoided Infrastructure Costs

The 25-year GSI Scenario will avoid:

- Capital costs for large scale gray infrastructure CSO reduction projects
- Annual costs associated with pumping and treating stormwater through the CSS
- Potentially, other costs associated with “gray infrastructure” for properties located within the MS4.

The authors used the avoided cost calculators in the Avoided Infrastructure Costs Module to estimate these benefits.

5.2.5.2 Large-Scale CSO Reduction Projects

First, the Plan estimates that the 25-year GSI scenario will reduce CSOs by an average of 529 million gallons per year and that it would cost approximately $136.4 million to provide the same level of CSO reduction through gray infrastructure storage systems. Because the authors wanted to use the other cost calculators included in the Avoided Infrastructure Benefits Module (i.e., rather than including all avoided costs in the manual data entry option), they entered this amount directly into the Tool (Cell B29) as the avoided cost for large-scale CSO reduction projects (deep tunnels), overwriting the cost curve formula imbedded in Cell B29

5.2.5.3 Avoided Stormwater Pumping and Treatment

Under the 25-year GSI Scenario, 67% of the GSI will be located within the CSS. In addition, the Plan assumes that 75% of the stormwater runoff captured through GSI "reenters the CSS." Thus, 50% (67% x 75%) of the 1.059 billion captured through GSI each year will be removed from the system. This will result in avoided pumping and treatment costs of approximately $746,700 each year, based on the Plan's unit cost estimate of $1.41 per thousand gallons for wastewater pumping and treatment.

5.2.5.4 Other Avoided Stormwater Management Costs

Finally, that Plan assumes that approximately 50% of the impervious area managed (637 acres) through GSI will be installed at redevelopment sites as a result of the City's "first-flush" ordinance. It also assumes that policies would be put in place to incentivize and/or require GSI and that the ordinance would include additional requirements. In absence of these policies/incentives, developers would likely continue to install more conventional systems (e.g., detention, piping, conveyance systems).

Within the CSS, the avoided costs associated with GSI at redevelopment sites is included in the avoided cost estimate for large-scale CSO reduction projects. However, the plan assumes that approximately 33% of GSI will be installed in the MS4. Assuming this ratio applies evenly across all GSI types/practices, approximately 200 impervious acres (33% of 637 acres) would be managed through GSI as a result of the ordinance. Based on the Tool's default cost estimate for conventional stormwater management ($3 per square foot of impervious area managed), this would result in an avoided cost of $26.5 million. This cost is assumed to be spread evenly across the 25-year construction period.

5.2.5.5 Avoided Maintenance and Replacement Costs for Non-stormwater Assets

The 25-year GSI scenario includes a significant number of green roofs (close to 3 million square feet, approximately 600 roofs) and permeable pavement installations (7.2 million square feet based on a 2.0 loading ratio). These GSI practices avoid costs associated with their non-stormwater purposes (i.e., roofs and parking lots). Based on the default values and assumptions included in the Tool, green roofs will avoid $42.8 M (2019 USD) in traditional roof replacement costs over the analysis period due to their longer useful life. The Tool assumes green roofs are installed at new/redevelopment sites, and/or when roofs on existing buildings would have been replaced; over the course of the analysis period, green roofs will avoid 1.36 traditional roof replacement cycles for the 600 roofs, on average.

Avoided maintenance costs for traditional roofs and pavement amount to $1.32 million per year once all green roofs and permeable pavement is installed**.** Together total present value benefits of avoided replacement costs over the 50-year analysis period equal approximately $40.3 million.

GSI Practices - Enter Acres Managed or Number of BMPs

GSI Practice (BMP)	CLASIC BMP Name	Effective Impervious Acres Managed (acres)	Number of BMPs	Volume Capacity by BMP type (cft)	Calculated BMP Area (Footprint) (square feet)	Annual Runoff Volume (cft)
Rain gardens	Rain gardens		-	-	-	-
Bioretention facilities	Infiltration trenches	708.4	802	2,520,062	4,408,272	79,279,098
Green roofs	Green roofs	57	598	202,505	2,987,534	6,370,642
Tree planting/street trees	*	151.2	118,000	548,700	82,962,564	16,916,421
Permeable pavement	Permeable pavement	329	329	1,170,385	7,165,620	36,819,344
Cisterns - rainwater harvesting	Rainwater harvesting	8.29	45	30,080		927,373
Rain barrels - rainwater harvesting	Rainwater harvesting	11.48	1,000	7,352.9		1,284,583
Constructed wetland	*		-	-	-	-
Wet ponds	Wet pond		-	-	-	-
Biofiltration/grass or vegetated swale	Grass swale		-	-	-	-
		1,265		4,479,085		141,597,462

* CLASIC does not address "Tree planting/street trees" or "constructed wetland"

GSI BMP Design Specifications

GSI Practice (BMP)	Volume of BMP components: Depth (inches)	Ponding Depth (inches)	Porosity (0 to 1)	Volume capacity (cft)	BMP size: Avg. BMP footprint (sq ft.)	Run-on-ratio (Impervious area managed / BMP area)
Rain gardens	18	6	0.437		100	14.1
Bioretention facilities	24	6	0.437		5,500	7.0
Green roofs	6	0.5	0.35		5,000	0.83
Tree planting/street trees				5		
Permeable pavement	12	0.5	0.437		21,780	2.0
Cisterns - rainwater harvesting				668		
Rain barrels - rainwater harvesting				7.4		
Constructed wetland	24		0.72		21,780	17.6
Wet ponds	36		1		21,780	36.7
Biofiltration/grass or vegetated swale	4		1		10,000	4.0

* CLASIC does not address "Tree planting/street trees" or "constructed wetland"

Figure 5-8. Tool Snapshot - GSI Scenario Data Entry for City of Lancaster 25-Year GSI Implementation Scenario.

5.2.5.6 Energy Savings

The significant number of green roofs (600) and trees (118,000) included in the 25-year GSI Scenario will result in energy savings for buildings. In the Northeast climate zone, the average street tree will save 85 kWh in electricity and 30.2 therms of natural gas per year at full growth. Applying the average commercial/residential rate in Pennsylvania, each tree saves $9.58 in electricity and $45.12 in natural gas costs per year, at full growth. Over the 50-year analysis period total present value energy savings from trees amounts to $67.6 million. The present value savings accounts for tree growth over time, as well as year in which they are planted.[3]

The authors used Philadelphia as the reference city within the Tool to estimate green roof energy savings. Over the analysis period, close to 3 million square feet of green roof area will be installed. For this case study, the authors assumed that the roofs do not need irrigation, have an average leaf area index of 2, and an average soil depth of 6-inches (these inputs can be changed by users). Based on these assumptions, total energy savings amount to 0.49 kWh per square foot and 0.02 therms per square foot per year for electricity and natural gas, respectively, at full implementation. Over the 50-year analysis period, total present value energy savings for green roofs are more than $3.5 million.

Capturing stormwater runoff through GSI will also reduce energy use associated with stormwater pumping and treatment in the CSS. Lancaster's WWTP currently has an average flow rate of 20 MGD (City of Lancaster, 2020). Based on the default values in the Tool, the average treatment energy intensity for this size plant is 1,700 kWh/MG. Average energy pumping intensity is 2,520 kWh/MG. Applying these estimates, avoided wastewater pumping and treatment will save 2.23 million kWh per year at full implementation of the GSI Scenario. The monetary savings associated with these reductions are included in the avoided infrastructure benefit module. However, the energy savings serve as key inputs into the estimation of air quality benefits.

Potable water supply offsets from rainwater harvesting will reduce energy requirements for drinking water treatment. The Tool estimates that rainwater harvesting will result in approximately 7.3 MG of potable water supply offsets each year once all systems are installed. Currently, approximately 50% of public water supply in Lancaster comes from surface water sources (USGS 2015). Assuming the remainder comes from groundwater and applying the default average energy intensity estimates for these two sources, potable water supply offsets will reduce energy use for drinking water treatment by 13,428 kWh per year. The monetary savings associated with these reductions are included in the water supply benefit module.

5.2.5.7 Water Supply

While not explicitly stated, the authors estimate that the GSI Scenario includes approximately 45 cisterns and 1,000 rain barrels. If used properly, the stormwater that is captured through these rainwater harvesting systems will offset the use of potable water supplies (as noted above). Based on default values in the Tool,[4] RWH systems will offset approximately 7.3 million gallons of potable water supply per year once all systems are installed (~22 AF). To estimate the value of these potable water supply offsets, the authors applied the average retail potable water rate ($/AF) from the Tool for

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[3] The Tool assumes that all trees are planted as part of the user's GSI scenario. For Lancaster, some existing trees were also included in the analysis by Mittman et al. 2014. For this case study, the number of existing trees was not available. Thus, the Tool treats them as trees planted over time. This results in an underestimation of total benefits.

[4] To estimate potable water supply offsets from rain barrels, the authors used Washington D.C. as the reference city in the Tool. This is the closets city to Lancaster included in the list of reference cities in the Tool for which rain barrel benefits are calculated. Rain barrel benefits are based on modeling and results from Liftosky and Jennings (2014).

Pennsylvania. This results in a total potable water supply benefit of $58,363 per year at full implementation of the GSI Scenario.

GSI practices that infiltration water into the ground have the potential to increase groundwater supplies for later use. According to the USGS, groundwater accounts for approximately 50% of public water supply in Lancaster. Thus, infiltration from GSI practices could result in water supply benefits. The Tool estimates that 3,054 AF per year is managed through GSI practices that infiltrate water into the ground. As noted above, the Plan indicates that 25% of the stormwater captured in the combined sewer area reenters the CSS. This accounts for close to 17% of all infiltrated stormwater (25% multiplied by the 67% of stormwater capture that occurs in the CSS). For this case study, the authors did not have detailed information on the groundwater aquifer that underlies Lancaster. For the purposes of demonstration, it is assumed that that 50% of the stormwater treated through GSI is infiltrated into an aquifer used for drinking water. Thus, 41.5% was entered into the Tool as the percentage of total infiltration that goes to a water supply aquifer (accounting for both the 17% that reenters the CSS and the 50% that is infiltrated into a water supply aquifer). The authors also assumed a recharge efficiency rate of 77.5%. To value the additional groundwater, the wholesale water rate included in the Tool for Pennsylvania ($125/AF) was applied. Based on these inputs, total water supply benefits amount to $122,765 per year once all practices are installed.

5.2.5.8 Air Quality

At full implementation, the 25-year GSI scenario will save approximately 14,355 MWh of energy per year. This will result in reduced pollutants associated with emissions from power plants. In addition, the significant number of trees and added vegetation remove pollutants from the atmosphere, resulting in health benefits for City residents. The Tool estimates that at full implementation and growth of all trees, each year the GSI Scenario will reduce NOx by 23.4 MT, Sox by 16.8 MT, PM2.5 by 10.6 MT, and O3 by 113.9 MT. This translates to a present value benefit of $66 million in avoided health care costs over the 50-year analysis period.

5.2.5.9 Property Values

The significant increase in vegetation and GSI-related enhancements will results in aesthetic improvements across the City of Lancaster that will affect the value of nearby properties. The authors used data from the U.S. Census (Option 2 in the Tool) to estimate the baseline property values within the City of Lancaster for single family homes and multi-family buildings. Based on estimates from the literature and the mix of GSI practices included in the GSI Scenario, the weighted average increase in property values from GSI improvements (excluding green roofs) is 5%. For green roofs, the authors input 7% into the Tool for the expected increase.

GSI will be implemented throughout the city and the increase in vegetation and tree canopy will cover close to 40% of the city (once trees reach full growth). It is therefore assumed that 40% of properties could potentially be affected by GSI improvements. However, looking at maps of the City, it appears that approximately 25% of properties will not realize increases because they are already located in highly vegetated areas or near green spaces. Based on these inputs, GSI implementation will result in a present value benefit of $8.3 million over the analysis period (the Tool assumes that this benefit is distributed across the first 30-years of the analysis period). It is important to note that the average values from the Census data (e.g., approximately $82,000 per single-family home, average attached and detached).

5.2.5.10 Heat Stress Reduction

Urban greening and changes in the reflectivity of paved surfaces will reduce peak temperatures in Lancaster on extremely hot days. Using Philadelphia as a reference city (and adjusting for population), the Tool estimates that the 25-year GSI implementation scenario will reduce urban temperatures by

0.39 degrees Fahrenheit. By 2050, this reduces the number of extremely hot days in Lancaster by 6.6, saving an estimated 0.65 lives in that year (statistically) and reducing emergency room visits and hospitalizations due to extreme heat by 31 and 5, respectively. Over the analysis period, total present value benefits amount to more than $108 million in avoided mortalities and morbidities.

The heat stress reduction benefits estimated are significant. In one sense, however, they are conservative because the Tool only estimates heat stress reduction benefits associated with a 10-percentage point increase in surface reflectivity and/or vegetation. At full implementation, the 25-year GSI scenario will result in a much greater increase than 10 percentage points.

5.2.5.11 Recreation

Lancaster's Plan leverages park restoration and reconstruction projects outlined in the City's Urban Park, Recreation and Open Space Plan, which was completed in 2009. The Plan lays out specific concepts for the renovation and restoration of 5-park related GSI projects (as demonstration projects) that will manage storm water runoff from adjacent roadways and other impervious areas. The park improvements described in the Plan (e.g., tree planting, restoring basketball courts with permeable surfaces), paired with the improvements for the overall restoration of the parks will likely result in increased visitation. However, because the GSI projects are part of an overall park improvement program, only a portion of benefits associated with this increased visitation can be attributed to GSI. Further, the parks already exist; thus, benefits associated with park improvements include only the expected increase from current visitation.[5]

One way to estimate the benefits that can be attributed to GSI is to allocate the total benefits associated with the park improvements based on the percentage of the improvements that the GSI projects make up (e.g., this could be based on percentage of total cost or park improvement area). Typically, more detailed analysis is required to estimate how park visitation may change (i.e., increase) as a result of improvements relative to current visitation. For this case study, the authors make some simple assumptions for demonstration purposes. First, it is assumed that the GSI projects make up 25% of the total costs of the planned improvements and allocate 10% of the benefits. It is also assumed that the park improvements will increase visitation by 50% from current levels. So, for every 150 visits to the park post-improvement, 50 can be allocated to the improvements themselves, and 25% of those are allocated to GSI projects (8.3% of total benefits).

To understand the value of park improvements, the authors indicate in the Tool that the GSI Scenario will have "stormwater park" benefits. It is assumed that there will be five parks (associated with the 5 projects) with an average size of three acres (based on data from the Plan). Additional factors used to estimate park visitation include poverty rate (26.5% in Lancaster) and the number of residents within a one-mile radius (24,696 based on an average density of 7,865 residents per square mile). Assuming individuals typically visit parks eight months of the year in Lancaster, total visits across the five parks would amount to 19,776 per year; 1,632 of these visits (8.25%) are allocated to the GSI projects. Based on a direct use value of $8.80 per visit, total recreational benefits amount to $14,358 per year at full implementation.

In addition to park visits, Lancaster residents will benefit from urban greening and neighborhood improvements associated with GSI. In the recreation module, the authors indicate that the GSI Scenario includes recreational benefits associated with this general neighborhood greening.

[5] Residents who visit the parks may also benefit from the improvements because they will likely derive a greater value per trip. The Tool does not directly allow users to estimate changes in use values.

It is assumed again, that residents in Lancaster typically recreate outside seven months of the year and that 28% of residents will benefit from this neighborhood greening in terms of recreation. This represents the area of tree canopy and/or ground-level vegetation under the GSI Scenario (40% at full tree growth) and accounts for the percentage of people who are assumed to not visit parks or recreate (30%, based on surveys from the NRPA, see Appendix G). Based on these inputs, the Tool estimates that general neighborhood greening will result in an additional 38,821 trips per year, resulting in $160,719 in annual benefits.

Over the analysis period total present value benefits for recreation amount to approximately $3.0 million.

5.2.5.12 Carbon Reduction Benefits

Based on the default values included in the Tool the eGrid RFCE region, the Tool estimates that the GSI Scenario will avoid 8,527 MT of CO_{2e} emissions each year, at full implementation. The value of avoiding these emissions (assuming $51 per MT in 2020 and a real increase over time for the SCC) amounts to $434,871. The Tool estimates that trees will sequester 9,955 MT CO_{2e} each year at full growth, while other vegetation and green roofs will sequester 414 MT and 566 MT per year, respectively. However, green roofs only sequester carbon for four years, after which it is assumed to reach equilibrium and have no additional carbon benefits. Accounting for the GSI implementation timeline and tree growth over time, total present value benefits for carbon over the 50-year analysis period amount to $16.8 million.

5.2.5.13 Terrestrial Ecosystem Benefits

The 25-year GSI Scenario adds more than 90 million square feet (close to 2,100 acres) of potential habitat area. For this case study, the authors assume that 50% of this area (across all practices) is designed to provide habitat benefits. This results in $31.2 million present value benefits over the 50-year analysis period.

5.2.5.14 Water Quality Benefits

Because avoided gray infrastructure costs are included as a benefit in this analysis, it is not appropriate to include water quality benefits of the GSI Scenario. The analysis assumes that water quality benefits are the same under gray and green scenarios.

5.2.6 Results Summary

Figure 5-9 shows the present value benefits associated with the GSI Scenario over the 50-year analysis period; Figure 5-10 categorizes present value benefits by TBL category. Tables 5-8 and 5-9 present the annual physical unit benefits and monetized present value benefits and costs. As shown, the benefits of the GSI Scenario significantly outweigh the estimated costs. While this case study is intended for Tool demonstration purposes only, rather than an exact analysis of the City's plans for GSI, it does point to the significant potential for GSI to provide important community benefits to the residents of Lancaster.

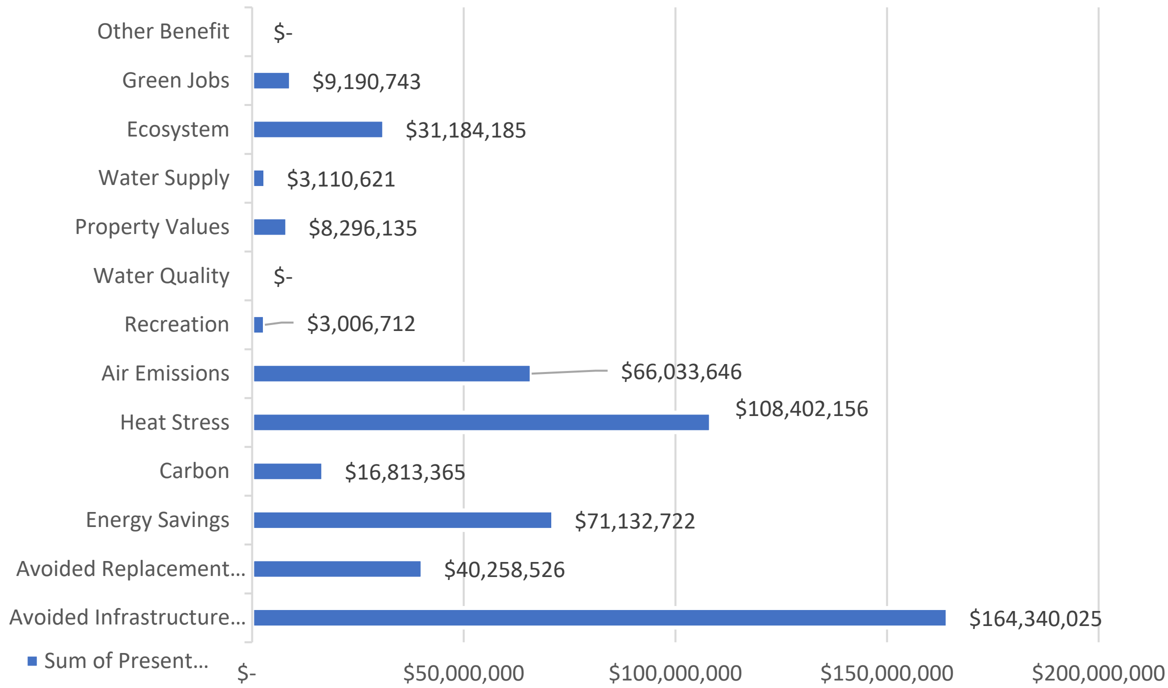

Figure 5-9. Present Value Benefits of Lancaster 25-Year GSI Implementation Scenario, Over 50-Year Analysis Period.

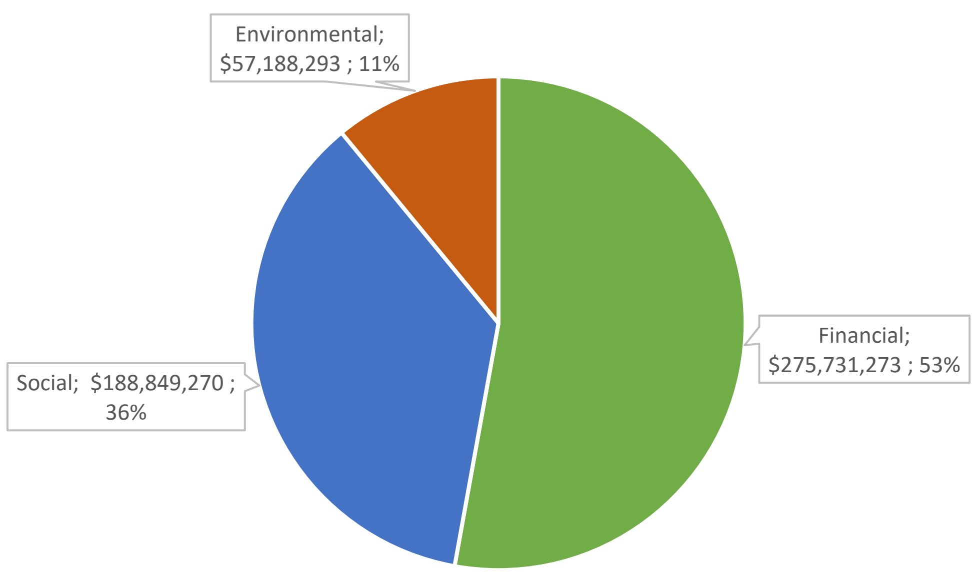

Figure 5-10. Present Value Benefits of Lancaster 25-Year GSI Implementation Scenario, Over 50-Year Analysis Period, by TBL Category.

Table 5-8. Annual Physical Unit Benefits of Lancaster 25-Year GSI Implementation Scenario, at Full Implementation.

Benefit category	Benefit	Physical units
Energy savings	Electricity Savings	13,687,261 kWh
	Natural Gas Savings	3,608,513 kWh
Air quality benefits	Sulfur Dioxide Reduction	16.81 MT
	Nitrogen Oxide Reduction	23.37 MT
	Particulate Matter Reductions	10.59 MT
	Ozone Reduction	113.91 MT
	Avoided GHGs from Energy Use	8,527 MT
Carbon reduction	Avg. CO_{2e} Sequestered - Trees (Yr. 30)	9,955 MT
	Avg. CO_{2e} Sequestered - Green Roofs	566 MT
	Avg. CO_{2e} Sequestered - Bioretention, Rain Gardens	414 MT
Water supply	Potable Water Supply Offsets	22 AF
	Groundwater Recharged	982 AF
Heat stress reduction	Avoided Fatalities (2050)	0.65 deaths
	Avoided Hospitalizations (2050)	5.1 hospitalizations
	Avoided Emergency Room Visits (2050)	30.9 visits
Property values	Single Family Residential (properties affected)	4,385 properties
	Multifamily Residential	651 properties
Recreation	Stormwater Parks	1,632 visits
	Neighborhood Greening	38,821visits
Green jobs	Construction jobs (filled by otherwise unemployed)	157 job-years (total)
	Annual maintenance jobs (filled by otherwise unemployed)	24.5 job-years
Ecosystem	Terrestrial habitat area	1,037 acres

Table 5-9. Present Value Benefits and Costs of Lancaster 25-Year GSI Implementation Scenario, Over 50-Year Analysis Period.
(2019 USD)

Benefit Category	Present value	Annualized
Avoided Infrastructure Costs	$ 164,340,025	$ 5,925,121
Avoided Replacement Costs	$ 40,258,526	$ 1,451,482
Energy Savings	$ 71,132,722	$ 2,564,621
Carbon	$ 16,813,365	$ 606,190
Heat Stress	$ 108,402,156	$ 3,908,335
Air Emissions	$ 66,033,646	$ 2,380,779
Recreation	$ 3,006,712	$ 108,404
Property Values	$ 8,296,135	$ 299,109
Water Supply	$ 3,110,621	$ 112,150
Ecosystem	$ 31,184,185	$ 1,124,316
Green Jobs	$ 9,190,743	$ 331,363
Total benefits	$ 521,768,836	$ 18,811,871
Total costs	$ 241,515,082	$ 8,707,593
Benefit cost ratio	2.160	

5.2.7 Comparison to CNT and American Rivers Guide

Benefits estimated with the Guide by Mittman et al. (2014) included avoided gray infrastructure capital costs, avoided stormwater pumping and treatment costs, energy savings, air quality improvements, and carbon reduction benefits. The methodologies and inputs used to estimate avoided gray infrastructure costs and avoided costs for pumping and treating stormwater are the same in both case studies. Our results represent the same benefits updated to 2019 USD.

The Tool estimated significantly higher energy savings associated with trees. This seems to be due to the significantly higher estimates for savings per year attributed to trees. For example, the Tool includes a default value of 85 kWh per tree for the Northeast climate region, while Mittman et al. (2014) used 39 kWh per tree. The estimate included in the Tool represents average savings for 21 of the most common street tree species in the northeast region. The methods and inputs used in both studies rely on data/information developed by the USFS.

The Tool also estimates significantly higher air quality benefits, particularly for ozone. To estimate these benefits, the Tool relies on ozone uptake and removal rates for urban areas by state published by the USFS in 2014 (Nowak et al. 2014). These estimates are based on per meter squared of leaf area, while the Guide's published estimates are per tree. In addition, the Tool includes pollutant uptake and energy emissions reductions for $PM_{2.5}$. The authors do not believe that monetized estimates for $PM_{2.5}$ were available in 2010 (when the Guide was developed). Reducing $PM_{2.5}$ has a much higher economic value compared to other pollutants. Estimates for carbon reduction between the two case studies were relatively similar.

The biggest difference between the Guide and the Tool is that Tool quantifies a greater number of benefits, and compares benefits and costs over time, rather than estimating annual benefits at full implementation. However, many of the same approaches and methodologies are utilized.

5.3 Case Study 3: GSI in the Public Right-of-Way; Seattle, Washington

5.3.1 Background

The City of Seattle plans to use GSI to manage 700 million gallons of stormwater per year by 2025. Seattle Public Utilities (SPU) is working with multiple partners to achieve this goal through the implementation of several different GSI-based programs. As part of this effort, SPU is focused on leveraging the multiple benefits of GSI to create opportunities for addressing public health, workforce development, youth empowerment, walkability in neighborhoods, and safe and inclusive access to neighborhood gathering spaces.

Case study highlights

- Quantifies benefits of three bioretention sites in the public right-of-way that provide pedestrian improvements and recreational benefits
- Integration of "multiple objective decision analysis" (MODA) method for evaluating qualitative benefits.
- Evaluation of project slated for construction in 2021.

The Natural Drainage System (NDS) Partnering Program makes up a key component of SPU's overall GSI implementation plan. It is a multi-year capital improvement program focused on constructing street-side bioretention systems (or NDSs) in three of the City's high priority watersheds. When completed, the program will manage flow and provide water quality treatment for 44 acres of impervious area within the public right-of-way. The City of Seattle Department of Transportation (SDOT) is a key program partner.

This case study focuses on the series of NDS Partnering Program projects planned for implementation in the Longfellow Creek Watershed. Longfellow Creek flows through urbanized neighborhoods in West

Seattle; it is approximately three miles in length and drains more than 2,000 acres. Approximately one-third of the creek flows through underground pipes beneath the urban landscape. The creek is an important salmon-bearing tributary in the Lower-Duwamish River basin.

SPU is partnering with several agencies to ensure that the Longfellow Creek projects provide multiple benefits. SDOT will provide pedestrian safety and mobility improvements, while the City's Office of Arts and Culture will incorporate art installations at one of the project sites through 1% for Arts[6]. The projects are also being paid for in part by the King County Flood Control District and the Levy to Move Seattle.[7] Project design has been informed through extensive outreach to community members within the affected neighborhoods to ensure projects are consistent with their priorities.

SPU has identified several important goals and values for stormwater management projects that the Tool does not capture. To incorporate these aspects of proposed projects into its' decision-making, SPU has developed a multiple objective decision analysis (MODA) framework. The MODA framework is not quite finalized; however, this case study presents the draft MODA for the Longfellow Creek projects as an additional tool to help understand the benefits and values of proposed stormwater infrastructure options.

5.3.2 Key Inputs

The Longfellow projects are located in Seattle's Delridge and Westwood neighborhoods. SPU reports that this area receives approximately 37-inches of rainfall per year that results in runoff; the projects within the Longfellow Creek Watershed are designed to manage runoff associated with 0.5-inches of rainfall, which represents 80% of the average annual runoff volume. percentile storm.

The management area encompasses approximately 125 acres around the project sites; based on the population density of the Delridge neighborhood (5,030 persons per square mile), the authors estimate a study area population of approximately 1,000 people. Seattle is within the Pacific Northwest climate zone.

5.3.3 GSI Scenario

The GSI Scenario analyzed includes three project sites within the Longfellow Creek Watershed that will collectively manage 5.8 impervious acres within the public right-of-way. Figure 5-11 shows the location of these projects within the watershed, as follows:

- The 24th Ave SW project, which includes NDS installations and a partnership with SDOT to build sidewalks along 4 city blocks; project improvements include street-side bioretention plantings, street trees, and pedestrian accessibility upgrades.
- The Sylvan Triangle project, a relatively small project that includes NDS installations and street tree plantings at a busy intersection.
- The SW Kenyon St project includes significant stormwater management and other improvements at a street end that serves the community, and specifically kids on their way to school, as a pathway across Longfellow Creek. In addition to NDS installations, project elements include the creation of a community gathering space that provides access to Longfellow Creek, improving the existing Longfellow Creek trail/pathway (including making it safer and more accessible and replacing an existing bridge), and adding more lighting. The project also includes a significant art installation.

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[6] A City ordinance that sets aside 1% of capital improvement project funds for the commission, purchase, and installation of artworks.

[7] A $930 million voter-approved levy that provides funding to improve traveler safety, maintain streets and bridges, and invest in reliable affordable travel options.

Figure 5-12 presents artist renderings of the project, which were developed at the 60% design phase.

The authors entered the Longfellow Creek projects into the Tool as bioretention projects; however, the projects also include 89 deciduous street trees and increased vegetated area that do not necessarily provide additional stormwater management benefits (at least in terms of volume managed). The additional vegetated area was entered as biofiltration and additional volume capacity benefits associated with it were zeroed out. The authors did the same for trees. Figure 5-13 shows how data was entered into the Tool on the GSI Scenario worksheet.

5.3.4 Costs and Timeline

For this case study, the authors assume a 2.8% real discount rate and an analysis period of 50-years (these reflect the Tool default values). The project is slated to begin construction in 2021 and will take approximately one year to construct.

Total capital costs for the Longfellow projects amount to $5.7 million, while O&M costs will average $17,000 per year. SPU estimates that it will incur $50,000 in significant replacement/rehabilitation costs every 20 years. Over the 50-year analysis period, total present value capital, O&M, and replacement costs amount to $5.87 million (Figure 5-14).

Figure 5-11. GSI Project Sites, Longfellow Creek Watershed, Seattle, WA.
Source: City of Seattle (2020)

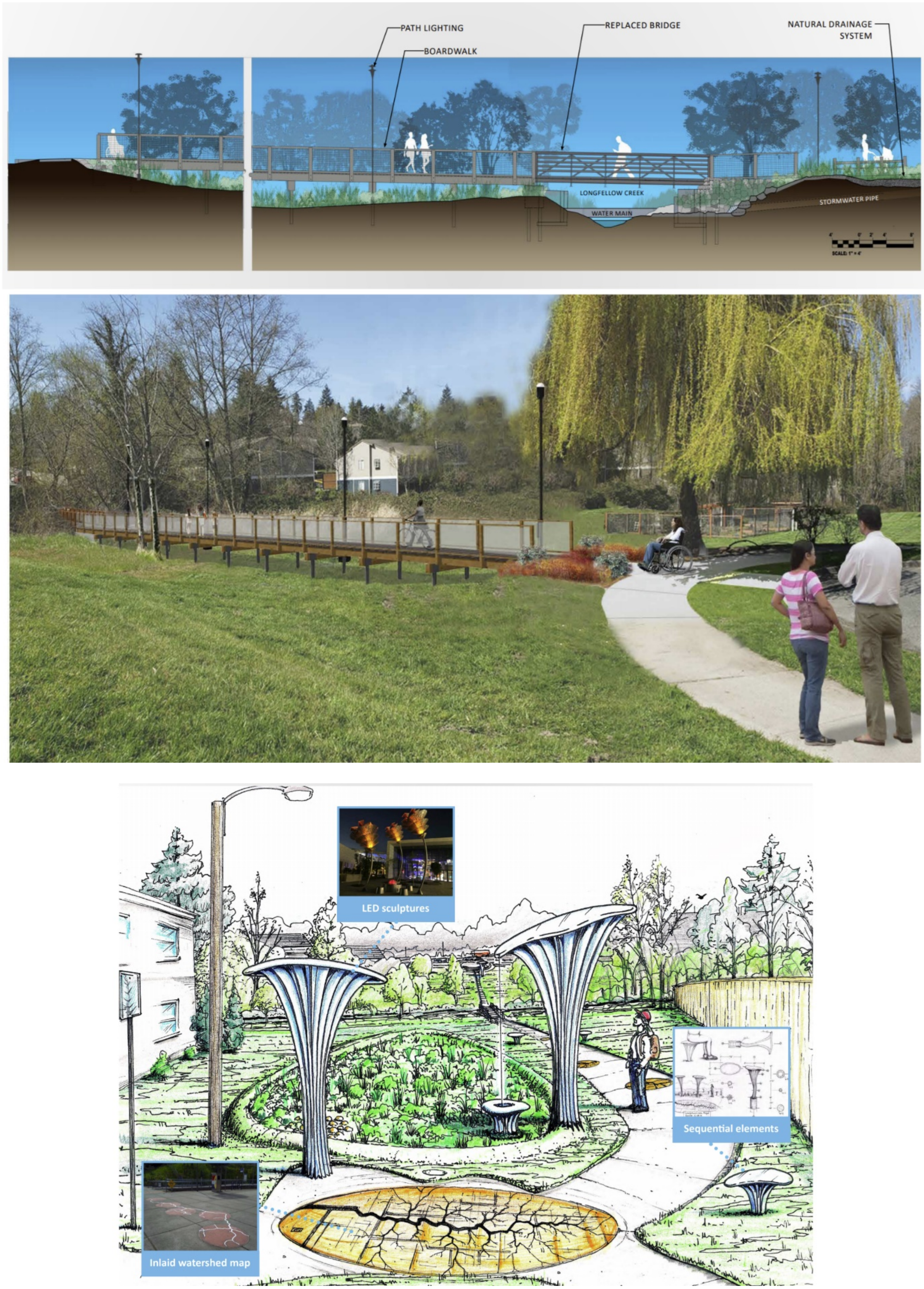
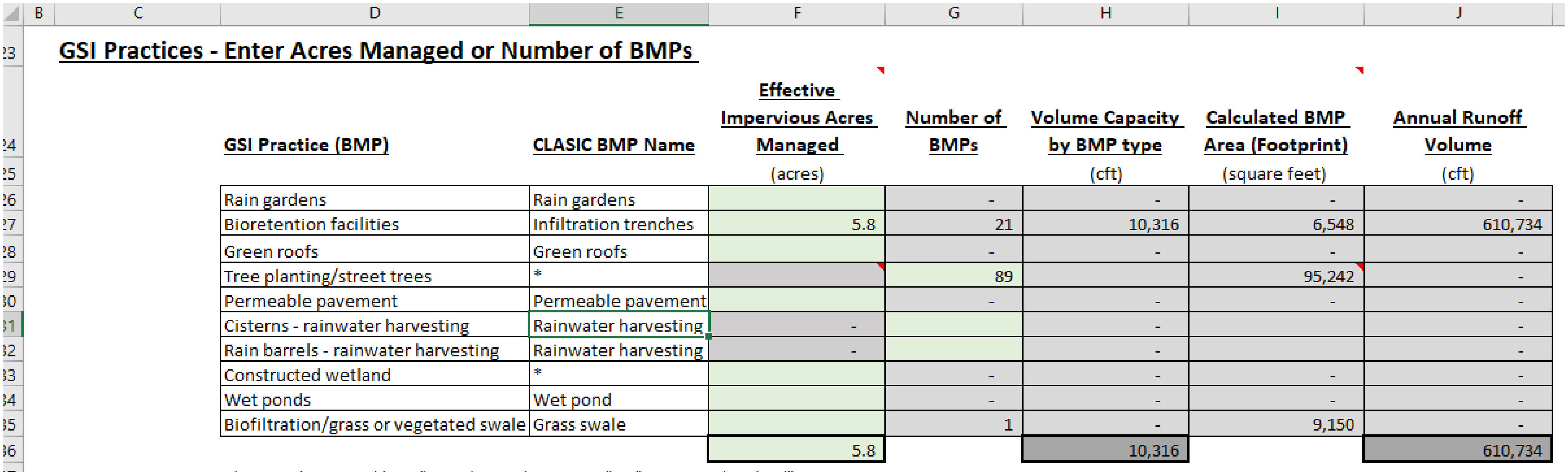


Figure 5-12. Artist Renderings of the SW Kenyon Street Project, Seattle, WA.
Source: City of Seattle (2020)



GSI Practices - Enter Acres Managed or Number of BMPs

GSI Practice (BMP)	CLASIC BMP Name	Effective Impervious Acres Managed (acres)	Number of BMPs	Volume Capacity by BMP type (cft)	Calculated BMP Area (Footprint) (square feet)	Annual Runoff Volume (cft)
Rain gardens	Rain gardens		-	-	-	-
Bioretention facilities	Infiltration trenches	5.8	21	10,316	6,548	610,734
Green roofs	Green roofs		-	-	-	-
Tree planting/street trees	*		89		95,242	-
Permeable pavement	Permeable pavement		-	-	-	-
Cisterns - rainwater harvesting	Rainwater harvesting	-		-		-
Rain barrels - rainwater harvesting	Rainwater harvesting	-		-		-
Constructed wetland	*		-	-	-	-
Wet ponds	Wet pond		-	-	-	-
Biofiltration/grass or vegetated swale	Grass swale		1	-	9,150	-
		5.8		10,316		610,734

Figure 5-13. Tool Snapshot - GSI Scenario Data Entry for Longfellow Creek Projects, Seattle, WA.

Total Cost for GSI Scenario (Manual entry)

Total capital	5,700,000
Annual O&M (at full implementation)	17,000

Enter replacement costs manually below (Row 63)

Construction Begin Year (2020 = 1)	Construction Period (yrs)		Discount rate	2.8%
2	1		Analysis period	50

Year		2019	2020	2021	2022	2023	2024	2025	2026	2
		0	1	2	3	4	5	6	7	
Total costs	**Sum**									
Capital Costs	**5,700,000**	-	-	5,700,000	-	-	-	-	-	-
Maintenance Costs	**850,000**		-	-	17,000	17,000	17,000	17,000	17,000	17,0
Replacements Costs	**100,000**									
Total	**6,616,000**	-	-	5,700,000	17,000	17,000	17,000	17,000	17,000	17,0
Present Value	**Sum**									
Capital Costs	**5,393,723**	-	-	5,393,723	-	-	-	-	-	-
Maintenance Costs	**430,092**		-	-	15,648	15,222	14,808	14,404	14,012	13,6
Replacement Costs	**42,911**		-	-	-	-	-	-	-	-
Total	**5,866,727**	-	-	5,393,723	15,648	15,222	14,808	14,404	14,012	13,6

Figure 5-14. Tool Snapshot – Costs and Timeline Data Entry for Longfellow Creek Projects, Seattle, WA.

5.3.5 Benefits

5.3.5.1 Avoided Infrastructure Costs

For this case study, the authors calculate the total benefits (including water quality) of the Longfellow projects and compare them to costs. Thus, it is not appropriate to include avoided infrastructure costs as part of the benefit-cost ratio.

The Longfellow projects are located within the separate sewer area of the city; in this drainage area, runoff is directly discharged to Longfellow Creek. However, the projects are specifically being built under the City's consent decree for CSO reduction, in which the City negotiated to defer fixing barely out of compliance CSOs that occur elsewhere in the City to focus on projects in the MS4 that would provide greater water quality benefits. Thus, if data is available on the costs of the avoided CSO projects, they could be counted as avoided infrastructure costs; however, only the net increase in water quality benefits provided by the Longfellow projects could then be included (i.e., the additional water quality benefits above and beyond those that would have been provided by the CSO control projects). This would likely result in a greater benefit cost ratio because the Longfellow projects are more cost-effective in terms of water quality gains.

5.3.5.2 Water Supply

The projects do not include rainwater harvesting practices or recharge local groundwaters. There are therefore no water supply benefits.

5.3.5.3 Energy Savings

The Longfellow projects will add 89 deciduous trees; this results in energy savings for heating and cooling in buildings. Under both alternatives, each tree will save \$6.30 per year in electricity and \$2.31 per year in natural gas once it is fully mature (the Tool assumes full maturity at year 30). This is lower than energy savings associated with trees in most other climate zones because of Seattle's relatively moderate climate. Total present value energy saving benefits are relatively small, amounting to only about \$11,700 over the study period.

As noted above, while much of Seattle is served by a combined sewer system, the Longfellow Creek projects are located in the MS4 portion of the city and will manage stormwater that would otherwise be directly discharged to the Creek without treatment. Thus, there are no energy savings associated with reduced pumping and treatment of stormwater through the combined sewer system.

5.3.5.4 Air Quality Improvements and Associated Health Benefits

At full tree growth, the Longfellow projects will save approximately 6,012 kWh of energy per year. This will result in modest emissions reductions from power plants. In addition, trees and added vegetation associated with the NDS improvements will remove pollutants from the atmosphere, resulting in health benefits for neighborhood residents. The Tool estimates that at full growth of all trees, the NDS projects will reduce NOx by 0.05 MT, Sox by 0.02 MT, PM2.5 by 0.02 MT, and O3 by 0.27 MT. Total present value air quality benefits are also relatively small, amounting to \$130,000 over the study period.

5.3.5.5 Property Value Benefits

The planned NDS and pedestrian improvements will provide aesthetic improvements and enhance quality of life for neighborhood residents. This is reflected in increased values for properties located near or directly adjacent to the projects. As noted above, the 24^{th} Avenue SW project spans 4 blocks, locating NDS, street trees, sidewalks, and other pedestrian improvements directly adjacent to 69 single family homes. The Sylvan Triangle project is located in a mostly commercial area but is directly across from two single family homes. The average value of these properties is \$575,910. The authors used

Google Earth to count the number of single-family properties affected by the NDS projects and Zillow to estimate the average value of these homes.

To estimate the total property value benefit associated with these two projects, an average increase of 4.25% is assumed to be associated with the improvements. This is a relatively conservative estimate given the number of trees that will be planted as part of the NDS projects, because trees often realize larger increases. However, the authors apply the 4.25% based on findings from a study that evaluated the property value benefits associated with a similar street improvement project conducted by SPU (Ward et al. 2008). It is further assumed that only the properties directly adjacent to projects (i.e., the 71 total single-family homes) would realize an increase in value. Finally, the authors allowed for 87% of the property values to be included in the analysis, subtracting out the air quality and energy saving benefits to avoid double counting. Overall, the present value property value benefits associated with the 24th Ave. SW and Sylvan Triangle projects amount to $1.275 M.

The Kenyon SW Street project includes significant aesthetic improvements, as well as the creation of a community gathering space; based on Google Earth imagery, it is located directly adjacent to several multi-family buildings. While the aesthetic, mobility, and safety improvements might very well increase the value of the surrounding buildings, many of these benefits will likely be tied to the recreational benefits that the project provides. Property value increases are therefore not included as benefits for this portion of the project.

5.3.5.6 Recreation

The Kenyon SW Street project will provide an important community gathering space, as well as a safe way to access Longfellow Creek. For this case study, the authors classified the development of this site as providing similar recreational benefits as a pocket park. Based on Google Earth imagery, it is estimated that the park will be approximately 0.3 acres in size and will serve 1,000 residents (this is the maximum recommended by NRPA but less than the number of residents within one quarter mile of the park based on the population density of the neighborhood). The authors assume that weather in Seattle is amenable to park visits approximately 11 months of the year. Based on these inputs, the park will see approximately 12,900 visits per year. Based on the characteristics of the park, including the planned artistic improvements and opening up of Longfellow Creek, the Tool estimates that the direct use value associated with the new community space will amount to $8.80 per visit.

In addition to the pocket park, the 24th Ave SW project will provide urban greening and pedestrian improvements that will encourage mobility through the neighborhood. The authors used the general urban greening component of the recreation module to estimate the benefits associated with these improvements. First, the area of that would benefit from general urban greening was limited to the area directly adjacent to these projects; this accounts for approximately 15% of the 125-acre study area (this was determined using the measurement tool on Google Earth). Again, the authors estimated that recreation activity can occur 11 months of the year in Seattle. Overall, the Tool estimates that the improvements will support an additional 550 instances of recreational activity within the 24th Ave. SW project area.

In total, the Tool estimates that over the 50-year study period, present value recreational benefits will amount to approximately $2.93 million.

5.3.5.7 Heat Stress

EPA CIRA models do not report a statistically significant relationship between extremely hot days and mortalities. Thus, the Tool is not able to calculate additional lives saved or avoided health effects associated with the cooling effect of GSI. However, the City of Seattle Office of Emergency Management

(OEM) reports that excessive heat events result in significant adverse effects for city residents (Seattle OEM 2019), particularly the elderly, infants, the homeless, low-income residents, and people who are socially isolated. OEM states that Seattle's typically mild summers result in a population that is less acclimatized to extreme heat; thus, health effects associated with heat begin in Seattle at lower temperatures compared to many other places. OEM also cites the following studies:

- Statistical analysis of King County mortality data found that adverse health effects for heat begin to rise at 78.6° F (cite).
- Calkins et al. (2016) found that an 8% increase in Basic Life Support calls and a 14% increase in Advanced life Support calls on excessive heat days in King County (over a 6-year study period).
- Isaksen et al. (2016) found a 2% increase in hospitalizations and a 10% increase in risk of death on EHE days in King County over a 30-year period, with risk increasing as heat increases.
- Both studies cited above identified the elderly as an especially vulnerable population. The studies also revealed an increased risk on EHE days for EMS calls, diabetes-related mortality, kidney disorders, acute renal failure, natural heat exposure, and asthma hospitalizations for young and middle-aged adults, a population generally thought to be more resilient to heat.
- According to OEM, a study of heat vulnerability on a national scale (Reid et al. 2009) found that Seattle is on par with Chicago, site of a 1995 EHE that killed over 700 people. The study used a Heat Vulnerability Index (HVI), driven by four factors: land cover, lack of air conditioning, the proportion the population with chronic medical conditions, and social vulnerability (race, poverty, age, and housing conditions).

Based on aerial maps and Google Earth imagery, the 24th Ave. SW project has the potential to provide significant cooling effects to households located directly adjacent to the improvements (69 single-family households) and associated health. The location of this project appears to fall within an area with a relatively high HVI, as determined by Reid et al. (2009). The other projects (Kenyon Street SW and Sylvan Triangle) will likely provide minimal heat stress reduction benefits. The Kenyon Street SW project appears to be located in an area that is highly vegetated and will therefore do little to increase shade/surface reflectively of the site; the Sylvan Triangle site is relatively small and will install NDS systems within an already vegetated area, although the addition of trees at this site may provide some additional cooling benefits.

Given the number of studies cited above, as well as additional studies cited by OEM in The Seattle Hazard Identification & Vulnerability Analysis, it may be possible to estimate the heat stress reduction benefits associated with the 24th Ave SW project (e.g., by scaling findings to the population affected by improvements). These benefits could then be incorporated into the Tool as an additional benefit on the Results Dashboard (and included in the overall benefit-cost analysis). However, as discussed in more detail below, SPU incorporates heat stress reduction benefits into its' MODA methodology. For this case study, the authors rely on the MODA to provide an assessment of benefits that are not quantified in the Tool.

5.3.5.8 Green Jobs

The Tool estimates that the Longfellow projects will support 31 construction job-years and requires approximately 0.2 full time employees per year for ongoing maintenance. The authors assume that 25% of construction jobs and 100% of maintenance jobs are filled by individuals who would otherwise be unemployed/targeted as part of a workforce development program. Total present value benefits associated with the creation of these "green jobs" (construction and maintenance) range from approximately $116,00 to $170,000, depending on the valuation method applied.

5.3.5.9 Water Quality

Improving water quality is the primary objective of the Longfellow Creek projects; as noted above, the creek is an important salmon-bearing tributary of the Duwamish River. Currently untreated stormwater runoff flows directly into the creek, carrying urban pollutants with it. To estimate the water quality benefits of the projects, the authors assume a baseline level of water quality of 4 on the 10-pt water quality scale and increase to 5.5 once the projects are fully functioning (a 1.5 unit increase). Other key inputs into water quality meta-analysis are as follows:

- The change does not occur in an estuary
- Water quality changes affect local freshwater bodies
- 2010 Median household income is $63,088 (2010 USD)
- The affected water supports recreation and approximately 10% of the affected population use the creek for this purpose (note: this is a rough estimate based on the natural areas/parks along the affected portion of the creek).

Based on these inputs, the meta-analysis incorporated into the Tool estimates that households in Seattle would be willing to pay $43.88 per year to improve water quality within the City's freshwater bodies. However, the Longfellow projects represent only a portion of SPU's planned water quality improvement projects. To allocate the percent of total WTP that can be attributed to these projects, the authors divided the cost of the Longfellow projects by the total cost for SPU's six-year water quality capital improvement plan. The resulting percentage, 1.4%, is then multiplied by the annual WTP per household ($43.88) and the total number of households in Seattle (283,510). Based on this methodology, water quality present value benefits will amount to $4.41 million over the 50-year period.

5.3.5.10 Carbon Reduction Benefits

Based on the default values included in the Tool for the eGrid NWPP region, the Tool estimates that the Longfellow NDS projects will avoid 4.7 MT of CO_{2e} emissions each year, at full tree growth. The Tool estimates that trees and other vegetation will sequester 15.2 MT CO_{2e} each year at full growth. Accounting for the GSI implementation timeline and tree growth over time, total present value benefits of carbon reduction over the 50-year analysis period amount to $26,100.

5.3.5.11 Terrestrial Habitat and Ecosystem Benefits

The Longfellow NDS projects will add more than 111,000 square feet of potential habitat area through bioretention and street trees (this includes bioretention that provides similar tree canopy area for trees at full growth). For this case study, the authors assume that 75% of this area (across all practices) is designed to provide habitat benefits. This results in $86,400 in present value benefits over the 50-year analysis period.

5.3.5.12 Additional Benefits

There are several additional benefits associated with the Longfellow Creek projects that the Tool does not capture. For example, the project on 24th Ave. SW will address an existing flooding problem that has developed as a result of a lack of drainage infrastructure. SPU has not analyzed the avoided flood damage costs associated with these improvements. However, these benefits (and others) are accounted for in the utility's MODA framework, as described in more detail below.

5.3.6 Results Summary

Figure 5-15 shows the present value benefits associated with the Longfellow Projects over the 50-year analysis period; Figure 5-16 categorizes present value benefits by TBL category. Tables 5-10 and 5-11 present the annual physical unit benefits and monetized present value benefits and costs. As shown, the benefits of the projects outweigh the estimated costs at a ratio of 1.53. The largest benefits (in terms of monetary valuation) include those related to property values, water quality, and recreation. Many of the other GSI benefits appear relatively small in comparison; however, when scaled up across all of SPU projects (e.g., to meet SPU's 700 M gallon goal), these benefits will begin to add up. In addition, for this case study, the authors applied relatively conservative assumptions. For example, property value benefits associated with multi-family buildings located near the Kenyon Ave. site were not included in the analysis. The Tool also did not calculate any potential heat stress reduction benefits; however, based on information from the City of Seattle OEM, EHEs have adversely affected local residents. The 24th Ave. SW project seems to have the potential to provide moderate heat-related benefits.

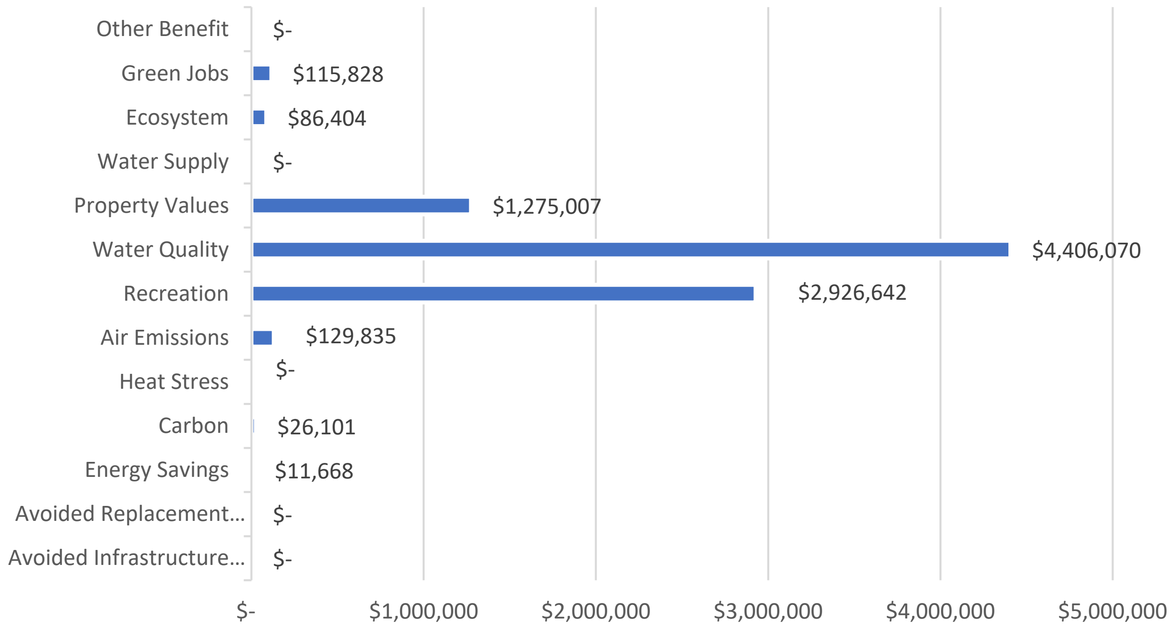


Figure 5-15. Present Value Benefits of Longfellow Creek Projects, Over 50-Year Analysis Period, Seattle, WA.
(2019 USD)

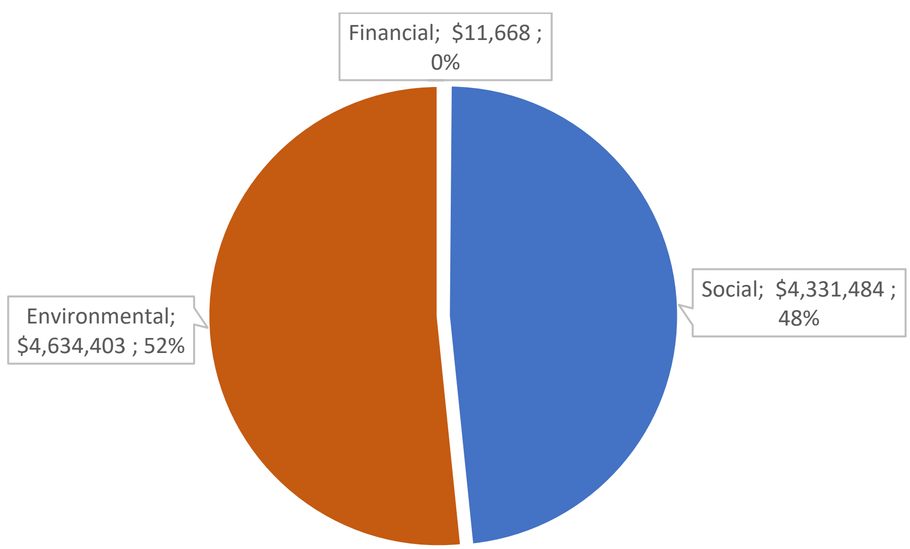


Figure 5-16. Present Value Benefits of Longfellow Creek Projects, Over 50-Year Analysis Period, by TBL Category, Seattle, WA.
(2019 USD)

Table 5-10. Annual Physical Unit Benefits for Longfellow Creek Projects, Seattle, WA.
Assumes Full Tree Growth.

Benefit category	Benefit	Physical units
Energy savings	Electricity Savings	6,012 kWh
	Natural Gas Savings	198 kWh
Air quality benefits	Sulfur Dioxide Reduction	0.02 MT
	Nitrogen Oxide Reduction	0.05 MT
	Particulate Matter Reductions	0.02 MT
	Ozone Reduction	0.27 MT
	Avoided GHGs from Energy Use	4.7 MT
Carbon reduction	Avg. CO_{2e} Sequestered - Trees (Yr. 30)	13.8 MT
	Avg. CO_{2e} Sequestered - Bioretention, Rain Gardens	1.5 MT
Water supply	Groundwater Recharged	12.22 AF
Property values	Single Family Residential (properties affected)	71 properties
	Multifamily Residential	Not estimated
Recreation	Pocket Park	12,887 visits
	Neighborhood Greening	550 visits
Green jobs	Construction jobs (filled by otherwise unemployed)	8 job-years (total)
	Annual maintenance jobs (filled by otherwise underemployed)	0.2 jobs (per year)
Ecosystem	Terrestrial habitat area	2.55 acres

Table 5-11. Present Value Benefits and Costs Over 50-Year Analysis Period, Longfellow Creek Projects, Seattle, WA.
(2019 USD)

Benefit Category	Present value	Annualized
Avoided Infrastructure Costs	$ -	$ -
Avoided Replacement Costs	$ -	$ -
Energy Savings	$ 11,668	$ 436
Carbon	$ 26,101	$ 976
Heat Stress	$ -	$ -
Air Emissions	$ 129,835	$ 4,856
Recreation	$ 2,926,642	$ 109,464
Water Quality	$ 4,406,070	$ 164,798
Property Values	$ 1,275,007	$ 47,689
Water Supply	$ -	$ -
Ecosystem	$ 86,404	$ 3,232
Green Jobs	$ 115,828	$ 4,332
Total benefits	$ 8,977,555	$ 335,783
Total costs	$ 5,866,727	$ 219,431
Benefit cost ratio	1.53	

5.3.7 SPU's Multiple Objective Decision Analysis Framework for GSI Projects

As noted above, SPU is the process of developing a MODA methodology to review alternative stormwater/infrastructure projects. The purpose of the MODA is to evaluate how individual projects contribute to key SPU performance categories and values that SPU is aiming to achieve as it implements community-based projects. For each value identified, SPU assigns a rating of 0.1 to 5; a 0.1 rating means that the infrastructure option will not provide value in that category, while a 5 means that that the maximum value is provided. Ratings of 1 and 3 represent a low and medium rating, respectively. Table 5-12 shows the 14 value categories that SPU has included in its draft MODA framework, as well as the criteria for evaluating infrastructure improvement options within each value category.

As part of the MODA framework, SPU developed weighting criteria for each value (and value sub-category, as applicable). The weighting represents the relative importance (in terms of project criteria) associated with each value. Table 5-13 shows the weighting criteria and value ratings for the Longfellow NDS projects, compared with those associated with a gray infrastructure project that would provide similar water quality benefits. To develop a final score, each value rating is multiplied by its' relative value weight. As shown, the proposed GSI projects provide a much greater benefit (84% higher rating across all value categories) compared to a baseline gray infrastructure project that would provide comparable water quality benefits.

Importantly, many of the values included in the MODA are not included/quantified in the Tool. For example, the MODA specifically addresses equity concerns by including values associated with providing benefits to historically underserved neighborhoods and protecting against potential displacement impacts in these neighborhoods. Another key objective for SPU is to work with partners to meet other City and community-defined goals (e.g., related to safety, mobility, open space, and climate resilience). The cost savings and other benefits associated with these partnerships are difficult to quantify. Many of the objectives reflected in the values are not typically included in benefit-cost analysis. The MODA therefore provides an additional tool with which to evaluate and communicate potential project benefits.

Table 5-12. SPU MODA Framework (Draft)
Source: Adapted from spreadsheet provided by SPU representative

SPU Performance Category	Value	Criteria for assessing Value Infrastructure Improvement Option
Address Multiple System Improvements for LOB	Known Sewer System Problems	Addresses sewer overflow risk (streets and homes) and/or addresses sewer asset management needs, including existing sewer pipe failure risk, sewer pump station upgrade need, or other failure risk as defined through asset management plans (AMPs)
	Known Drainage System Problems	Reduces risk of flooding and/or addresses drainage asset management need, including existing drainage pipe asset failure risk or other drainage asset failure risk as defined through AMPs
	Water Quality and Aquatic Health	Addresses water quality and quantity system impacts (SW/WW pollution priorities, including CSO reduction and Consent decree requirements, creek flashiness, lack of creek floodplains). Includes physical stream modifications that improve habitat for aquatic life.
Expanded Environmental Outcomes	Environmental Sustainability	Minimizes anthropogenic GHG emissions and provides carbon sequestration, supporting Citywide goal of being carbon neutral by 2050 (and State HB 2311)
		Encourages environmentally responsible customer/ community behavior change (e.g., reducing pollutants at the source)
		Enhances ecosystem value (aquatic or terrestrial habitat)
	Climate Risk Resilience	Decreases SPU Drainage and Wastewater (DWW) system risk and frontline community risk from climate change impacts (extreme downpours, drought, SLR)
		Decreases other SPU line of business (LOB, i.e., water) system risk from climate change impacts (e.g., extreme downpours, drought, SLR).
	Seismic Risk Resilience	Decreases SPU system seismic risk
Environmental Justice & Service Equity	Historically underserved community benefits	Solves problems within historically underserved area, and solutions are located within the historically underserved area. This includes anticipated cumulative impacts from climate change.
	Anti-displacement	Does not result in displacement risk and/or actions are being incorporated to help offset displacement risk (option provides increased jobs, placemaking, housing stability or other equity and wealth building strategies to underserved communities).

(continued)

Table 5-12. Continued.

SPU Performance Category	Value	Criteria for assessing Value Infrastructure Improvement Option
Customer Experience	**Long Term Community Benefits - Citywide and City defined**	Helps to achieve a City Family need related to mobility/ community connectivity (e.g., Improved Transportation, Traffic Calming, support SDOT fulfilling pedestrian master plan or bike lanes). This benefit includes the health outcomes associated with ped/bike mobility.
		Helps to achieve a City Family need related to Open Space. This benefit includes the health outcomes associated with open space (reduction in asthma, diabetes, poor mental health, life expectancy).
		Provides health benefits (beyond stormwater, ped/bike mobility, and open space covered above). Contributes to air quality, food security, lower physical harm safety risk and/or health disparities defined for the specific geographic area.
	Long Term Community Benefits	Includes community-defined priorities through project outreach, may be amplifying benefits already identified by city, or maybe be newly defined priorities.
	Short term - Construction Risk and Impacts	Impacts to access and mobility, and wellbeing (e.g., noise and vibration, dust, light pollution)
Growing outcomes through HOW we do our work	**Economic opportunity**	Offers local economic development opportunity (job creation, new/enhanced local market), such as apprenticeships, jobs, local contracts, local procurement, assistance to small businesses.
	Innovation	Has potential for problem solving that might be a catalyst for future methods and/or partnerships.
	Relationship to existing and planned system improvements	Leverages known infrastructure improvement needs beyond Agency/LOB initiating the project (e.g., Known City/ County Family need)
		Scale of option is appropriate given planned future investments (e.g., not placing infrastructure or surface improvements in area likely to be reconstructed in relatively near future).

Table 5-13. SPU MODA Rating for Longfellow Creek Projects, Seattle, WA.
Source: Courtesy of SPU.

				SPU rankings	
Value	**Value sub-category**	**Value's weight**	**Sub-category % of value weight**	**Longfellow NDS projects**	**Comparable gray infrastructure project (WQ)**
Known Sewer System Problems		8.10%	100%	0.1	0.1
Known Drainage System Problems		7.30%	100%	5	0.1
Water Quality and Aquatic Health[a]		6.60%	100%	5	5
Environmental Sustainability	Carbon	2.31%	30%	4	0.1
	Customer environmental behavior	2.31%	30%	5	1
	Ecosystem value	3.08%	40%	4	0.1
Climate Risk Resilience	SPU DWW/frontline community risk	5.46%	70%	0.1	0.1
	Other SPU LOB risk	2.34%	30%	1	0.1
Seismic Risk Resilience		4.50%	100%	0.1	0.1
Historically underserved community benefits		13.40%	100%	3	3
Anti-displacement		8.40%	100%	3	0.1
Long Term Community Benefits	Mobility/connectivity	2.64%	33%	5	0.1
	Open space	2.64%	33%	3	0.1
	Other health benefit	2.64%	33%	3	0.1
Long Term Community-defined benefits -		9.60%	100%	0.1	0.1
Short term - Construction Risk and Impacts		2.40%	100%	3	3
Economic opportunity		4.70%	100%	3	1
Innovation		4.20%	100%	4	3
Relationship to existing and planned system improvements	Known infrastructure need	2.25%	30%	3	3
	Investment scale appropriate	5.25%	70%	4	3
Overall weighted score				**2.14**	**1.16**

a. Categories highlighted in blue are quantified in the GSI TBL Benefit Cost Framework and Tool.

5.4 Case Study 4: Northeast Ohio Regional Sewer District's Green Infrastructure Grant Program

5.4.1 Background

The Northeast Ohio Reginal Sewer District (NEORSD) is a regional wastewater and stormwater management agency serving 62 communities and close to 1 million customers in the greater Cleveland area of Northeast Ohio. NEORSD is working under a federal Consent Decree to reduce CSOs through Project Clean Lake—a 25-year program that will reduce CSO-related pollution in Lake Erie by 4 billion gallons per year. At the heart of Project Clean Lake is the construction of large-scale storage tunnels and treatment plant enhancements. However, the program also includes significant investment in public GSI projects that capture stormwater runoff before it can enter the combined sewer system.

Case study highlights

- Quantifies benefits of nine GSI projects funded through NEORSD's Grant Program.
- Customized property value analysis.
- Incorporation of stormwater management benefits of underground storage systems.

In addition to public GSI projects implemented through Project Clean Lake, NEORSD recognizes the importance of leveraging partnerships with the private sector, other public agencies, and non-profit to build GSI on private and public lands. Toward that end, NEORSD established a Green Infrastructure Grant (GIG) Program in 2014. NEORSD does not receive "credit" for GIG projects toward its Consent Decree obligations; however, the program remains an important part of NEORSD's overall stormwater management strategy.

NEORSD's GIG Program funds GSI projects that detain and/or remove stormwater from the combined sewer system, which serves the City of Cleveland and several neighboring communities. The program is open to nonprofit organizations, NEORSD member communities, governmental entities, and/or businesses/private landowners or developers working in partnership with member communities. Grant funding is available for retrofit projects at existing non-residential sites, as well as for new and redevelopment projects. Projects implemented through the program are specific to each site, and they can include a range of GSI practices.

NEORSD reports that many GIG projects are implemented by community development corporations, nonprofit organizations focused on revitalizing specific neighborhoods throughout the City of Cleveland. Other awardees include member communities, faith-based organizations, universities, museums, and watershed groups. This case study analyzes the costs and benefits of NEORSD's GIG Program projects funded in 2020. This includes 9 projects in total located across the combined sewer service area.

5.4.2 Key Inputs

The projects funded through the GIG program for 2020 are located within the City of Cleveland. NEORSD reports that Cleveland receives approximately 36.7-inches of rainfall per year that results in runoff; the GIG projects are designed to manage runoff associated with 0.9-inches of rainfall, which represents the 90th percentile storm.

The management area encompasses the 51,840 acres of the combined sewer area; based on the population density of Cleveland (5,107 persons per square mile), the authors estimate a study area population of approximately 413,000 people. Cleveland is within the Northeast climate zone.

5.4.3 GSI Scenario

The GSI Scenario includes the nine projects funded through the district's 2020 grant program cycle. Together, the project sites will manage runoff from approximately 4.0 impervious acres, or approximately 2.91 million gallons of stormwater per year. Table 5-14 provides a summary of these projects, including the "Total Project Cost" and the "GI Grant Award" amount provided by NEORSD.

Table 5-14. Summary of NEORSD Green Infrastructure Grants Program 2020 Projects, Cleveland, Ohio.
Source: Adapted from ArcGIS Storyboard provided by NEORSD

Project Name	Total Project Cost	GI Grant Award	Project Description
The Greening of Karamu House	$324,176	$245,276	Permeable pavers will replace asphalt parking lot
Neighborgreen Business Centre Phase I Green Infrastructure	$700,162	$250,000	A rehabilitated property will become a headquarters for sustainable energy services. New infrastructure includes bioretention, permeable pavers & underground infiltration chambers.
Julia De Burgos Cultural Arts Center Green Infrastructure Retrofit	$199,748	$199,748	Reconfiguration of an existing parking lot to include 3 bioretention and infiltration basins
Providence House West Campus Parking Lot Pavement Replacement	$297,650	$250,000	Permeable pavers will replace asphalt parking lot
Barrio Distribution Center Green Campus	$467,763	$249,741	A new parking lot to support locally owned business will include a cistern, underground chambers, porous concrete, and bioretention
La Salle Parking Lot Green Retrofit Green Infrastructure Grant	$281,667	$244,057	Rehabilitation of historic theater parking lot will include bioretention and underground chambers
NOACA Net Zero Cool	$222,000	$185,000	Building improvements include bioretention, a green wall, and cistern that will collect and convey 70% of roof water; cistern storage will be used to irrigate green wall
St. Vitus Parish Social Hall & Learning Center	$371,470	$250,000	New installation will include a permeable paver parking lot
West Boulevard Parking Lot Green Retrofit	$62,752	$62,123	A new parking lot to support locally owned business will include permeable pavers and bioretention

Figure 5-17 shows how these projects were entered into the Tool on the GSI Scenario tab. Notably, three of the GIG projects listed above include the installation of underground storage chambers/vaults. While these traditional gray infrastructure projects do not provide co-benefits, they do provide important water quality/stormwater management benefits that the authors wanted to capture (e.g., avoided infrastructure costs). The authors therefore modified the GSI Scenario tab to incorporate these BMPs. Specifically, the authors substituted "underground filtration" in the cell where "biofiltration" typically appears and zeroed out the "Calculated BMP Area (Footprint)" cell in that row. Normally, the Tool would use the Calculated BMP Area to estimate co-benefits associated with biofiltration BMPs' vegetated area; zeroing this cell out ensures that no additional co-benefits related to vegetation are attributed to underground systems.

Additional customizations include the manual entry of the Number of BMPs (Column G), the BMP Area (Column I) for bioretention and permeable pavement facilities, and the Annual Runoff Volume (Column J) by practice type. These estimates were calculated by NEORSD. In addition, the authors zeroed out the stormwater management benefits the Tool automatically calculates for the 18 shade trees that will be incorporated into the different projects. This is because the total stormwater managed is reflected in the other BMP types. Cells for which data was manually entered are highlighted in yellow in Figure 5-17.

GSI Practices - Enter Acres Managed or Number of BMPs

GSI Practice (BMP)	CLASIC BMP Name	Effective Impervious Acres Managed (acres)	Number of BMPs	Volume Capacity by BMP type (cft)	Calculated BMP Area (Footprint) (square feet)	Annual Runoff Volume (cft)
Rain gardens	Rain gardens		-	-	-	-
Bioretention facilities	Infiltration trenches	1.14	6	3,650	4,458	112,057
Green roofs	Green roofs		-	-	-	-
Tree planting/street trees	*		18			
Permeable pavement	Permeable pavement	1.61	5	5,155	46,082	158,256
Cisterns - rainwater harvesting	Rainwater harvesting	0.26	2	400		25,557
Rain barrels - rainwater harvesting	Rainwater harvesting	-		-		-
Constructed wetland	*		-	-	-	-
Wet ponds	Wet pond		-	-	-	-
Underground storage/detention		1.0	3	3,051		93,676
		4.0		12,256		389,547

* CLASIC does not address "Tree planting/street trees" or "constructed wetland"

Figure 5-17. Tool Snapshot - GSI Scenario Data Entry for NEORSD's GIG Program Projects, Cleveland, OH.

5.4.4 Cost and Timeline

The total capital cost for the nine projects combined is $2,927,388; NEORSD covered approximately 66% of these costs, with the total GIG Award amounting to $1,935,945. For this case study, the authors used the total project costs, with some adjustments based on input from NEORSD. Specifically, two of the estimates for total project costs included costs for non-stormwater components of the project. The authors subtracted these costs from the total project cost. With this adjustment, total capital costs across the nine projects amounted to $2,470,149. The authors assumed a two -year construction period for all projects.

Because each project is located on a private commercial property, NEORSD accrues no maintenance costs after installation. For this case study, the authors assume that maintenance costs for private property owners do not significantly increase overall property maintenance costs from baseline conditions. Maintenance costs are therefore not included in the cost calculation. The authors used the default discount rate of two percent over a 40-year analysis period.

5.4.5 Benefits

5.4.5.1 Avoided Infrastructure Costs

NEORSD's GIG Program funds projects that remove stormwater volume from the combined sewer system and, in some cases, address localized flooding/drainage issues. These projects go beyond the benefits provided by the large-scale CSO reduction gray infrastructure projects being constructed as part of Project Clean Lake. To provide these benefits in another way would require additional onsite stormwater management through traditional infrastructure systems (e.g., such as would be built to meet post construction stormwater requirements).

For this case study the authors assumed underground detention systems as the baseline gray infrastructure scenario. To estimate the cost of installing underground detention at the nine grant project sites, the authors isolated the costs of underground infiltration vaults (and associated site preparation, mobilization, excavation, etc. costs) funded through the grant program. These costs were increased (using industry cost curves for underground retention and detention systems) to reflect the costs associated with underground detention (i.e., based on the cost curves, underground detention systems are more expensive than underground infiltration/retention systems). This resulted in an estimated avoided gray infrastructure cost of approximately $2.83 M across the nine project sites. The authors entered this value directly into the Tool, rather than relying on the RS Means default cost, which represents a lower-end estimate.

By default, this methodology incorporates the same costs that are included in the cost estimates for the grant-funded projects (e.g., design, engineering, mobilization, demolition, construction, and contingency), thus providing a fair comparison of the grant funded projects to "all-gray" projects. Because the authors did not include maintenance costs in the cost estimate, there are no avoided maintenance costs.

In addition to avoided capital costs, the GIG projects will result in reduced pumping and treatment of stormwater through the combined sewer system. Specifically, the projects will remove an estimated 2.91 MG from the system each year (on average). NEORSD estimates the cost for pumping and treatment to be $0.68 per thousand gallons ($680/MG); thus, the total annual value of avoided pumping and treatment costs amounts to $1,981 per year.

The authors used "Option 1" on the Avoided Infrastructure Costs tab to directly enter avoided infrastructure costs into the Tool.

5.4.5.2 Avoided Replacement/Maintenance Costs for Non-stormwater Assets

For green roofs and permeable pavement, the Tool estimates avoided replacement and/or maintenance costs for their traditional non-stormwater alternatives (i.e., traditional roofs and pavements). While none of the GIG projects incorporate green roofs, five of the nine proposed projects will collectively install 46,082 square feet of permeable pavement. While the Tool does not estimate avoided (lifecycle) replacement costs due to the variable estimates for permeable pavement useful life, it does calculate avoided maintenance costs for traditional pavement types.

The Tool incorporates different avoided maintenance costs depending on the type of traditional pavement that the permeable pavement will replace (i.e., maintenance costs for asphalt parking lots are much lower than maintenance costs for traditional asphalt streets or concrete areas). Of the five projects that will utilize permeable pavers for parking lots, only two are replacing existing asphalt parking lots, totaling 16,138 square feet. The remaining permeable pavement area will be laid on vacant lots. The authors assumed that 50% of these would have been asphalt parking lots (i.e., if the permeable pavers were not installed). Combined, the authors estimate 31,110 square feet of permeable pavement will replace asphalt parking lots, or 68% of the total square footage of permeable pavement added. With this assumption, the Tool calculates annual avoided maintenance costs for traditional asphalt of $4,378.

5.4.5.3 Property Value Increases

Most of the GIG projects for 2020 were awarded to businesses or nonprofits located in very low-income neighborhoods. Bioretention, green walls, and permeable pavers can improve neighborhood/property aesthetics, reduce flood risk, and/or increase positive “green business” perceptions. This can increase the property value of the lots and surrounding businesses and homes, particularly in poorer communities (see Appendix E).

Using 2019 property data publicly available through the Cuyahoga County Assessor’s Office, the authors estimated the baseline (aggregate) value of each parcel where the GIG projects will be installed. Where applicable, adjacent properties were also included in the valuation. For example, the parking lot for the La Salle Theater is adjacent to a residential home that will also benefit from the GSI retrofit. The authors reviewed the location of each project using Google Earth to identify properties that would likely be affected by GSI improvements.

In addition, several of the projects will be installed on vacant lots that will be redeveloped as part of the overall project. In these cases, the Cuyahoga County Assessor’s property valuation does not reflect the full value of the property, as it will be redeveloped. For projects that intend to develop empty parcels into businesses or parking lots, we utilized the cost of the project (if it were higher) to better reflect the value of the property with usable infrastructure, reasoning that the cost of the improvements would serve as a lower end estimate for the total redeveloped value. Table 5-15 shows the total aggregate baseline property value across the project sites, including any adjacent properties. In total, 17 parcels were combined to estimate the aggregate baseline property value for the GIG projects.

To estimate property value benefits in the Tool, the authors entered the aggregate baseline property value ($7,948,295) into Cell C25 under Option 1 on the property values tab. The next step was to determine the percentage increase in value that the GSI projects result in. As detailed in Appendix E, GSI projects in low-income areas can accrue higher property value benefits (on a percentage-point basis). By identifying the Census Tract where each project will be installed, and cross referencing with 2019 ACS Census Data for Median Household Income (MHI), the authors determined which properties are located in areas that have an MHI below the MHI for Cleveland overall ($30,907). For those properties in low-income neighborhoods with bioretention projects and trees, we assigned a property value increase of 8.5% (representing the average mid-point for trees from the literature); other properties were assigned the mid-range default value for bioretention of 4.25%. This resulted in a weighted average of 6% for the combined project property value increase from GSI. This weighted value was calculated outside of the Tool and directly entered into Cell C66, overwriting the default formula in that cell. The authors assumed 100% of the properties were affected by the GSI (Cell C71 in Tool) and that no portion would accrue lower increases in value (Cell C89 in Tool).

Table 5-15. Property Value Inputs for NEORSD GSI Grant Funded Projects, Cleveland, Ohio.
(2020 USD)
Source: Data from the Cuyahoga County Assessor's Office and NEORSD

Project Name	Total Baseline Property Value	Adjacent lot description
Barrio Distribution Center Green Campus	$467,763*	
Julia De Burgos Cultural Arts Center Green Infrastructure Retrofit	$702,200	Julia de Burgos Center + adjacent apartment building
La Salle Parking Lot Green Retrofit Green Infrastructure Grant	$511,600	La Salle Theater + adjacent house property
Neighborgreen Business Centre Phase I Green Infrastructure	$700,162*	
NOACA Net Zero Cool	$1,007,700	
West Boulevard Parking Lot Green Retrofit	$259,700	Adjacent restaurant
The Greening of Karamu House	$2,706,900	Includes entire parking area
Providence House West Campus Parking Lot Pavement Replacement	$1,220,800	
St. Vitus Parish Social Hall & Learning Center	$371,470*	
TOTAL PROPERTY VALUE	**$7,948,295**	

*Project costs were used instead of property value;

Based on these assumptions, the Tool calculates a total property value benefit of $437,156, or an average annual benefit of $15,897. Over the project analysis period of 40 years, this results in a net present value of $418,693. The authors believe this is a conservative estimate due to imperfect property value data, and the intrinsic value of installing GSI in low-income communities.

The Tool does not (by default) include property value benefits for commercial properties and/or for permeable pavement (in part because data for commercial properties can be difficult to ascertain). However, research suggests that commercial properties do benefit from GSI installations (see Appendix E, in some cases increases for commercial properties have been found to be greater than for residential properties). The Tool can easily accommodate commercial property value analysis in the cells designed for multi-family property values. In addition, a review of before and after pictures from previous grant years indicate that permeable pavement projects funded through the GIG Program result in aesthetic improvements to the benefitting property.

5.4.5.4 Heat Stress Reduction

The 2020 GIG projects will not in and of themselves result in a reduction in heat-related illnesses or deaths because they are distributed across a large area. However, if the GSI projects were concentrated in area such that they increased vegetated area/surface reflectivity by ten percentage points (e.g., if the projects were concentrated in a 15-acre area), the Tool estimates that health-related heat stress reduction benefits would amount to more than $242,400 over the 40-year analysis period in present value terms. This value could be used to show incremental benefits of projects that reduce heat stress if these projects were part of a larger plan to increase vegetated area over the city or a neighborhood by ten percentage points or more.

5.4.5.5 Additional Benefits

As shown in the next section, the authors used the Tool to calculate several additional benefits provided by the GIG projects; however, they are relatively small compared to the benefit categories presented above. While these benefits are small for any given project, the wide-scale implementation of GSI across a city can result in significant benefits as they begin to add up.

5.4.6 Results Summary

Table 5-16 shows the present value and annualized benefits and costs associated with the 2020 NEORSD GIG projects over the 40-year analysis period. Figure 5-18 categorizes present value benefits by TBL category. As shown, the largest benefits (in terms of monetary valuation) result from avoided infrastructure costs, followed by property value increases. Additional (smaller) benefits include reduced carbon and pollutant air emissions, water supply and ecosystem benefits as well as green job creation.

It is important to note that NEORSD does not have specific data on the avoided costs of gray infrastructure for onsite stormwater management. The authors relied on cost estimates from the CLASIC Tool to estimate these costs. An additional way to look at the benefits and costs of the grant-funded projects is to conduct a break-even analysis. Based on the Tool results, total present value benefits of the grant projects without the avoided capital costs for onsite stormwater management amount to $740,568. To "break even" (i.e., achieve a benefit-cost ratio of 1), total avoided gray infrastructure costs would need to amount to $1,657,405 in present value terms (approximately $184,156 per site). The CLASIC cost estimates far exceed this amount.

Table 5-16. Present Value Benefits and Costs Over 40-Year Analysis Period, NEORSD GSI Grant Funded Projects, Cleveland, Ohio.
(2020 USD)

Benefit Category	Present value	Annualized
Avoided Infrastructure Costs	$ 2,800,909	$ 127,554
Avoided Replacement Costs	$ 115,304	$ 4,215
Energy Savings	16,449	601
Carbon	$ 18,926	$ 692
Heat Stress	-not included in total	
Air Emissions	$ 36,497	$ 1,334
Property Values	$ 418,693	$ 15,306
Water Supply	$10,286	$ 376
Ecosystem	$ 15,588	$ 570
Green Jobs	$ 56,638	$ 2,070
Total benefits	$ 3,489,289	$ 189,996
Total costs	$ 2,397,972	$ 87,660
Benefit cost ratio	1.455	

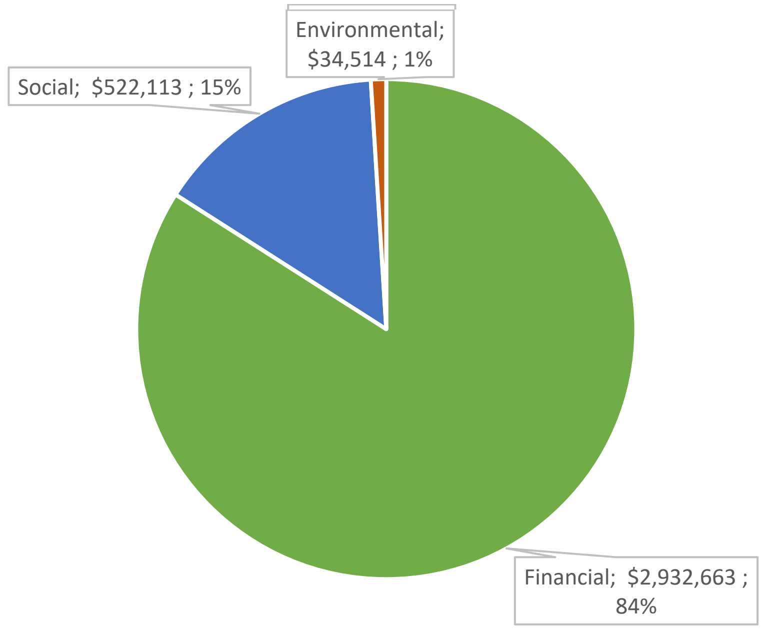


Figure 5-18. Present Value Benefits of NEORSD GI Grant Program Projects, Over 40-Year Analysis Period, by TBL Category, Cleveland, OH.
(2020 USD)

Further, as discussed in the St. Paul case study, evaluating the incremental costs and benefits of green vs. gray projects can also be an informative metric. For example, as stated above the grant-funded projects provide $740,568 in co-benefits, most of which would not be provided by gray infrastructure. Thus, the grant-funded project costs could exceed those associated with gray infrastructure onsite stormwater management by this amount and still result in a greater benefit-cost ratio.

CHAPTER 6

Conclusions and Suggestions for Future Research

The GSI TBL Benefit Cost Framework and Tool represents the most up to date methodologies and advancements in quantifying and monetizing the full range of TBL benefits associated with GSI. The Tool provides practitioners with a consistent and sound methodology for assessing benefits and costs. In addition to the Tool itself, this research provides the most comprehensive documentation of available literature and methods for assessing GSI co-benefits through a series of technical appendices. The case studies incorporated into this report demonstrate the potential for GSI projects to provide important community benefits that exceed project costs.

The Tool is not intended to supplement a detailed/customized site- or city-specific analysis. The economic benefits fully realized by a GSI program depend on several factors that cannot be captured within the scope of this research, including site-specific parameters, intentional design, location of GSI practices within the urban or suburban landscape, surrounding land uses, and more. In short, GSI must be designed and sited in ways that allow municipalities to fully realize its benefits. GSI practices must also be maintained to continue to support and provide the multiple benefits included in the Tool. The Tool does provide reasonable estimates for potential economic benefits, assuming intentional-design and siting of GSI practices. The importance of some GSI practices in providing co-benefits should not be understated; for example, projects that incorporate trees and green roofs result in greater co-benefits than those designed only with stormwater management in mind.

Finally, while the Tool represents a step forward in the economic evaluation of the benefits and cost of GSI, the authors have identified several areas for future research that could not be accommodated within the scope of this work. First, there are several knowledge gaps/research needs related to specific benefit categories, as follows:

- The authors explored several methodologies for including flood risk reduction benefits in the Tool. Due to the site-specific nature of flood reduction benefits associated with GSI, particularly in urban settings, the authors were not satisfied that any of the methodologies that could be accommodated within the scope of this research would provide reasonable economic estimates. However, in Appendix L, the authors identified several potential methodologies and/or frameworks that could be integrated into the Tool with additional research and resources.
- The research on ecosystem benefits of GSI is lacking, and economic valuation literature on terrestrial ecosystem benefits is also limited. Organizations such as The Nature Conservancy and others are conducting research in this area; ideally, the Tool could be adapted in the future to better incorporate this research. Specific research questions include how GSI can be designed to best support specific habitat or biodiversity goals, as well as the scale or network of habitat areas that are necessary to realize these benefits.
- The water quality valuation method included in the Tool is designed to provide order-of-magnitude estimates for water quality improvements associated with GSI scenarios. While the Tool provides guidance on how to tailor the methodology to individual projects and GSI programs, the Tool would benefit from further research on methodologies available for quantifying and monetizing water quality benefits. One potential avenue for this is to better integrate the Tool with the CLASIC tool in the future. This would allow for a better quantification and comparison of water quality and runoff reduction benefits for both GSI and gray infrastructure-based alternatives. Additional valuation methods associated with specific water quality outcomes could then be explored.

- Another benefit category that could benefit from additional research is the effect of GSI on heat stress reduction in urban areas. The effect of vegetation and increases in surface reflectivity on urban temperatures has been relatively well-researched. However, less data is available on the relationship between reduced temperatures and heat-related illnesses (and avoided health care costs). The Tool currently quantifies reductions in heat-related illnesses based on state-level correlations of heat-related mortalities and morbidities.
- Finally, another important area of needed research includes the provision of benefits related to transportation; for example, for traffic calming purposes, pedestrian mobility, and/or reduced pavement maintenance costs (e.g., due to shading). Pairing GSI and transportation projects has the potential to result in significant cost savings across both types of projects

In addition to specific benefit categories, the Tool does not explicitly include frameworks or methods for incorporating the benefits associated with GSI that cannot be quantified. As a quote attributed to Albert Einstein states: 'Not everything that can be **counted counts** and not everything that **counts** can be **counted.**' Future iterations of the Tool may better accommodate the evaluation of non-quantified benefits (e.g., such as through multi-criteria decision-making). An example of such a framework is presented in the case study of GSI projects in Seattle, WA.

Further, while the Tool documentation highlights important equity issues, it assumes that GSI is distributed in such a way as to minimize adverse equity outcomes. The valuation methodology included in the Tool does not specifically address distributional impacts and/or equity concerns. This is an important topic that is currently being researched by several organizations/researchers within the water sector. A key research questions is how to best site and design projects as to minimize adverse equity outcomes or unintended consequences.

Finally, given the significant resources invested, and potential for the Tool to evolve, it is important to think about how future updates and iterations might be accommodated. This would be best supported through additional and more formal beta-testing of the Tool than could be supported within this scope of work. Ideally, the Tool could be adapted to a web-based platform so that future iterations can be easily updated and accessed by users.

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APPENDIX A

Avoided Gray Infrastructure Costs

A.1 Introduction

Green stormwater infrastructure (GSI) reduces the amount of stormwater entering sewer systems and local waterways. This in turn can reduce the need (and associated costs) for traditional or gray infrastructure practices that would otherwise be necessary to meet municipal goals related to water quality, combined sewer overflows (CSOs), channel protection, and/or flood risk reduction. In addition, in communities with combined sewers, GSI practices can reduce costs associated with pumping and treating stormwater at municipal treatment facilities (WWTPs). In some cases, GSI can reduce the need for increased wastewater treatment capacity in communities with municipal separate storm sewer systems (MS4s) that are aiming to meet specific water quality targets.

The key to quantifying the stormwater management costs that a user's GSI scenario would help to avoid is to clearly define the baseline "without GSI project scenario." To define the baseline, the user must ask what steps would be taken to meet the same objectives or stormwater management goal if the planned GSI program is not implemented. An important aspect of defining the baseline is that it must reflect the future. The baseline is not the same thing as the "current" situation. Defining the baseline means looking into the years ahead, and since the useful lifetime of most water quality/stormwater investments typically is 20 or more years, a matching long-term timeframe needs to be applied for the baseline and GSI options.

The "without GSI project scenario," and its' associated costs, will vary significantly depending on community-and site-specific circumstances. For example, the cost of gray infrastructure controls under a baseline alternative for cities with combined sewer systems will typically be much greater than for MS4s. However, MS4 communities facing significant water quality regulations (e.g., such as associated with Total Maximum Daily Load, TMDL, requirements) may also face significant costs due to increased requirements. Costs incurred under the baseline will also range based on the types of controls implemented, characteristics of the urban environment (e.g., land uses), hydrology and rainfall patterns, water quality and/or quantity goals, existing level of controls in place, and other local factors.

In addition, with a national-level tool, it is difficult to calculate the amount of gray infrastructure that GSI will offset. One challenge is that as the size of the area of interest changes, the assumptions about what gray infrastructure is offset by GSI also changes a great deal. For example, on a single lot or small development GSI may be used in lieu of gray collection and piping systems, whereas for a larger commercial site adding an infiltration practice may allow for a reduction in the size of detention required, but the collection system would be unchanged. Further, the sizing of many traditional infrastructure practices (i.e., conveyance pipes and detention basins) is determined based on peak flow rates rather than storage capacity for an estimated runoff volume. At a neighborhood or watershed scale, implementation of GSI will reduce the need for large conveyance, storage, and regional treatment, but the extent and timing of actual offsets may not directly correlate. Some level of hydraulic model or calculation is required to accurately reflect the reduction or avoided gray infrastructure investment that the GSI scenario will achieve. It is beyond the scope of this research (which is focused on benefits valuation and uses simple assumptions to calculate stormwater runoff reductions associated with GSI) to incorporate these methods.

For these reasons, the ideal situation is for users of the GSI TBL Benefit Cost Framework and Tool (Tool) to directly enter the costs associated with their baseline scenario into the Tool, including capital, O&M, and replacement costs, using community-specific data. For users who do not have this data available, the Tool provides some general guidelines for developing an order-of-magnitude estimate and applies national average costs for stormwater management on per square foot of impervious area basis. These estimates are intended for planning purposes only.

As an important note, there are different ways to account for the gray infrastructure costs that GSI projects will offset. When directly comparing a gray infrastructure alternative to a GSI alternative, this benefit is accounted for by comparing the costs of each alternative. When evaluating a GSI alternative on its own, avoided costs can be accounted for on the benefits side of the ledger. Because the Tool does not compare multiple alternatives (e.g., it does not compare a gray infrastructure alternative to a GSI-based alternative), it employs the latter approach. If the user plans to compare the results of the Tool (i.e., the benefits and costs of a GSI scenario) to the benefits and costs associated with a gray infrastructure alternative (calculated outside of the Tool), any avoided baseline or gray infrastructure costs should not be included as a benefit of the GSI scenario. This would result in a double counting of benefits/costs.

The following sections provide example cost estimates for conventional stormwater management and describes methods that valuation studies and models have used to estimate avoided gray infrastructure costs. The final section describes how the Tool allows users to calculate these benefits.

A.2 Findings from the Literature

This section provides example cost estimates for traditional stormwater management practices, as well as an overview of how existing tools and studies have incorporated avoided infrastructure and treatment costs into economic analyses of GSI.

The cost estimates presented below are intended to serve as examples of potential cost ranges, rather than an exhaustive review of literature on this topic. In addition, the reported estimates come with some caveats. First, the literature rarely includes detailed descriptions of the exact cost elements included in a given estimate. For example, in some cases, costs for design and engineering are specifically cited, in others it is not clear whether they are included. It also is not always clear whether cost estimates represent average or marginal costs per volume of stormwater managed, pumped, or treated, although in most cases, it seems that average costs are reported. When thinking about how GSI improvements might reduce the amount of gray infrastructure that is needed (e.g., the size of a storage facility), the marginal cost is a more appropriate measure.

In addition, the dollar year in which costs are reported is not always documented. When this information was available, the project team updated individual cost estimates to 2019 USD using the Consumer Price Index (CPI). Otherwise, costs are updated based on the source study publication date. All cost estimates reported below are in 2019 USD unless otherwise noted.

Finally, many of the examples highlighted below reflect cost savings associated with GSI compared to gray infrastructure. However, it is important to remember that even when gray infrastructure may be a more cost-effective solution in terms of stormwater management, the gray infrastructure or conventional stormwater management costs would still be avoided under the user’s GSI scenario. Combined with other benefits, the user’s GSI scenario may result in greater benefits compared to a gray-only solution.

A.2.1 Avoided Stormwater Pumping and Treatment

In CSO communities, GSI reduces the volume of stormwater that enters the combined storm sewer system and ultimately flows to a WWTP. In addition to CSO reduction benefits, this results in reduced pumping and treatment associated with the volume of stormwater removed. The value of avoided pumping and treatment is equal to the annual GSI volume reduction (gallons or cubic feet, ft^3, of stormwater retained through GSI) multiplied by the unit cost for pumping and treatment ($/gallon or $/$ft^3$).

Costs associated with pumping and treating stormwater vary based on the size and load of the WWTP, pollutant load reduction requirements, local topography, and geographical situation of the site (which affects the level of pumping required), treatment process, local energy costs, and other site-specific factors. Table A-1 shows examples found in the literature for stormwater pumping and treatment costs in various CSO communities. As shown, costs range significantly - from $0.24 to $1.35 per 1,000 gallons for stormwater pumping and treatment and from 0.09 to $1.18 per 1,000 gallons for treatment only.

Table A- 1. Stormwater Pumping and Treatment Cost Estimates for Combined Sewer Systems.
(2019 USD)

Location	$/1,000 gals	Treatment and/or Pumping	Source
Lancaster, PA	$ 1.35	Pumping and treatment	U.S. EPA 2014
Narragansett Bay, RI[a]	$ 1.19	Pumping and treatment	Roseen et al. 2011
Portland, OR[b]	$ 0.24	Pumping and treatment	Roseen et al. 2011
Milwaukee, WI[c]	$ 1.18	Treatment only	Buckley 2011
Seattle/King County, WA	$ 0.14	Treatment only	U.S. EPA 2017
Metropolitan Water Reclamation District of Greater Chicago, IL	$ 0.09 to $ 0.11	Treatment only	Wise et al. n.d.; CNT and American Rivers 2010

a. It is assumed that this estimate includes treatment; text states that operational and maintenance costs of large gray infrastructure storage tunnel are $1 for every 1000 gallons (2009 USD), the bulk of which are attributed to electrical costs for pumping.
b. As reported by Roseen et al., the City of Portland recognizes that GSI reduces costs associated with pumping and conveying stormwater through the existing combined sewer system. The city measures this by applying a rate of $0.0001 per gallon treated and $0.0001 per gallon pumped (2009 USD). However, costs reported by Roseen et al. for an individual pump station and treatment plant in Portland are much higher.
c. Based on text from Buckley et al. 2011, this estimate includes treatment costs only.

As part of a feasibility study for the Guadalupe-Blanco River Authority (TX), Urban Engineering et al. (2012) found that treatment costs can be much higher than shown in Table A-1, particularly for smaller plants as operating costs show significant economies of scale. Specifically, based on historical data for WWTP operations of different sizes, the study showed costs ranging from $15.00 per 1,000 gallons for a very small WWTP to $1.00 per thousand gallons for a WWTP with a capacity of 2 MGD (2011 USD). In most cases, WWTPs in CSO communities will be much larger than 2 MGD; however, some communities may have several smaller satellite plants.

A.2.2 Avoided Capital Investments for Traditional Stormwater Management Practices

In addition to avoided pumping and treatment of stormwater, GSI can reduce or offset the need for new capital investments in conventional stormwater management practices, including deep tunnels, surface and subsurface storage facilities, detention basins, conveyance piping, and more. Use of GSI can also result in significant cost savings at new development and redevelopment sites. The following sections provide examples of avoided costs associated with GSI across these different scenarios.

A.2.2.1 Large-Scale CSO Reduction Projects

In communities with combined storm sewer systems, traditional approaches for reducing CSOs include construction of large underground storage tunnels and supporting infrastructure, development of separate drainage systems to convey stormwater flows (i.e., sewer separation), and/or the development of additional municipal treatment capacity. For example, in efforts to meet CSO-related consent decree requirements, several cities have invested billions of dollars in deep tunnel storage projects. In some cases, these cities have been able to reduce at least a portion of tunnel/storage-related costs by integrating GSI into their overall stormwater management approach. As reported by Roseen et al. (2011), Kansas City, Missouri integrated distributed GSI solutions into their plan for reducing CSOs in lieu of building two 3 MG gray storage tanks in the city's Middle Blue River Basin. The use of GSI was estimated to save the city $19 million (2009 USD) in capital costs, while achieving the same level of CSO reduction as the gray-only alternative (i.e., the storage tanks). Other cities, including Washington DC, New York City, and Milwaukee, have seen similar success in applying hybrid green/gray infrastructure approaches to stormwater management (e.g., see PlaNYC 2007, MMSD 2009).

Table A-2 shows examples from the literature for costs associated with large underground gray infrastructure storage facilities in various CSO communities. Again, as shown, costs range significantly - from a low of $2.88 per gallon of storage capacity in Milwaukee to a high of $21.10 per gallon in Kansas City.

Table A-2. Gray Infrastructure CSO Reduction Cost Estimates, Storage Facilities.
(2019 USD)

Location	$/gallon of storage capacity	Gray infrastructure project description	Source
Providence, RI	$11.63	30 ft. diameter deep tunnel with a 62 MG capacity; plus two near-surface interceptors that convey flow to the tunnels	Roseen et al. 2011
Milwaukee, WI	$2.88	Cost per gallon of additional deep tunnel storage capacity	MMSD 2009
Kansas City, MO	$21.10	Two 3 MG CSO storage tanks	Roseen et al. 2011
Portland, OR	$4.77 – $10.19	Low estimate represents City of Portland's marginal cost for avoided gray infrastructure; higher estimate represents costs associated with large East Side CSO Tunnel and associated infrastructure (83 MG capacity)	Roseen et al. 2011
Washington DC	$19.50	Gray infrastructure underground storage; includes 30% above construction costs for planning, design, construction management.	Corona Environmental Consulting, 2020

In addition to these estimates, Wise et al. (n.d.) reports cost equations for various stormwater management practices based on volume of stormwater storage capacity (i.e., volume of storage capacity is the independent variable, cost is the dependent variable). Resulting cost estimates range from $5.07 per gallon for a 30 MG facility to $15.03 per gallon for a 0.15 MG facility (2019 USD).[1]

GSI can also reduce the need for investments in sewer separation projects. For example, as reported by Roseen et al. (2011), in 2000, the City of Portland was faced with the need to upgrade an undersized sewer pipe system in an area of the city that covered approximately 2.3 square miles. The city initially planned to construct a new separate stormwater collection system, which would have cost an estimated $144 million (2009 USD). However, staff developed an alternative plan that incorporated both green and

[1] Cost equations from Wise et al. (n.d.) were adapted from Heaney et al. 2002; Wise et al. updated equations to 2009 USD. To obtain estimates we used the equations Wise et al. and updated results to 2019 USD based on the Consumer Price Index (CPI).

gray infrastructure approaches. The new plan included $11 million of GSI-based projects, with a total cost of approximately $81 million (2009 USD). Overall, the integrated approach resulted in a savings of $63 million (2009 USD) for the city. Since that time, the City has been able to prioritize cost-effective GSI approaches over several proposed sewer separation projects (see Table 3-7 Roseen et al. 2011).

The cost of sewer separation varies considerably based on several factors, including but not necessarily limited to (U.S. EPA 1999):

- Location and layout of existing sewers
- Location of other utilities that will have to be avoided during construction
- Other infrastructure work that may be required
- Land uses and costs
- Construction method used (e.g., open cut verses microtunneling)

Examples of sewer separation project cost estimates from the literature include:

- Based on Roseen et al. (2011), the City of Portland's average cost for sewer separation projects amounts to approximately $161,700 *per effective impervious acre (IA) controlled*. [2] Across 11 projects, Portland's estimates ranged from a low of $68,155 per IA to a high of $1.14 M per IA.
- In its 2007 Long Term Control Plan (LTCP) for reducing CSOs, the City of Elkhart, Indiana (City of Elkhart 2007) reported sewer separation cost estimates based on data from 21 cities across the U.S. The average cost amounted to approximately $101,000 (average) to $146,000 (weighted average) per CSO drainage area acre, ranging from $10,500 per acre (Plymouth Township, MI) to $543,400 per acre (San Francisco, CA).[3]
- On the higher end, the City of Alexandria's LTCP reports average cost per drainage area acre of $477,800 for sewer separation projects in Alexandria and Washington DC.
- Albany Pool's (New York) LTCP reports costs of $240,000 per drainage area acre, based on data from Onondaga County, New York (APJVT 2011).

A.2.2.2 Conventional Stormwater Management Practices

In addition to large-scale CSO reduction projects, both CSO and MS4 communities implement a wide range of stormwater management practices, including surface storage facilities, conveyance piping, underground storage vaults, and detention basins. Table A-3 shows cost estimates for two common practices – surface detention basins and underground detention (e.g., storage vaults). These estimates are based on findings from the literature, CLASIC data, and the project team's consulting experience.

In some cases, GSI can offset the need for additional stormwater conveyance piping and/or reduce the need to upsize existing piping. For example, in a study, in the Blackberry Creek watershed near Chicago, Illinois, Johnston et al. (2006) estimated the avoided costs associated with a reduced need for stormwater piping due to the use of GSI to control peak discharges. Using Federal Highway Department pipe sizing requirements, the authors estimated that GSI would result in a downstream benefit of $430 (2019 USD) per developed acre in avoided pipe costs. In reviewing and reporting the results of this study, CNT and American Rivers (2010) notes this estimate represents an initial cost savings and that performing a life-cycle cost analysis would provide a better measure of total benefits. In addition, the

[2]Average cost represents weighted average estimate based on IAs controlled per project. Estimate excludes the highest estimate reported by Roseen et al. 2011 for Portland, which amounted to close to $2.9 M per IA. We did not include this estimate in the average calculation because of the extreme cost compared to all other estimates.

[3] These estimates are not directly comparable to Portland's estimate, which is based on effective impervious acres controlled.

method is dependent on peak flow rates, allowable ponding time, and pipe size requirements, and is best determined using hydrologic modeling.

Table A-3. Capital Costs for Surface and Subsurface Detention.
(2019 USD)

Control	Cost per gallon (storage capacity)	Source/Notes
Detention basin	$ 0.11	CNT Original GVC (2005); low estimate
	$ 0.22	CNT Original GVC (2005); high estimate
	$ 0.05	Wise et a. (n.d.)
	$ 0.09	Cost curves developed for Corona Environmental Consulting for consulting project, WRF (2021) - average estimate for range of detention basin sizes included in CLASIC
	$ 0.17	WRF (2021 - average estimate for range/type of detention basins included in CLASIC
Subsurface detention/storage vaults	$0.68	CNT National GVC (2009); low estimate
	$3.62	CNT National GVC (2009); high estimate
	$6.35	City of Calgary (2019); cost curves developed for Corona Environmental Consulting project, WRF (2021) - average estimate for range storage vault sizes included in CLASIC
	$9.66	Mateleska (2016) - cost for subsurface infiltration/detention system (aka infiltration chamber), based on Opti-Tool.

In an analysis of stormwater management alternatives for a specific neighborhood, the City of Calgary (2019) applied an interesting approach to value the avoided costs associated with GSI alternatives that reduced the need to upgrade existing stormwater pipes. Specifically, the City recognized that the alternatives that included pipe upgrades would increase peak flows; in some cases, this would result in exceedance of the peak flow design standard of 5.03 m^3/s. The City calculated the cost (or penalty) for exceeding the target flow rate by estimating the cost to construct a regional detention facility near the outlet of the piped conveyance. A relationship was then developed to equate the cost or benefit as “an outfall penalty.” Flows in excess of 5.03 m^3/s were given a cost while flows less than 5.03 m^3/s were given a negative penalty or a benefit as it would reduce the need to provide a facility elsewhere in the watershed. The calculated peak flow penalty was determined to be a linear relationship of $565,000 per m^3/s (2018 CDN) for flows above the design target flow rate (or included as a benefit if below the design target flow rate).

A.2.2.3 Reduced Costs for Development and Redevelopment Projects

Some studies (Clar 2003, U.S. EPA 2013) have documented significant cost savings for developers that employ GSI and low impact development techniques (LID) in lieu of conventional stormwater management. In addition to decreasing the amount of underground drainage infrastructure and/or detention facilities, GSI can reduce the need for other stormwater management-related facilities including curbs and gutters, erosion control measures, catch basins, and outlet control structures. Comprehensive GSI and LID designs can also save space and can reduce the amount of land disturbance required during construction, saving money on site preparation (NRDC 2006). Studies in Maryland and Illinois show that new residential developments using GSI saved $3,500 to $4,500 per lot (quarter- to half-acre lots) when compared to new developments with conventional stormwater controls (NRDC 2006).

These types of savings can also accrue to municipalities that implement roadside GSI projects and green streets. For example, as reported by CNT and American Rivers (2010), Seattle Public Utilities (SPU) found that its’ Street Edge Alternatives (SEA) project, which included roadside bioretention combined with narrowing the roadway, eliminating traditional curb and gutter, and placing sidewalks on only one side of the street, saves the city 15 to 25%, or $100,000 to $235,000 per block (2010 USD), compared with conventional stormwater control design (CNT and American Rivers 2010). Additionally, SPU identified cost savings in terms of the life span of the project; SEA streets are designed to improve performance as plantings mature, whereas traditional systems tend to degrade over time (Wong and Stewart 2008, as cited in CNT and American Rivers 2010).

A.2.3 Life Cycle Costs and Asset Life Extension

When considering avoided conventional stormwater management costs, it is important to account for all costs that would be incurred over the analysis period in absence of GSI implementation, including capital, O&M, and replacement costs. Maintenance cost comparisons have shown that in some cases, GSI can be less expensive than conventional gray infrastructure (American Rivers et al. 2012, U.S. EPA 2010, 2013). Table A-4 presents estimates from the literature for annual maintenance costs for conventional stormwater management practices as a percent of construction costs. Similar to the other costs reported in this appendix, O&M costs will vary significantly depending on site- and community-specific factors.

Table A-4. Example O&M Cost Estimates for Conventional Stormwater Management as a Percent of Construction Costs.

Stormwater management practice	O&M costs as a percent of construction costs	Source
Storage tanks	0.15 - 1.5%	Corona Environmental Consulting (2020), City of Alexandria (2015)
Tunnels	1.0%	City of Alexandria (2015)
Detention basins	1% – 2.7%	CNT 2005, WERF 2009
Underground storage vaults	0.25 – 0.35%	CNT 2009
General stormwater management (across conventional practices)	3.5%	City of Portland/David Evans and Associates 2008

Additional savings can accrue for some GSI practices because they have a longer asset life compared to their traditional alternatives; this can result in significant savings in the form of avoided replacement costs. For most GSI practices, avoided replacement costs should be captured through the assessment of baseline life cycle costs for the alternative conventional stormwater management practices. Green roofs and permeable pavement are an exception because their traditional alternatives are not related to stormwater management (i.e., traditional roofs and regular pavement or asphalt would not be included as an avoided stormwater management practice in a gray infrastructure baseline alternative). However, research shows that green roofs and permeable pavement (in some cases) can last longer than their traditional alternatives (David Evans and Associates 2008, U.S. GSA 2011, CNT 2009). In addition, implementation of green roofs and permeable pavement will offset costs associated with traditional roof and pavement maintenance. Table A-5 shows the maintenance and replacement costs, and expected useful life for permeable pavement, green roofs, and their traditional alternatives, based on various sources from the literature.

A.2.4 Methods for Estimating and Incorporating Avoided Gray Infrastructure Costs

Several tools and studies have applied different assumptions and methods to estimate the avoided costs associated with GSI (or to compare the costs of GSI to the cost for conventional alternatives). For example, the Center for Neighborhood Technology (CNT) has developed two tools designed to help users assess the performance, costs, and benefits of GSI solutions compared to conventional stormwater management approaches. The first tool, known as the Original Green Values Calculator

(GVC), allows users to assess the hydrologic and financial conditions for stormwater management alternatives at the watershed or neighborhood scale. The Original GVC applies the TR-55 and Rational methods to calculate stormwater runoff volume and peak flows for a given site. The tool can apply up to six GSI practices to create a comparison between conventional (i.e., pipes, curbs, gutters, and detention ponds) and GSI scenarios (i.e., green roofs, rain gardens, vegetated swales, trees, native vegetation, and permeable pavement). The tool relies on estimates from the literature for construction costs, maintenance costs, and the useful life of different practices to calculate net present value (NPV) lifecycle costs associated with each alternative. The Original GVC was developed in 2005; it does not appear that the cost data has been updated since that time.

Table A-5. Maintenance and Replacement Costs for Pavement and Roofs.
(2019 USD)

Pavement type	Maintenance costs ($/sq ft/yr)	Replacement costs ($/sq ft)	Expected Useful life (years)
Permeable Concrete[a]	0.015	$ 4.87	20-40 [b]
Permeable Asphalt	0.015	$ 2.10	20-40 [b]
Permeable Pavement	0.028	$ 5.92	15-50 [b]
Concrete Sidewalk/Driveway[b]	0.04	$ 6.76	30 - 40
Asphalt Street[b]	0.07	$ 5.29	17.5[b]
Asphalt Parking Lot[b]	0.18	$ 6.73	15[c]
Roof type	**Maintenance costs ($/sq ft/yr)**	**Replacement costs ($/sq ft)**	**Expected Useful life (years)**
Black Roof[d]	$0.07	$ 10.53	17
Extensive Green Roof[d]	$0.32	$ 9.61	40-60[c]
Semi-Intensive Green Roof[d]	$0.43	$ 11.26	40-60[c]

a. Maintenance and replacement costs for permeable pavements are based on cost estimates from CLASIC
b. CNT National Green Values Calculator (2009)
c. Kats and Glassbrook (2016)
d. U.S. GSA (2011)

In 2009, CNT developed the National GVC. Like the Original GVC, the National GVC compares the lifecycle costs and benefits of GSI practices to those of a conventional stormwater design; however, it varies from the Original GVC in a few ways. The National tool is focused on runoff volume reduction. This is modeled by calculating the runoff volume capture capacity for different GSI practices (this is how the Tool is designed). Volume capture in this context implies infiltration, evapotranspiration, and reuse; it does not include detention in ponds or vaults for gradual discharge into the sewer. The National GVC does not produce any peak flow results - all runoff volume captured is assumed to be kept on site. In addition, the tool is meant for a single site or a campus of buildings contained on a single site.

The National GVC estimates lifecycle costs for conventional and GSI approaches based on estimates from the literature (per square foot or storage capacity of the stormwater practice). The infrastructure components included in the “gray infrastructure” or conventional development scenario include:

- Concrete Sidewalk and Driveway
- Curbs and Gutters
- Standard Roof
- Streets
- Parking lots
- Conventional Stormwater Storage
- Turf Grass

For the GSI scenario, the need (and associated costs) for these infrastructure components are reduced or offset as GSI practices are added in. GSI practices incorporated into the tool include green roofs, planter boxes, vegetated filter strips, native vegetation, rain gardens, trees, vegetated swales, rain barrels, cisterns, amended soils, downspout disconnects, permeable pavers, porous asphalt, porous concrete, and gravel. Conventional stormwater storage is assumed to be an underground vault that would be needed to meet the on-site runoff volume capture requirements if no GSI is implemented. There is no cost included in the National GVC for pipes or detention ponds because the National GVC does not determine peak flow and therefore cannot accurately determine the necessary storage required to meet local allowable release rates (CNT 2009). The tool estimates a range of capital costs for conventional stormwater storage of between $0.68 to $3.62 per gallon of capacity; annual O&M cost estimates range from 0.25% and 0.35% of total capital costs.

The proprietary tool, Autocase, which is designed to estimate the costs and TBL benefits of GSI at the site level, includes a methodology for estimating avoided costs based on the assumption that GSI will reduce the need for detention facilities and stormwater conveyance piping. For detention, Autocase applies a simple calculation to estimate avoided costs based on the effective impervious area of the site and associated stormwater runoff volume; it does not account for differences in sizing for detention based on peak flow calculations. Thus, every gallon of cubic feet of GSI volume capacity is assumed to offset an equivalent amount of detention. Autocase assumes a capital cost for detention of $2.42 per ft3 and an O&M cost of $0.023 ft3 per year.

To estimate avoided piping costs, Autocase assumes that 1 foot of piping (12" diameter) is required for each 152 square feet of effective impervious area. Effective impervious area is determined as the equivalent area of impervious space to reach the same runoff volume in the site's design storm as the actual site. Autocase documentation provides the following example: "adding concrete or asphalt to a design leads to a need to also add piping to handle stormwater. If enough asphalt were added to a site to produce 1,000 cubic feet of runoff, and a design storm is 6 inches of rain, then the effective impervious area of the site would be 2,000 square feet (1000 cubic feet / 0.5 feet), implying a need for approximately 13.3 feet of pipe" (Impact Infrastructure 2017). Based on documentation for Autocase 3.0, the tool assumes a capital cost of $53.28 per foot of pipe and an annual O&M cost of $0.31 per foot of pipe.

Rather than estimating avoided costs associated with individual practices (i.e., detention, piping, underground storage), some studies have relied on the average or typical costs associated with managing stormwater over a unit of impervious area or stormwater volume. For example, in a study on the economic benefits of GSI in Ann Arbor, Michigan, Buckley et al. (2011) estimated the avoided costs associated with four planned GSI projects based on the stormwater fees that homeowners pay to the city. The rationale for this approach is that the revenues generated from these fees pay for stormwater capital improvement projects (which are presumably mostly gray infrastructure/conventional management practices), as well as for the operations and maintenance of the city's stormwater program. As in many cities, the stormwater fees in Ann Arbor are based on the amount of impervious land on each property. Table A-6 shows the city's stormwater fees for residential properties in 2011 (as reported by Buckley et al. 2011); for commercial and other properties, the city charged a flat rate of $331 per acre per quarter (or $1,324 per acre per year).

Table A-6. Annual Residential Stormwater Fees, Ann Arbor.
(2011 USD)

Impervious Area (sq. ft.)	Annual Stormwater Fee
Less than 2,187	$52.96
2,187 – 4,175	$92.68
4,176 – 7,110	$158.88
More than 7,110	$278.04

Source: Data from Buckley et al. 2011 (rates originally retrieved from City of Ann Arbor website, 2011).

Assuming average annual precipitation is 35 inches per year, Buckley et al. (2011) estimates the total volume of stormwater associated with each square foot of impervious area is about 21.8 gallons. Using the average impervious areas from each of the ranges shown in Table A-6, the authors estimate that stormwater fees amount to between $1.34 to $2.22 per 1,000 gallons of stormwater (2011 USD). The four GSI projects under evaluation were estimated to capture more than 1.5 billion gallons of stormwater per year. Applying the avoided cost of stormwater management as calculated from stormwater fees, the author estimates an annual savings associated with four GSI projects of between $2.0–$7.0 million dollars (2011 USD). The 50-year NPV of these benefits equals $53.2– $184.6 million (2011 USD).

The authors note that in some instances, stormwater rates may not fully account for all costs associated with managing stormwater with gray infrastructure and that further, estimates from the literature suggest stormwater rates could range up to $4.60 per 1,000 gallons. At the same time, however, stormwater fees are intended to cover all activities associated with a communities' stormwater management costs, including associated with all aspects of MS4 compliance, which go beyond capital infrastructure projects and associated maintenance. These costs would not be avoided under a GSI scenario.

As reported by CNT and American Rivers (2010), the City of Portland used an estimated cost per square foot of impervious area managed to calculate the avoided costs of conventional stormwater management approaches. Specifically, the Portland Bureau of Environmental Services estimates that it costs the city $2.71 (2008 USD) per square foot in capital infrastructure costs to manage the stormwater generated from impervious areas; it costs an additional $0.095 per square foot in annual O&M. As described by CNT and American Rivers (2010), the city uses the following equations to estimate the resulting avoided cost savings:

1) conventional cost of structure ($/SF) * total area of structure (SF) = total expenditure for conventional approach ($)
2) total expenditure for conventional approach ($) * % retained = avoided cost savings ($)

David Evans (2008), the source study that CNT and American Rivers (2010) reviewed, offers the following example. Based on the $2.71 cost per square foot, the City would have a one-time expenditure of approximately $108,400 to manage stormwater generated from a 40,000 square foot conventional roof. Since a green roof retains 56% of the total volume of stormwater runoff, the City would avoid $60,700 in capital costs from not having to manage this amount of stormwater.

A.3 Tool Methodology for Quantifying Avoided Gray Infrastructure Costs

The GSI TBL Benefit Cost Framework and Tool (Tool) allows the user to incorporate avoided costs in several ways. Across all methods, it is important to note that avoided costs must reflect costs associated with managing the same amount of stormwater that is managed in the user's GSI scenario. That is, avoided costs are the costs for gray or conventional approaches that would achieve the same stormwater management goal as would be achieved under the user's GSI scenario. In addition, the Tool does not include data on costs associated with upgrading municipal WWTPs as an alternative to GSI implementation (e.g., as a way meet TMDLs or other water quality requirements). If applicable, the user can input this information into Tool as part of their baseline (avoided cost) alternative.

Finally, for all avoided gray infrastructure, it is also important to clarify what the timeline would have been for project implementation. This is important to be able to compare present value costs of the GSI scenario to its present value benefits (in this case avoided costs for conventional stormwater management). The Avoided Cost module includes questions on the timing of avoided projects.

A.3.1 User Input

If the user can estimate the cost of alternative stormwater management based on local data, they can enter it directly into the Tool. This will require the following inputs:

- Capital costs
- Capital construction implementation period (the Tool assumes construction will occur within one year unless the user indicates otherwise).
- Annual O&M costs

The Tool uses this information to calculate NPV avoided costs.

A.3.2 Avoided Stormwater Pumping and Treatment

For CSO communities, the Tool automatically calculates avoided stormwater pumping and treatment costs based on a percentage (user-entered) volume of stormwater retained annually through GSI practices. Based on estimates from the literature, the Tool uses a default value of $1.27 per 1,000 gallons. However, users can input their own cost estimate based on local data.

A.3.3 Large-Scale CSO Reduction Projects

CSO communities also have the option of applying estimates from the literature to estimate avoided costs associated with reduced need for deep tunnels/underground storage tanks and/or sewer separation projects. For deep tunnels, the user must indicate the percentage of total volume managed under the GSI scenario that would be managed through deep tunnels under the baseline scenario (up to 100%). For sewer separation projects, the user must indicate the portion (acres) of the study area that would be managed through sewer separation under the baseline alternative. The Tool will automatically calculate the stormwater volume managed associated with this area.

For deep tunnels, the Tool estimates avoided costs using the cost equation reported by Wise et al. (n.d.), updating results to 2019 USD. For sewer separation, the Tool assumes an average cost of $100,000 per drainage acre, based on the average cost across 21 cities as reported in the LTCP for the City of Elkhart, Indiana. Annual O&M costs are estimated at 1% of total capital for both practices. Again, the user can enter community-specific costs, if desired.

If the large-scale CSO reduction projects do not manage 100% of the volume that is managed under the user's GSI scenario, the Tool will automatically estimate the remaining avoided costs based on the methodology described below.

A.3.4 All Other Stormwater Management Practices

For all other conventional practices, the Tool applies an average capital cost for stormwater management of $3 per square foot of impervious area managed. This cost estimate follows the approach described for the City of Portland above (which applied $2.71 per square foot of impervious area managed, 2008 USD), and represents the stormwater management allowance cost from RS Means. Specifically, it is included in RS Means as being representative of a typical gray infrastructure scenario, "absent further information" or specific cost detail. That amount is allocated for either surface or subsurface detention, with actual costs varying by size and type of detention. The cost includes markups and does not include surface infrastructure and conveyance, which may or may not be offset by GSI. It therefore represents a relatively conservative estimate for conventional stormwater management (and is very similar to Portland's $2.71/ft^2, which when updated to 2019 USD equates to #3.22/ft^2). For O&M costs, we follow Portland's approach and assume annual O&M amounts to 3.5% of total capital.

While we recognize that this method is a simplified approach, we feel it is not more or less accurate than an approach that attempts to estimate avoided costs without specific calculations related to peak flow. In addition, the user has the option to input community-specific data to better estimate avoided costs for their location and specific GSI scenario.

A.3.5 Avoided (Non-stormwater) Maintenance and Replacement Costs

The Tool includes avoided maintenance costs for traditional roofs and pavement as avoided costs associated with the GSI scenario. For green roofs, the Tool also includes avoided replacement costs due to the much longer useful life of green roofs compared to traditional roofs. This calculation assumes that green roofs are implemented at the time a roof on an existing have been replaced or rehabilitated or are installed on new or redeveloped buildings. Thus, avoided capital costs are not included in the calculation. Maintenance and replacement costs and useful life assumptions are based on estimates presented in Table A-5 above. The Tool does not include avoided replacement costs associated with permeable pavement because more research is needed on this topic.

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APPENDIX B

Energy Savings

B.1 Introduction

Some green stormwater infrastructure (GSI) practices, including trees and green roofs, can help shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. In addition, in cities with combined sewers, implementation of GSI can reduce the volume of stormwater entering the combined sewer system, which in turn can reduce energy demands for pumping and treatment at municipal wastewater treatment plants (WWTPs).[4] Finally, if rainwater harvesting systems are included in a user's GSI scenario, the resulting potable water offsets reduce energy demand for drinking water treatment and distribution.

This appendix provides an overview of the direct energy saving benefits (i.e., avoided energy use/costs) associated with GSI and describes how these benefits are quantified and monetized in the GSI TBL Benefit Cost Framework and Tool (Tool). As an important note, reductions in energy use also result in decreased greenhouse gas (GHG, including carbon dioxide, CO2) and other air pollutant emissions (e.g., sulfur dioxide, SO_2, and nitrogen oxides, NOx) from power plants. These benefits are not addressed here but are described in corresponding Appendices E and L, on air quality improvements and carbon reduction benefits associated with GSI. Further, the direct financial savings associated with avoided stormwater pumping and treatment (including energy costs) are incorporated into the calculation of avoided gray infrastructure costs (see Appendix B) and are therefore not described here. However, because the reduction in energy use will result in reduced emissions and associated air quality benefits, it is necessary to quantify the amount of energy use avoided from reduced pumping and treatment.

B.2 Findings from the Literature

This section provides an overview of findings from the literature related to the effect of trees and green roofs on building energy demands, as well as the energy savings associated with reduced stormwater pumping and treatment in combined sewer systems.

B.2.1 Building Energy Savings: Trees

Trees can reduce building energy demands for cooling and heating by providing shade and evaporative cooling and blocking winter winds. The energy saving benefits associated with trees have been well studied (e.g., Heisler 1986; McPherson et al. 1994, 2005; McPherson and Simpson, 2003; Akbari et al., 1997, 2002; Nowak et al. 2011, 2012). Extensive research by the U.S. Forest Service[5] and others demonstrates that tree-related energy savings vary based on local climate, location of the tree relative to the building, size and type of tree, and building characteristics (e.g., building height, level of insulation, use of air conditioning). For example, studies have found that in colder areas, trees can actually increase energy demand for heating in the winter if they cast shade on buildings (Nowak et al. 2016). At the same time, trees that serve as wind breaks in warm areas generally do little to reduce building energy demand (CNT and American Rivers 2010).

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[4] This benefit does not typically apply in separate storm sewer systems because stormwater is diverted directly to local drainage ways via gravity (i.e., not routed through a treatment plant.

[5]Over the past 30 years, USFS researchers have conducted extensive research on the ecosystem services that trees provide, including building energy savings. Much of this work was initially led by Heisler, McPherson, and more recently, Nowak.

Several studies have estimated the per-unit energy savings imparted by trees based on different factors. For example, McPherson et al. (1994) used modeling to conduct a Chicago-based simulation that looked at three heights of trees, placed at three distances away from the building, at a variety of orientations (east, south, north, west). The test building was a three-story brick building with two units on each floor. The simulation indicated that trees to the west of a building have the greatest potential for reducing air conditioning costs because they block out the afternoon sun. Similarly, trees on the east side also reduced energy consumption. A tree on the south side however, had the potential to increase heating costs in the winter because they cast shade on the building. Findings from the study indicate that a single 25-foot tall tree can reduce heating and cooling electricity needs by 2 to 4% in a building, while three strategically placed trees can reduce consumption by up to 10%.

Between 2000 and 2010, the USFS developed a series of community tree guides that quantify benefits and costs for representative large, medium, and small broadleaf trees and coniferous trees in each of 16 U.S. climate regions. The tree guides provide quantitative benefit values for "yard trees" (those planted in residential sites) and "public trees" (those planted on streets or in parks). In the Community Tree Guide for the Midwest, McPherson et al. (2006) estimates that 20-years after planting, annual electricity savings due to reduced demand for cooling for a medium-sized tree range from 69 kWh for a public tree to 213 kWh for a tree in a residential yard opposite a west-facing wall. The difference in benefits provided by public vs private trees is presumably because public trees are more often located further away from buildings. This may not be as important for trees that reduce demands for heating in cold climates by blocking winter winds, as McPherson et al. (2006) reports greater natural gas savings for public trees in the Midwest. The community tree guides also report incrementally larger energy savings associated with larger trees.

In a study of five American cities—Berkeley, California; Fort Collins, Colorado; Bismarck, North Dakota; Cheyenne, Wyoming; and Glendale, Arizona—McPherson et al. (2005) used computer simulations to examine changes in building energy use caused by shade from street trees. For this study, the location and distribution of street trees with respect to buildings was based on a field sample for each city. Results indicated that

> "energy savings were particularly important in Berkeley ($553,061 per year, $15/tree)[6] and Cheyenne ($186,967 per year, $11/tree). The close proximity of street trees to buildings in Berkeley resulted in substantial shading benefit during the summer (95 kWh/tree). In Glendale, where summer cooling loads were much greater, trees provided virtually no shade to buildings because of their location along wide boulevards. Their cooling benefit (44 kWh/tree) largely was due to air-temperature reductions associated with evapotranspiration. Winter heating savings were substantial in Cheyenne ($88,276, $5/tree), where low temperatures and strong winds accentuated tree windbreak effects."

Using real-world data from 160 households in Alabama, Pandit and Laband (2010) found that the quality of shade, from less dense shade to more dense shade, influences overall energy savings. The authors report that for a house with 19.3% shade coverage and average shade density, trees reduce cooling-related electricity use by 3.8% on average, compared to a house with no shade. A house with the same shade coverage (19.3%) but with more dense shade, reduces summertime electricity use by 9.3%. The authors estimated that on average, every 10% of shade coverage amounts on average to approximately 1.29 kWh reduction in cooling-related energy use, although this varies by climate and other factors.

As far as species impact on energy consumption, broadleaf trees typically provide greater overall

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[6] Dollar values are assumed to be reported in 2005 USD, the year of publication. This was not specifically stated by the authors.

benefits compared to evergreens, but this can vary based on local climate conditions and tree location (NYC DEP, n.d.). Akbari (2002) and others describe how, unlike evergreens, broadleaf deciduous trees lose their leaves in the winter, thereby allowing more sunlight to reach the building, which in turn reduces heating costs (NYC DEP, n.d.). However, Nowak et al. (2016) notes that even deciduous trees cast winter shade, typically blocking 35% of incoming solar radiation when off-leaf. In addition, in colder climates that experience winter winds, evergreens planted to the north and west side of buildings can serve as more efficient windbreaks (McPherson et al. 2006).

Over the past 15 to 20 years, USFS and private sector partners have worked to integrate its extensive research on the benefits and costs of trees into a suite of software tools, now known as i-Tree. i-Tree is a collection of analysis tools that allow practitioners to inventory and assess the benefits and costs of trees in various settings. i-Tree users can quantify and value the ecosystem services provided by trees, including energy savings, pollution removal, carbon sequestration, avoided carbon emissions, avoided stormwater runoff, and more. i-Tree provides baseline data so that the growth of trees can be followed over time and average annual benefits can be estimated accordingly. There are currently seven different i-Tree applications; i-Tree Streets (formerly known as the Street Tree Assessment Tool for Urban forest Mangers, or STRATUM) allows users to assess the benefits and costs of various street tree species across 16 climate zones. As detailed below, we have integrated energy saving estimates from i-Tree Streets for common street tree species (by region) into the Tool. This will allow users to calculate energy savings on a per-tree basis for their specific climate zone.

B.2.2 Building Energy Savings: Green Roofs

Green roofs can also reduce building energy demand both heating and cooling. Green roofs provide better insulation than conventional roofs, reduce the transfer of heat from a building's exterior to its interior through the roof, and lower roof surface temperatures through evaporative cooling (Wise et al., n.d., U.S. EPA 2018). As reported by Clements and St. Juliana (2013), the energy savings provided by green roofs depend on:

- Local climate factors, such as temperature, relative humidity, and wind speed
- Building characteristics, including number of stories, level of insulation, and the portion of the building's heating and cooling load that is caused by heat flow through the roof;
- Characteristics of the roof itself, including soil depth, extent of foliage, moisture content of the growing media, and materials used for areas not covered in plantings (ASU, n.d.; Theodosiou 2003; Gaffin et al. 2005, as cited in Wise et al., n.d.; Clark, Adriaens, and Talbot 2008; Garrison, Horowitz, and Lunghino 2012).

Empirical research demonstrates the energy saving benefits of green roofs in different climates (American Rivers et al. 2012). For example, Chicago's 20,300-square-foot green roof located on half of its City Hall–County Building is estimated to yield $3,600 in annual building-level energy savings (American Rivers et al. 2012). The green roof on the Target Center Arena in Minneapolis, which encompasses 113,000 square feet, has reportedly decreased annual building energy costs by $300,000 (American Rivers et al. 2012). As further evidence of green roof energy savings in cooler climates, a Canadian model of a 32,000-square-foot green roof on a one-story commercial building in Toronto found reductions in total cooling and heating energy demand of 6 and 10%, respectively. When applied to the warmer climate of Santa Barbara, California, the same model estimated a 10% savings in cooling costs (U.S. EPA 2008, as cited in American Rivers et al. 2012).[7]

In a report prepared for the city of Portland, Oregon, David Evans and Associates (2008) reviewed several studies that quantified the energy savings associated with green roofs (e.g., Dawson 2002, Acks 2006). Results of this review suggest that total energy savings from reduced heating and cooling generally range between 5% and 15% compared to buildings with conventional roofs. Moreover, two Portland-based studies found that extensive roofs were effective in reducing annual cooling and heating by 12% for a single-story, 17,500-square-foot building. Savings ranged between 0.17 kWh and 0.63 kWh per square foot due to reduced cooling demand, and 0.02 therm per square foot due to reduced heating demands (David Evans and Associates 2008, Lee et al. 2007).

Francis and Jensen (2017) conducted a systematic review of 41 studies that evaluated reductions in building energy consumption related to green roofs. Of the 41 studies, the authors found 20 to be directly comparable because they reported changes in annual energy consumption. These studies reported a wide range in building energy use attributed to green roofs, from an increase of 7% to a decrease of 90%. The authors state that the large range in documented effectiveness may be explained by the heterogeneity of the parameters analyzed (e.g., climate, media depth, baseline level of insulation), as well as by the fact that most of the results were obtained through modelling, where extreme situations are easily tested. The largest spans in effectiveness were found in studies testing the influence of roof insulation. Not surprisingly, uninsulated buildings resulted in high energy savings, while the energy savings for well-insulated buildings were found to be relatively low. The influence of other parameters, such as media depth, vegetation type, climate, building typology, irrigation status, and coverage rate, was also investigated but Francis and Jensen report that these parameters had less of an impact as compared to roof insulation.

In a study commissioned by the Natural Resources Defense Council (NRDC) on the benefits of green roofs in Southern California, Garrison, Horowitz, and Lunghino (2012) report that during the summer, a green roof can reduce the average daily energy demand for cooling in a one-story building by more than 75%. However, the authors state that modeling results have generally indicated overall energy savings of up to 25% annually, depending on building and green roof characteristics and the site's climate (Garrison, Horowitz, and Lunghino 2012). Another finding of this report was that green roofs can provide additional energy savings for buildings that have rooftop air-conditioning systems. Air-conditioning systems typically begin to decrease in operational efficiency at about 95°F. Because green roofs reduce the ambient air temperature on-site, they can help to avoid efficiency losses that occur on hot summer days, thereby reducing costs and energy used for cooling (Garrison, Horowitz, and Lunghino 2012).

Sailor (2008) performed extensive modeling and simulations to explore the various factors that lead to building energy savings from green roofs.[8] Applying these models, Sailor et al. (2012) conducted simulations that compared nine variations of green roofs to both black and white membrane control roofs. The investigation included a total of eight buildings – new office and new multi-family buildings, in each of four cities: Houston, Texas; New York City, New York; Phoenix, Arizona; and Portland, Oregon. The models indicate that building energy performance of green roofs generally improves with increasing soil depth and vegetative density. Heating (natural gas) energy savings were greatest for the multi-family buildings in the colder climates, while cooling energy (electricity) savings varied for the different

[7] The sources consulted for this report do not differentiate between energy savings associated with extensive green roofs (generally defined as having a depth of 3 to 6 inches) versus intensive green roofs (having a depth of more than 6 inches to accommodate larger plants).

[8] Sailor and his colleagues have integrated the U.S. Department of Energy's EnergyPlus building energy simulation program with a comprehensive green roof simulation module to analyze the effects of roof surface design on building energy consumption.

building types and cities. In all cases, a baseline green roof resulted in energy cost savings for heating compared to the conventional black membrane roof. However, because a high level of roof insulation was assumed, overall savings were found to be relatively modest. In addition, in six of the eight test buildings, the white control roof[9] resulted in lower annual energy cost than the baseline green roof. However, a high vegetative cover green roof was found to outperform the white roof in six of the eight buildings.

The models developed by Sailor (2008) require the end-user to have substantial expertise in energy modeling. With the goal of allowing nonexperts to obtain quick estimates of how green roof design decisions might affect building energy use, Dr. Sailor and his colleagues at Portland State University partnered with researchers from the University of Toronto and Green Roofs for Healthy Cities to develop the National Green Roof Energy Calculator (ASU, n.d.). This free online tool compares the estimated annual energy performance of a commercial or residential building with a green roof against the estimated performance of the same building with a conventional roof or a white roof. The built-in assumptions of the online calculator originate from Dr. Sailor's more complex whole-building energy simulation model, the Department of Energy's EnergyPlus model, and actual measurements of roof surface data, soil moisture, and other variables from specific green roofs that have been studied.

Dr. Sailor has generously provided the WRF project team with output from the 8,000 simulations that back up the National Green Roof Energy Calculator for use in the Tool. This includes energy savings estimates for green roofs with different characteristics in 100 reference cities in the U.S. and Canada. This data allows users to estimate the energy saving benefits of green roofs based on local climate and various roof characteristics (e.g., irrigation status, vegetative cover, soil depth).

B.2.3 Energy Savings: Avoided Stormwater Pumping and Treatment

As noted earlier, GSI practices reduce the amount of stormwater that enter combined sewer systems and, in some cases, can reduce the need for increased wastewater treatment capacity in separate sewer systems aiming to meet specific water quality targets. This is in turn reduces energy demands associated with wastewater pumping and treatment. While the monetary value of this benefit is already accounted for through calculation of avoided gray infrastructure costs (see Appendix B), the reduction in energy use provides indirect air quality and associated health benefits from reduced emissions (including carbon and others, see appendices E and L). Thus, it is necessary to quantify the reduced energy demand associated with reductions in wastewater treatment.

According to the Electric Power Research Institute and the Water Research Foundation (WRF/EPRI, 2013), municipal wastewater treatment systems in the U.S. use approximately 30.2 billion kWh per year, accounting for close to 0.8% of the nation's total electricity use. Energy requirements at WWTPs depend in part on the level of treatment required, which influence the treatment method and technologies used (EPRI 2013, U.S. EPA. 2015). Treatment requirements are usually dictated by the characteristics of the receiving water body or disposal area, and treatment approaches and objectives vary significantly across the U.S. (EPRI/WRF 2013).

There are three general levels of treatment, including primary, secondary, and tertiary (advanced), with various treatment technologies available at each stage. EPRI/WRF (2013) reports that between 1996 and 2013, total energy demands from WWTPs across the U.S. increased by 74%, in large part due to widespread implementation of secondary treatment processes. Secondary wastewater treatment typically includes aeration for removing dissolved organic matter and nutrients; aeration is the principal

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[9] A white roof is painted with solar reflective white coating and reflects up to 90% of sunlight (as opposed to traditional black roofs which reflect only 20%).

energy-using process in wastewater treatment (EPRI 2013). Advanced WWTPs produce effluents of the highest quality but at the cost of significant energy use (EPRI 2013).

Table B-1, developed by EPRI (2002), demonstrates how energy use varies across treatment type, showing for example, that plants utilizing trickle filtration (a secondary treatment method) have lower energy intensity on average, while plants that utilize nutrient removal as part of an advanced treatment process have higher energy intensity. Table B-1 also shows that energy use varies by size of treatment, with larger plants using less energy, likely due to economies of scale.

Table B-1. Unit Electricity Consumption for Wastewater Treatment by Size of Plant.

	Unit Electricity Consumption (kWh/MG)			
Treatment Plant Size (MGD)	**Trickling Filter**	**Activated Sludge**	**Advanced Wastewater Treatment**	**Advanced Wastewater Treatment with Nitrification**
1 MGD	1,811	2,236	2,596	2,951
5 MGD	978	1,369	1,573	1,926
10 MGD	852	1,203	1,408	1,791
20 MGD	750	1,114	1,303	1,676
50 MGD	687	1,051	1,216	1,588
100 MGD	673	1,028	1,188	1,558

Source: EPRI 2002; Reprinted with permission from EPRI.

In 2013, EPRI and WRF published energy intensity values (kWh/MG) for various unit wastewater treatment processes. This research, which served as an update to a similar study conducted in 1996 (and the values reported in EPRI 2002), used information from the literature, private research groups, and actual WWTP data (from U.S. EPA's EnergyStar dataset) to identify energy use for WWTPs based on various factors, including plant size, level of treatment, and other key process elements.

Table B-2 shows the EPRI/WRF (2013) weighted average energy intensity estimates for WWTPs of various sizes and reports the prevalence of some of the treatment characteristics that influence energy use. For example, as shown, fine bubble diffusion predominates as the secondary treatment of choice in all but the smallest of plants. Fine bubble diffusion is an aeration technology that is more efficient than other available aeration processes such as mechanical aeration. A relatively high percentage of WWTPs also employ nitrification practices, which increases energy use. In addition, larger treatment plants are more likely to generate electricity onsite, which helps to offset energy demands.

Table B-2. Weighted Average Values for Wastewater System Parameters.
From filtered U.S. EPA EnergyStar dataset

			Predominant Treatment Processes		
Average Daily Flow Range (MGD)	**Energy Use Intensity (kWh/MG)**	**% Generating Electricity Use Onsite**	**Predominant Secondary Treatment Process**	**% Nitrifying**	**Biosolids Disposal**
< 2	3,300	10	Mechanical aeration	68	Land application
2 – 4	3,000	14	Fine bubble	66	Land application
4 – 7	2,400	7	Fine bubble	59	Land application
7 – 16	2,000	45	Fine bubble	59	Land application
16 – 46	1,700	39	Fine bubble	61	Landfills
46 – 100	1,700	44	Fine bubble	33	Land application
101 - 330	1,600	18	Fine bubble	46	Land application

Source: EPRI/WRF 2013; Reprinted with permission from EPRI.

Although the EPRI/WRF report discusses energy use for pumping through collection systems, it is not entirely clear whether (or how) the weighted average estimates in Table B-2 account for energy use associated with pumping wastewater to the WWTP; however, it appears that they do not. For the purposes of the Tool, we assume that the estimates below are for treatment only.

In combined sewer systems, pumping wastewater and stormwater through the collection system and storage facilities, and ultimately, to the WWTP can require significant amounts of energy. EPRI/WRF (2013) report an energy intensity estimate for wastewater pumping of 220 kWh/MG. However, this estimate reflects a national average, which is largely weighted towards MS4 systems, and seems to be quite low for communities with combined sewers. For example, Capodaglio and Olsson (2020) report that typical sewage systems pumping energy requirements have been estimated to be over twice the average amount of energy used for treatment of the wastewater to high standards. Further, the authors state that without considering losses due to pump efficiency (typically between 65% and 80%) pumping energy requirements average approximately 69 kWh per population equivalent (PE) per year. Using this estimate, and applying some basic assumptions (e.g., 75 gallons of wastewater flow per person per day), yields an average energy intensity of 2,250 kWh/MG for wastewater/stormwater pumping. This is closer to the magnitude of estimates referred to in the literature for combined systems.

B.3 Tool Methodology for Quantifying and Monetizing Energy Savings

This section describes the methodology the project team developed and integrated into the Tool for calculating avoided energy use associated with GSI, including building energy savings, savings from reduced stormwater pumping and treatment, and savings associated with potable water supply offsets.

B.3.1 Building Energy Savings: Trees

As noted above, the USFS has developed a suite of software packages, known as i-Tree, that allow practitioners to inventory and assess the benefits and costs of trees in various settings. The i-Tree Streets package uses tree growth and benefit models for urban tree species in 16 climate zones to estimate the monetary value of the ecosystem services that street trees provide, including energy savings. Based on extensive field sampling and simulation modeling, i-Tree Streets (and other i-Tree models) represents the most comprehensive and peer-reviewed source of information and data on the benefits of urban trees.

In 2009, Casey Trees and Davey Tree partnered with the USFS to integrate i-Tree Streets data into an easily accessible online tool that allows users to estimate the per-tree benefits of street trees based on diameter at breast height (dbh, a common size measurement for trees), species, region, and adjacent structures (e.g., residential, commercial, industrial). This tool is known as the National Tree Benefit Calculator (NTBC). As described below, the project team integrated data from the NTBC into the Tool. This allows users to estimate the benefits of street trees planted as part of the GSI scenario they are analyzing.

First, the project team relied on data from the Urban Tree Database (McPherson et al. 2016) to identify the most common street tree species in each of 16 U.S. climate zones (see Figure B-1). Based on field sampling of more than 14,000 trees in 17 reference cities, the Urban Tree Database also contains 365 sets of tree growth equations for 171 distinct species across the 16 climate zones. The project team used these equations to estimate dbh for the 15 to 20 most common street tree species in each climate zone based on age of tree (i.e., the independent variable). We then entered the estimated dbh at 30 years for each tree (by region) into the NTBC. Table B-3 shows the average dbh and associated energy savings (for cooling and heating) for the most common street tree species in each region. As shown, trees provide cooling-related energy savings in every region, while reductions in demand for heating are realized only in colder regions, including the Midwest, North, and Northeast.

Using the equations developed by McPherson et al. (2016), we calculated the dbh for each tree across multiple years (i.e., at different tree ages). This allows us to incorporate annual energy saving benefits into the Tool for each year of the user's selected analysis period. Rather than having the user input specific tree species, the Tool uses the average per-tree energy savings estimates for the most common street tree species in each region. While some tree species have much higher stormwater capture benefits (the primary benefit of interest for stormwater managers), site constraints can prevent planting of certain species (e.g., larger trees). While we have relied on average benefits for common street tree species, we excluded species from this estimate if they had particularly low stormwater capture benefits (also calculated through the NTBC).

To monetize energy savings, the Tool incorporates 2019 data from the Energy Information Administration (EIA) on average electricity costs per kWh (and natural gas costs per Btu) by state, for residential and commercial customers. Users also have the option of entering local energy costs.

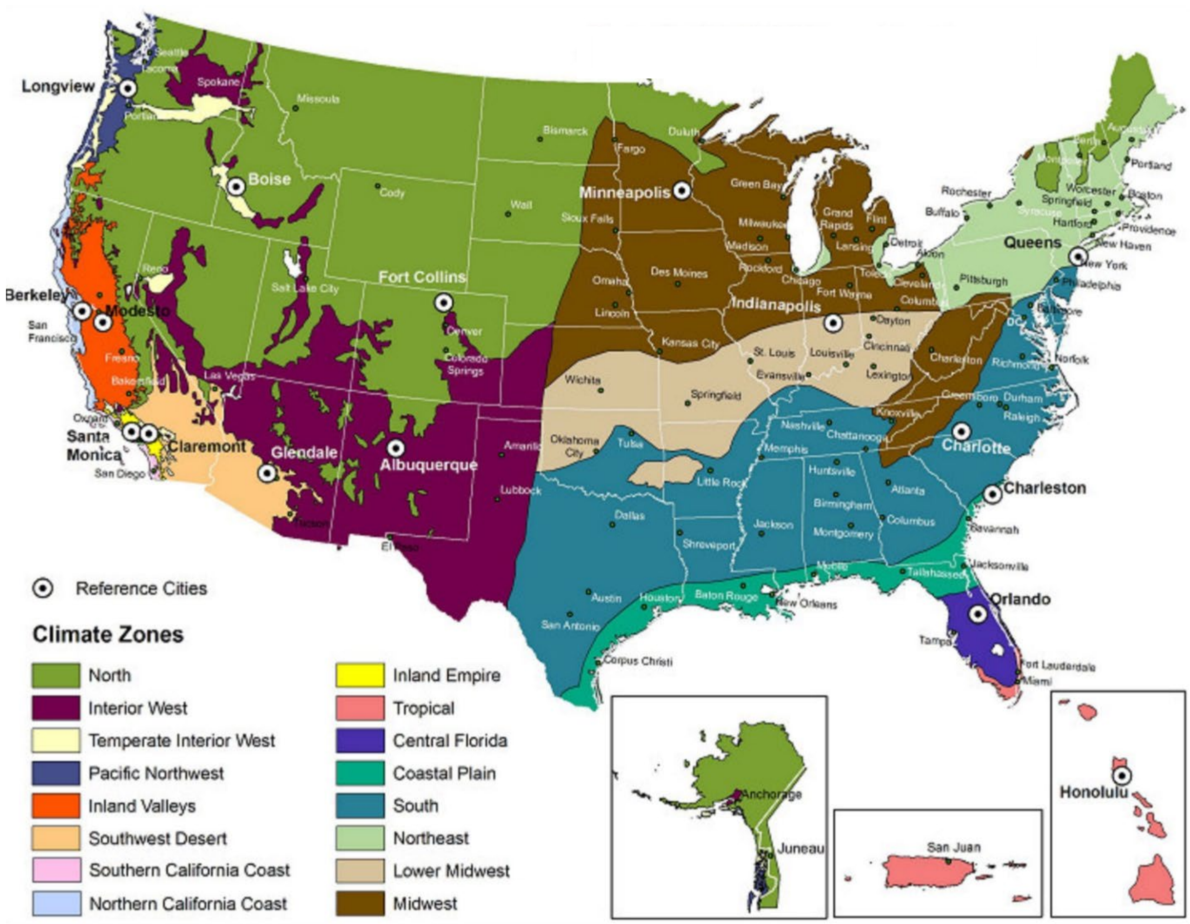

Figure B-1. i-Tree Climate Zones.
Source: U.S. Forest Service, n.d.

B.3.2 Building Energy Savings: Green Roofs

As described above, the project team integrated data from the National Green Roof Energy Calculator into the Tool to allow users to estimate the energy saving benefits associated with different types of green roofs in their region (i.e., kWh and therms). The information in the Calculator is based on annual building energy simulations carried out by Dr. Sailor and his colleagues at Portland State University.[10] In total, 8,000 simulations were conducted for the calculator, including for 100 cities (and their corresponding weather and precipitation files), 2 building vintages ("old" and "new"), 2 building categories (office and residential), and 20 roof types. Two of the roof types corresponded to dark and white (control) membrane roofs. There were also 9 distinct green roofs modeled (based on varying soil depth and leaf area index), and each green roof was modeled both with and without irrigation. Table B-4 shows the various inputs the Calculator uses to estimate energy savings for different types of green roofs.

Table B-3. Average Annual Energy Savings for Cooling and Heating for Common Street Tree Species at Year 30, by U.S. Climate Zone.

Climate Zone	Number of Tree Species	Average dbh at 30-years[a]	Average Annual Electricity Savings from Reduced Cooling (kWh)[b]	Average Annual Natural Gas Savings from Reduced Heating (Therms)
Central Florida	17	23.7	97	0
Coastal Plain	17	17.9	158	3
Inland Empire	21	16.1	122	0
Inland Valleys	22	15.4	164	1
Interior West	20	15.7	112	4
Lower Midwest	20	15.9	72	2
Midwest	17	21.3	267	36
North	20	16.1	125	12
Northern California Coast	21	14.6	132	3
Northeast	21	13.4	85	30
Pacific Northwest	22	19.3	68	2
South	21	22.4	154	5
Southern California Coast	18	14.1	60	0
Southwest Desert	18	16.1	182	1
Temperate Interior West	20	16.0	205	9
Tropical	19	14.5	82	0

a. Average dbh calculated based on McPherson et al. 2016
b. Energy savings calculated using National Tree Benefit Calculator

[10] Dr. Sailor completed the green roof simulations while at Portland State University; he is now with Arizona State University, which houses the Green Roof Energy Calculator (ASU, n.d.).

Table B-4. Green Roof Input Variables, National Green Roof Energy Calculator.

Variable category	Input range
Leaf area index[a]	0.5, 2, 5
Soil depth (cm)	5, 15, 30
Building type[b]	Multi-family residential; Office building
Building vintage[c]	Old, New
Irrigation status	Yes, No

a. Leaf area index (LAI) is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows. LAI is a dimensionless value, ranging from 0 (which represents bare ground) to 6 (which represents a dense forest).

b. Calculator relies on the U.S. Department of Energy "benchmark building" input files for a medium office building and a midrise apartment. The building types published by DOE are further divided into 16 distinct input files, each representing a U.S. climate zone. The input files account for internal and environmental loads on the building, mechanical/HVAC equipment schedules/efficiencies, and models any building system for each of the 8760 hours in a "typical" year.

c. "NEW" building vintage corresponds to building characteristics as specified in ASHRAE 90.1-2004. The "OLD" category of buildings generally represents building characteristics typical of 1980s vintage construction.

Source: ASU, n.d.

While the Green Roof Energy Calculator also calculates financial savings associated with reductions in energy use, this calculation is based on utility rate schedules from 2010. The project team integrated data from the EIA (2019) on average electricity costs per kWh (and natural gas costs per Btu) by state, for commercial customers. The Tool applies this to estimate the monetary benefit associated with energy use reductions from green roofs. Users also have the option of entering local energy costs.

B.3.3 Energy Savings: Avoided Stormwater Pumping and Treatment

This benefit only applies in combined sewer systems. The Tool automatically calculates the annual reduction in the volume of stormwater that is pumped and treated at WWTPs as a result of GSI. This is calculated in Benefits Module 1: Avoided Gray Infrastructure and Treatment Costs (Appendix A).

The user has two options for calculating energy savings associated with reduced pumping and treatment. First, the user can enter energy intensity estimates for pumping and treatment using local data. As shown in Table C-2 in a previous section, EPRI/WRF (2013) contains weighted average energy intensity estimates (kWh/MG) for treatment at WWTPs with different average daily flow ranges. As a second option, the user can select the size of the WWTP that would experience a reduction in flows in their community (or select an average size if this applies to more than one WWTP); the Tool multiplies the associated energy intensity estimate (from Table B-2) by the annual volume (MG) of stormwater retained through GSI to estimate treatment-related energy savings. The Tool also includes a default value of 2,520 kWh/MG (based on Capodaglio and Olsson 2020) to quantify energy savings associated with avoided stormwater pumping.

B.3.4 Energy Savings: Potable Water Supply Offsets

The Tool also applies energy intensity estimates from EPRI/WRF (2013) to estimate energy savings associated with potable water supply offsets. Water supply-related energy savings are based on the total volume of potable water supply offsets resulting from use of rainwater harvesting systems, as calculated in the Benefits Module 4: Water Supply. The user must complete the Water Supply module before energy savings associated with potable water supply can be calculated.

Once Module 4 is completed, the Tool automatically calculates the volume of stormwater that is diverted through rainwater harvesting each year. The user must indicate the percentage of water supply in their community that comes from surface water versus groundwater. Based on this input, the Tool calculates energy savings using energy intensity estimates for drinking water treatment and distribution from EPRI/WRF (2013):

- Surface water: 1,600 kWh/MG
- Groundwater: 2,100 kWh/MG

These estimates represent national averages for energy use associated with raw water conveyance, treatment, and distribution. However, energy use can vary significantly depending on system design and other local factors. The Tool allows the user to enter their own energy use estimates based on local data.

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APPENDIX C

Water Supply

C.1 Introduction

Green stormwater infrastructure (GSI) can provide important water supply benefits by offsetting potable water use and recharging local groundwater. Specifically:

- Water collected in rainwater harvesting systems can be used for outdoor irrigation, as well as for several (non-potable) indoor uses. This can significantly reduce potable water demand for households, businesses, and other water users.
- Water infiltrated into the soil through GSI practices can augment local groundwater supplies; groundwater serves as an important source of water supply in many communities (U.S. EPA, n.d.).

Rainwater harvesting systems can be implemented at various scales, with storage capacities ranging from small household rain barrels to large subsurface tanks that capture runoff from multiple parcels. The water supply benefits of rainwater harvesting depend on the quantity and timing of on-site water demand relative to the quantity and timing of stormwater runoff available for capture. These factors are influenced by local climate, total rainfall, distribution of rainfall depths, system storage capacity, and system operation and maintenance (NAS 2016).

Groundwater recharge benefits can also be realized across a range of scales, including through implementation of small distributed practices (e.g., household rain gardens), neighborhood bioretention projects, and regional aquifer recharge systems. The extent to which groundwater recharge augments local water supplies depends on the degree to which the recharge area is hydrologically connected to aquifers used for water supply or that might be used for water supply in the future. In aquifers connected to local streams, groundwater recharge can increase base flow, which can make additional water available for downstream users. Annual rainfall and land use patterns also affect the quantity of runoff available for groundwater recharge (NAS 2016).

GSI practices that reuse or infiltrate stormwater are particularly beneficial in areas experiencing (or expecting to experience) water scarcity. Offsetting potable water use through rainwater harvesting and/or recharging groundwater can increase water supply reliability, reduce the need to expand or upgrade existing water infrastructure, and/or avoid the development of more expensive water supply alternatives. The monetary value of these benefits can be quantified based on the direct market price of water, the avoided cost of alternative water supplies, and/or through studies that estimate household willingness-to-pay (WTP) to avoid water shortages. The most appropriate valuation method depends on the level of water scarcity in the region, local water and infrastructure costs, and other site-specific factors.

The following sections provide an overview of findings from the literature related to the water supply benefits of relevant GSI practices. Following this review, we provide an overview of the assumptions and methodology included in the GSI TBL Benefit Cost Framework and Tool (Tool)l for quantifying and monetizing these benefits.

C.2 Findings from the Literature

This section provides findings and examples from the literature on the water supply benefits associated with rainwater harvesting systems and stormwater infiltration for groundwater recharge, as well as the methods economists have used to value these benefits.

C.2.1 Rainwater Harvesting

Rainwater harvesting is accomplished by diverting stormwater runoff to a location where it can be used or stored for later use or release. For buildings, rainwater harvesting is typically focused on the capture, storage, and use of stormwater runoff from rooftops. At the household level, rainwater harvesting can include capture and direct use (e.g., through downspout systems routed directly to rain gardens), as well as capture and storage in rain barrels or cisterns. In residential applications, stormwater capture tanks tend to be relatively small (rain barrels and cisterns) and generally provide supplemental water for irrigation and other outdoor uses (NAS 2016). Large commercial, industrial, and institutional buildings more often include higher-capacity cisterns that provide water for both outdoor and non-potable indoor uses, such as toilet flushing and laundry washing. In these systems, rain is harvested from the roof of the building (or sometimes from pavement) and is filtered and stored in a cistern prior to being pumped for indoor use, as needed (Steffen et al. 2013).

NAS (2016) reports that at the household or small building scale, storage capacities and treatment for captured stormwater are typically limited due to cost. In addition, the water supply benefits of rainwater harvesting systems depend on the quantity and timing of on-site water demand relative to the quantity and timing of stormwater runoff available for capture. This can severely limit the viability of rainwater harvesting as a cost-effective source of water supply at the household level, particularly in arid regions (NAS 2016). Further, the operation and maintenance (O&M) of rainwater harvesting systems is key to realizing benefits. This is of particular concern for rain barrels, for which many utilities have reported very low rates of maintenance and upkeep by households (Clements et al. 2018, Crisostomo et al. 2014), thereby negating potential benefits.

Despite these limitations, several studies and real-world applications have demonstrated significant potable water supply savings associated with rainwater harvesting systems. For example, a 2016 study commissioned by the National Academies of Sciences (NAS) explored the amount of stormwater potentially available for various beneficial uses at different scales. As part of this study, the authors conducted an original analysis using WinSLAMM (the Source Loading and Management Model) to approximate potential water savings from household-scale stormwater capture and reuse in medium-density, residential development in six U.S. cities: Los Angeles, CA; Seattle, WA; Lincoln, NE; Madison, WI; Birmingham, AL; and Newark, NJ. In each location, the authors analyzed the use of rainwater harvesting to meet on-site irrigation and toilet-flushing demands. For simplicity, two stormwater storage volumes were considered:

- 70 gallons per household, representing two rain barrels at 35 gallons each
- 2,200 gallons per household, representing a single larger tank (8 ft diameter and 6 ft tall).

Tables C-1 and C-2 respectively present the results of the NAS (2016) analysis for the 70- and 2,200-gallon scenarios. Results indicate that water savings associated with the beneficial use of stormwater are largely dependent on tank size and the amount and timing of precipitation relative to water demand. For example, as shown in Table C-1, the authors found the potential for substantial household water savings, ranging from 24% to 28%, in four of the six cities analyzed under the 2,200-gallon storage tank scenario. These cities—Lincoln, NE; Madison, WI; Birmingham, AL; and Newark, NJ (all located in the Midwest or East Coast)—have year-round rainfall closely matching irrigation demands. Los Angeles and Seattle were found to have much lower water savings potential (5% and 15%, respectively), largely because the timing and intensity of rainfall limits the capacity of stormwater collection (NAS 2016). In addition, small stormwater water storage volumes result in much lower potable water savings - under the 70-gallon storage capacity scenario, savings ranged from less than 2% in Los Angeles to 10% in Newark (Table C-2).

Steffen et al. (2013) also assessed the potential benefits of residential rainwater harvesting across geographic regions. For this study, the authors used U.S. EPA's Stormwater Management Model (SWMM) to examine water supply and stormwater management benefits of residential rainwater harvesting in 23 U.S. cities across seven climate regions. The analysis was conducted for standard residential parcel and rooftop sizes using daily precipitation records and a daily water demand pattern developed for each city. Like NAS (2016), the authors examined potable water savings associated with use of stormwater for irrigation and toilet flushing. Water-saving efficiency benefits were determined for a range of rainwater cistern sizes.

Table C-1. Potential Potable Water Savings in Six Cities Based on a 100-Acre Medium Density Residential Area Using Two 35-Gallon Rain Barrels per Household.[a]

City	Base Use (Mgal/yr)[b]	Volume Potable Water Savings (Mgal/yr)			Percent Potable Water Savings (%)		
		Irrigation	Toilet Flushing	Both	Irrigation	Toilet flushing	Both
Los Angeles, CA	60.7	0.6	0.8	1.1	1	1.2	1.8
Seattle, WA	35.7	1.1	2.3	3	3.1	6.4	8.3
Lincoln, NE	35.8	1.8	1.5	2.3	5	4.2	6.3
Madison, WI	24.2	0.9	1.7	2.1	3.8	7	8.6
Birmingham, AL	24.3	0.6	1.6	1.8	2.6	6.4	7.3
Newark, NJ	24.7	0.9	2.1	2.5	3.5	8.6	10

a. Study assumes a density of 12 persons per acre; assumption regarding number of persons per household was not reported.
b. Represents household water demand for indoor uses and outdoor irrigation

Source: NAS 2016.

Table C-2. Potential Potable Water Savings in Six Cities Based on a 100-Acre Medium Density Residential Area Using One 2,200-Gallon Cistern per Household.

City	Base Use (Mgal/yr)	Volume Potable Water Savings (Mgal/yr)			Percent Potable Water Savings (%)		
		Irrigation	Toilet Flushing	Both	Irrigation	Toilet Flushing	Both
Los Angeles, CA	60.7	2.4	2.7	3.3	4	4.5	5.4
Seattle, WA	35.7	2.8	4.2	5.5	7.8	12	15
Lincoln, NE	35.8	7.6	3.9	9.2	21	11	26
Madison, WI	24.2	3.2	4.3	6.8	13	18	28
Birmingham, AL	24.3	2.4	4.3	5.8	9.7	18	24
Newark, NJ	24.7	3.2	4.2	6.9	13	17	28

Source: NAS 2016.

Table C-3 shows selected results of the study by region, including the cistern size necessary to capture 80% of the average annual rooftop runoff and the corresponding water-saving efficiency for non-potable indoor, outdoor, and total (non-potable indoor plus outdoor) water demand patterns. As shown, there is a wide variation in the size of cistern required to achieve 80% water yield capture; regions with higher annual precipitation require larger cisterns and can provide significant water-saving efficiencies. Regions with lower annual precipitation require smaller cisterns to capture 80% of rooftop runoff but provide significantly less water-saving efficiency potential. Note that the savings presented in Table C-3 cannot be directly compared to the NAS (2016) findings (Tables D-1 and D-2) because they represent percent reductions in water used for toilet flushing and outdoor irrigation, rather than a percent reduction in total household water use (such as presented in Tables C-1 and C-2).

Table C-3. Water-Saving Efficiency by Region for 80% Rooftop Water Yield Capture.[a]

Region (Cities)	Cistern Size (gallons)	% Reduction in Potable Water Demand for Specific Use		
		Toilet Flushing[b]	Outdoor Use[c]	Total[d]
Mountain West (*Denver, Salt Lake City*)	250	47	6	8
Southwest (*Albuquerque, Phoenix, Las Vegas*)	200	19	2	3
Southeast (*Atlanta, Miami, Savannah, Tampa*)	1,500	95	40	36
East Coast (*Baltimore, Norfolk, Richmond, Boston, Philadelphia, Providence*)	1,250	98	39	44
Midwest (*Milwaukee, Columbus*)	700	92	24	30
West Coast (*Los Angeles, Sacramento, San Diego*)	800	39	6	6
Pacific Northwest (*Portland, Seattle*)	1,800	95	19	24

a. assumes a 2,000 square foot roof
b. represents % reduction in toilet flushing demand
c. represents % reduction in outdoor irrigation demand
d. represents % reduction in total demand for toilet flushing and outdoor irrigation.

Source: Adapted from Steffan et al. 2013.

In addition to 80% capture, the authors also examined the benefits associated with installation of a single 50-gallon rain barrel on household water use. Table C-4 presents the results of this analysis by region. Results indicate that in semi-arid regions of the country (i.e., Southwest, Mountain West, and West Coast) rainwater harvesting has the potential to capture a relatively large percentage of rooftop runoff compared with areas that experience higher levels of precipitation (i.e., the East Coast, Midwest, Southeast, and Pacific Northwest). However, the potential water savings in semi-arid regions is much lower.

Table C-4. Water-Saving Efficiency Benefits by Region Based on Installation of a Single Rain Barrel (50 gal).

Region (Cities)	% Roof Runoff Captured	% Reduction in Potable Water Demand for Specific Use		
		Toilet Flushing	Outdoor Use	Total
Mountain West (*Denver, Salt Lake City*)	68	29	4	6
Southwest (*Albuquerque, Phoenix, Las Vegas*)	73	13	2	2
Southeast (*Atlanta, Miami, Savannah, Tampa*)	41	40	10	13
East Coast (*Baltimore, Norfolk, Richmond, Boston, Philadelphia, Providence*)	39	44	10	17
Midwest (*Milwaukee, Columbus*)	50	44	9	15
West Coast (*Los Angeles, Sacramento, San Diego*)	51	15	2	3
Pacific Northwest (*Portland, Seattle*)	47	51	5	12

Source: Adapted from Steffan et al. 2013.

In a 2014 study, Litofsky and Jennings evaluated rain barrel performance (in terms of stormwater capture and use for outdoor irrigation) in residential settings across 70 cities within the U.S. The authors developed an original model to simulate stormwater capture associated with a 62-gallon rain barrel servicing 500 square feet of roof area. The authors estimated irrigation demand associated with a 150 square foot garden, while accounting for length of the growing season and daily precipitation patterns (from 2000 – 2009) in each location. As shown in Table C-5, results of the analysis indicate that rain barrel performance is highly variable. Specifically, the rain barrels would achieve total roof service area runoff reductions ranging from 3% to 44%; the percent of irrigation demand satisfied ranges from 5% to 73%. The authors note that rain barrels are most effective at reducing stormwater runoff in areas that need it the least and are least effective at satisfying garden irrigation demands in areas in which irrigation is needed the most. The authors caution that communities should carefully consider the effectiveness rain barrels before advocating for their use over other alternatives. However, note that the estimates from Litofsky and Jennings (Table C-5) are quite a bit lower (in terms of % stormwater runoff captured) than the estimates from Steffan et al. (2013). It is not clear what accounts for these differences.

Table C-5. Precipitation Data and Stormwater Management / Water Supply Results for 70 Study Locations.

Location	Average Annual Precipitation (in)	Growing Season (days)	Average Growing Season Precipitation (in.)	% Roof Service Area Runoff Reduction	% Irrigation Demand Satisfied
Albuquerque, NM	15.0	195	9.40	17.9	32.4
Ann, Arbor, MI	38.9	170	20.26	9.2	62.7
Asheville, NC	38.0	176	20.21	9.5	61.7
Augusta, ME	42.5	164	19.68	8.3	66.4
Birmingham, AL	57.0	221	33.93	7.4	54.1
Bismarck, ND	17.7	130	11.17	14.5	52.0
Boise, ID	10.4	149	2.29	11.2	15.9
Boston, MA	44.1	214	26.05	10.3	60.8
Bozeman, MT	20.0	116	7.24	10.2	48.4
Caribou, ME	41.0	130	14.99	7.1	71.0
Casper, WY	11.2	120	5.11	16.2	35.0
Charleston, WV	45.5	182	25.61	8.4	65.8
Chicago, IL	37.2	187	24.05	10.7	59.6
Cleveland, OH	33.9	176	19.34	11.5	65.7
Corpus Christi, TX	30.6	323	28.75	14.2	31.9
Dallas, TX	35.6	267	27.59	12.1	38.9
Denver, CO	13.1	157	8.27	20.4	41.7
Des, Moines, IA	34.1	175	22.81	10.9	58.7
Elko, NV	10.1	93	1.42	5.7	12.0
Gatlinburg, TN	54.9	175	29.55	6.2	65.2
Grand Forks, ND	23.1	131	2.86	6.8	26.8
Hays, KS	23.9	166	15.93	12.8	47.0
Houston, TX	55.4	274	45.68	8.8	47.1
Indianapolis, IN	45.3	182	25.39	8.4	61.3
Jackson, MS	55.1	231	33.44	7.7	50.6
Kalispell, MT	14.0	99	4.43	11.1	37.8
Kansas, City, MO	37.7	204	28.92	11.6	59.0
Las, Vegas, NV	4.0	284	2.71	30.4	8.3
Lexington, KY	47.8	193	26.88	8.7	63.6
Little Rock, AR	49.9	235	31.04	9.3	52.7
Los Angeles, CA	11.0	365	11.04	20.3	12.8
Madison, WI	36.5	145	20.21	8.3	58.6
McAllen, TX	23.2	346	22.81	17.5	26.3

(continued)

Table C-5. Continued.

Location	Average Annual Precipitation (in)	Growing Season (days)	Average Growing Season Precipitation (in.)	% Roof Service Area Runoff Reduction	% Irrigation Demand Satisfied
Memphis, TN	52.7	236	32.01	8.7	52.5
Miami, FL	63.2	365	63.20	9.1	47.8
Midland, TX	13.8	227	10.78	18.7	25.6
Miles City, MT	11.5	145	7.23	20.2	40.5
Missoula, MT	13.3	115	4.90	13.1	35.5
Moab, UT	6.3	188	3.37	26.7	18.7
Montpelier, VT	39.0	143	18.12	8.2	72.6
New Orleans, LA	59.7	302	49.99	9.5	52.7
New York City, NY	47.7	231	33.16	10.3	61.4
Oklahoma City, OK	34.2	216	25.81	11.1	45.4
Omaha, NE	29.5	162	19.27	11.3	56.3
Phoenix, AZ	6.3	365	6.27	37.2	13.3
Pittsburgh, PA	39.6	171	20.87	9.6	66.6
Port Angeles, WA	25.8	226	9.98	12.9	35.7
Portland, OR	32.6	237	14.50	9.9	36.1
Raleigh, NC	43.67	207	26.43	9.5	57.1
Rapid City, SD	14.2	141	8.10	18.7	48.2
Reno, NV	6.6	135	1.00	8.3	7.9
Richmond, VA	46.4	207	30.37	9.0	56.6
Rochester, NY	34.7	167	17.30	10.1	62.8
Rock Springs, WY	7.0	114	2.56	19.9	26.4
Sacramento, CA	17.7	297	10.42	11.7	15.0
Salem, OR	36.2	173	6.29	5.7	26.5
Salt Lake City, UT	14.7	189	5.87	15.1	26.1
San Antonio, TX	32.2	270	28.11	12.1	34.6
Savannah, GA	44.1	269	35.57	11.4	51.7
Seattle, WA	36.3	252	19.20	10.7	42.0
Sioux Falls, SD	27.2	148	15.74	11.1	56.2
St. Louis, MO	40.0	205	25.24	10.7	58.8
St. Paul, MN	29.6	159	19.60	11.3	58.6
Tallahassee, FL	56.7	240	40.05	7.5	50.4
Tillamook, OR	82.1	165	16.17	3.0	38.0
Traverse City, MI	45.5	115	25.61	8.4	65.8
Tucson, AZ	9.1	270	7.55	28.2	20.8
Washington, DC	42.7	173	23.28	7.9	55
Yakima, WA	7.2	140	1.35	12	12.5
Yuma, AZ	2.1	365	2.09	44.5	5.0

Source: Litofsky and Jennings 2014; reprinted with permission from the American Society of Civil Engineers.

While the studies of residential rainwater harvesting described above rely on extensive modeling and provide estimates of potential savings, many real-world examples of larger-scale rainwater harvesting systems have documented significant potable water supply offsets. For example, in a study on the value of GSI for urban climate adaptation, Foster, Lowe, and Winkelman (2011) cite the following examples of successful stormwater harvesting projects:

- King Street Center (Seattle, WA) uses three 5,400-gallon cisterns to collect rooftop runoff for toilet flushing and irrigation. The collection and reuse system provides 60% of the annual water needed for toilet flushing, conserving approximately 1.4 million gallons of potable water each year.

- Solaire Building (New York, NY) collects rainwater in a 10,000-gallon cistern located in the building's basement. The collected water is used for toilet flushing and make-up water. The system and other measures have decreased potable water use in the building by 50%.
- Stephen Epler Hall at Portland State University (Portland, OR) has a storm-water management system that takes rain from the roofs of two buildings, and it diverts to several "splash boxes" in the public plaza. The water is filtered and collected in underground cisterns prior to its reuse for toilet flushing and landscape irrigation. The system conserves approximately 110,000 gallons of potable water annually.

In a 2017 report on the benefits of GSI within the private real estate sector, the Urban Land Institute (ULI) highlights several case studies of private real estate developments that have used rainwater harvesting to obtain substantial water savings. Of the 11 case studies highlighted in the report, seven included rainwater harvesting systems. In one example, the authors highlight a 2.1-acre mixed use redevelopment site in Boston (the Atlantic Wharf) where rooftop runoff is captured in a 40,000-gallon-capacity storage tank and used for irrigation. ULI reports that in combination with native landscaping, the system has reduced potable water use by 60%. In addition, the development's rooftop cooling tower uses rainwater, reducing potable water use by 15% compared to conventional HVAC systems (ULI 2017).

Rainwater harvesting systems can also be implemented at the neighborhood- (or larger) scale. Neighborhood-scale projects typically mix stormwater flows originating from several areas located close together. This most commonly includes the collection of stormwater flows from gutters in areas that are several acres to a few hundred acres in size. The captured stormwater is then stored in large subsurface tanks for nearby non-potable use (e.g., irrigation, toilet flushing, laundry washing, aesthetic water features). The potential water savings from neighborhood-scale stormwater capture depends on available stormwater storage volume and the groundwater infiltration rate, source area, land development types, and correlation of water demand with rainfall (NAS 2016). While these projects are important, the benefits and costs of this type of direct reuse are not included in the Tool. One reason for this is that they are not included in the CLASIC tool and therefore the project team does not have access to applicable cost data. In addition, these projects are site-specific and difficult to estimate within a national level tool.

C.2.2 Groundwater Recharge

GSI practices that infiltrate stormwater into the ground can provide important water supply benefits by recharging local aquifers. The extent to which groundwater recharge augments local water supplies depends on whether the recharge area is hydrologically connected to aquifers that are used for water supply (or that might be used for water supply in the future) or connected to local streams in conjunctive use systems. Annual rainfall and land use patterns also affect the quantity of runoff available for groundwater recharge (NAS 2016).

Several researchers have examined groundwater recharge and related water supply benefits associated with GSI, finding significant benefits across project scales. For example, the U.S. EPA commissioned a study (Tetra Tech 2016) to better understand the potential groundwater recharge benefits associated with small, distributed stormwater retention practices at projected new development and redevelopment sites. Specifically, the authors estimated the groundwater recharge benefits that would be realized if stormwater retention standards were implemented in areas within the contiguous U.S. that do not currently require stormwater retention. Groundwater recharge benefits were estimated under a range of retention scenarios for all counties that met the following criteria: 1) have "significant" groundwater use, meaning they fall within the upper 25th or 50th percentile for all counties (representing low and high scenarios); and 2) have a high or extreme Water Sustainability Index rating (a measure of water shortage vulnerability). These criteria were intended to limit the analysis to communities that would be expected to place a value on groundwater. In total, 24.6% and 31.8% of U.S. counties met these criteria under the 25th and 50th percentile scenarios, respectively.

The authors estimated the volume of stormwater runoff available for recharge using the Simple Method[11] and assumed that the retention practices would not increase groundwater recharge beyond what was capable during pre-development (i.e., the natural recharge rate, with some exceptions). In addition, the design storm event (e.g., the 90th percentile rainfall event depth) associated with a given retention scenario was assumed to be equivalent to the percent of annual stormwater runoff volume that could be recharged. Results of the analysis indicated that over the 19 year analysis period (2021 – 2040), potential cumulative groundwater recharge for water supply could amount to between 6.8 million to 10.8 million acre-feet. The authors note that these estimates are not intended to represent exact values, but rather to approximate the value that could be realized from implementing (or increasing) retention standards for new development and redevelopment sites in states where regulatory standards do not currently exist or are below the retention scenarios evaluated.

In another study of small distributed practices, Pitt et al. (2014) used WinSLAMM to evaluate the potential infiltration benefits of residential rain gardens in Kansas City, Missouri. The authors evaluated infiltration volume associated with rain gardens in a community with approximately 600 homes per 100 acres and 39 inches of rain per year. Findings indicated that total recharge could amount to 10 million gallons per year per 100 acres. In addition, only a small fraction of incoming water was lost through evapotranspiration in the rain garden (i.e., less than 10%) because of the large amount of water applied to relatively small areas. The authors did not specifically quantify water supply savings, which would depend on whether groundwater supplies in the region are under stress from excessive withdrawals and whether shallow groundwater infiltration projects ultimately recharge deeper aquifers or local streams used for water supply.

In a 2014 study, the Natural Resources Defense Council (NRDC) found that both distributed and large-scale GSI projects, including green streets, park retrofits, government building or parking lot retrofits, and infrastructure changes to divert runoff to large-scale spreading grounds, offer substantial opportunity for cities to increase local supplies of water throughout California. The authors estimate that stormwater capture in urbanized Southern California and the San Francisco Bay region has the potential to increase water supplies by 420,000 to 630,000 acre-feet per year - approximately as much water as is used by the entire city of Los Angeles each year (NRDC 2014). This estimate includes between 365,000 and 440,000 acre-feet per year that could be captured and stored in areas overlying groundwater basins used for municipal water supply and an additional 190,000 acre-feet per year captured through residential and commercial rooftop rainwater harvesting systems.

To conduct this analysis, NRDC used geographic information systems (GIS) to calculate the potential water supply that could be captured from existing impervious surfaces in urban and suburban landscapes through infiltration. Runoff calculations were based on average annual precipitation and total impervious cover for different land use types. Land use was also analyzed to assess whether development was located over a groundwater aquifer currently used for municipal water supply and to identify soil or geologic conditions that could obstruct runoff from infiltrating to a depth necessary to reach these aquifers. In areas where conditions are favorable for infiltration (i.e., NRCS Hydrologic Soil group A or B), the authors assumed that between 75% and 90% of the runoff could be infiltrated into

[11] The Simple Method is an empirical method intended to represent a wide range of storms as a function of watershed area and imperviousness (Tetra Tech 2016).

the ground, with the remaining portion lost to evaporation or transpiration. Where infiltrative capacity of the soils is suitable for recharge, but where soil conditions require a longer drawdown time for the water to infiltrate (e.g., NRCS group C soils), it was assumed that 65% to 80% of the runoff could be infiltrated into the ground. Where highly non-infiltrative soils are present (e.g., group D soils), or where development has occurred outside of areas underlain by a groundwater basin used for water supply, the authors assumed that rooftop rainwater harvesting would be used to capture stormwater.

The NAS (2016) study described in the previous section also used WinSLAMM to calculate the potential stormwater flows available for neighborhood-scale infiltration projects in its six case study cities, demonstrating that available runoff varies based on annual precipitation and across land use types. Table C-6 shows the results of this analysis, including average annual runoff quantities for three common land uses (i.e., commercial, industrial, and medium-density residential) in the six locations. For further context, the authors provide simplified examples comparing potential recharge volumes to outdoor water demands. As shown, total runoff estimates for Los Angeles range from 210,000 to 320,000 gallons per year per acre, depending on land use. Total capture of stormwater in the Los Angeles region could supply roughly only one-half of the city's outdoor irrigation requirements for medium-density, residential areas having turfgrass (410,000 gallons per year per acre). For the Lincoln and Newark scenarios, the available runoff is more than enough water to meet medium-density residential irrigation needs (150,000 gallons per year per acre in Lincoln; 45,000 gallons per year per acre in Newark). While recharge of groundwater through stormwater infiltration has the potential to provide important water supply benefits, the authors note that not all of the recharged groundwater would likely be withdrawn for later use; further, non-recovered groundwater and seepage and evaporation losses would also need to be considered in a water supply evaluation using more complex regional groundwater modeling (NAS 2016).

Table C-6. Calculated Annual Runoff Quantities for Different Land Uses in Six U.S. Cities.
(gallons per year per acre)

	Los Angeles	Seattle	Lincoln	Madison	Birmingham	Newark
Average annual rainfall (in.)[a]	17	42	28	30	50	44
Average annual runoff, gallons per year per acre (acre-feet per year per acre)						
Commercial	320,000 (0.98)	730,000 (2.24)	490,000 (1.50)	560,000 (1.72)	940,000 (2.88)	820,000 (2.52)
Industrial	250,000 (0.77)	630,000 (1.93)	460,000 (1.41)	450,000 (1.38)	610,000 (1.87)	710,000 (2.18)
Medium-density residential	210,000 (0.06)	380,000 (1.17)	260,000 (0.80)	270,000 (0.83)	310,000 (0.95)	490,000 (1.50)

a. average annual precipitation over 5-year analysis period, 1995 – 1999

Source: NAS 2016.

Earth Economics recently developed a tool to help practitioners estimate the benefits of GSI. Meant for screening purposes, this tool provides a simple method for estimating the groundwater recharge benefits associated with specific GSI practices. Inputs into the tool's calculation include (Wildish and Schmidt 2019):

- Volume of water falling on the GSI practice on an average precipitation day. This is estimated by calculating the volume of water hitting the BMP surface during an average rainfall. Additional areas that drain into the practice can be manually added in the tool by the user.
- Percent of rainfall captured by the GSI practice, based on estimates from the literature. Table C-7 shows the tool's assumptions by GSI practice.

- Number of precipitation days per year. The average number of precipitation days, by state, is provided within the tool. For a more localized analysis, users can input the average number of precipitation days per year in their city or region.

These inputs are multiplied together to determine total (annual) water supply benefits.

Table C-7. Earth Economics Green Infrastructure Valuation Tool: Assumptions for Percentage of Rainfall Captured by GSI Practice.

GSI practice	% rainfall captured	Source
Raingardens and Bioswales	99%	Xiao et al. (2017)
Pervious Pavement	70%	Selbig (n.d.)
Bioretention Ponds	80%	Guo et al. (2013)
Wetlands	80%	Jayaratne (2010)
Green Roofs	50%	Berghage et al. (2009)

Source: Wildish and Schmidt 2019.

As an important note, because urban runoff also contains pollutants, there exists the potential to contaminate groundwater during infiltration, thereby increasing human health risks (NAS 2016). Pollutants in urban stormwater can include salts, suspended solids, nutrients, heavy metals, organic compounds, and pathogens. The likelihood for these pollutants to migrate through the soil and contaminate groundwater during stormwater infiltration depends on several factors including infiltration rates, permeability and character of the soil or infiltration media, biological activity in the subsurface, depth to the water table, and the properties of the pollutants (NAS 2016). The use of stormwater infiltration for groundwater recharge could therefore necessitate additional treatment costs. These considerations are not accounted for within the scope of the Tool; however, they should be carefully considered through more detailed planning efforts.

C.2.3 Valuing Water Supply Benefits

As noted in the introduction, offsetting potable water use through rainwater harvesting and/or recharging groundwater can increase water supply reliability, reduce the need to expand or upgrade existing water infrastructure, and/or avoid the development of more expensive water supply alternatives. The monetary value of these benefits can be quantified based on the direct market price of water, the avoided cost of alternative water supplies, and/or through studies that estimate household willingness-to-pay (WTP) to avoid water shortages. The most appropriate valuation method depends on the level of water scarcity in the region, local water and infrastructure costs, and other factors.

The U.S. EPA report described above (Tetra Tech 2016) provides monetized estimates for the groundwater recharge benefits associated with small retention practices at projected new development and redevelopment sites in states that do not currently require retention. For this analysis, the authors used water supply price data to approximate the marginal value of groundwater recharge. Specifically, a single price per acre-foot of groundwater recharge was estimated for each state based on the price for raw, high quality water as represented by 1) western water rights transactions (for select western states); 2) retail utility water rates; and/or 3) wholesale bulk water purchases.[12] The authors note that permanent water rights transfers provide the most representative estimate for the marginal value of groundwater because they generally reflect the price users are willing to pay for an additional unit of water beyond their current supply. However, water rights transfer data was only available/applicable for

[12] Values for retail utility water rates and wholesale purchases were adjusted to reflect raw water prices. Analysis assumes that infrastructure to extract groundwater is in place because the geographic area of focus was selected, in part, based on counties that have used groundwater as a significant water source in the past.

8 of the 44 states included in the analysis. The value per acre-foot ranged from $23 per AF in Idaho to $738 per AF in Colorado, with an average value of $136 per AF across states (2019 USD).

Tetra Tech (2016) recognizes that the analysis provides very conservative estimates of the true value of groundwater, particularly in areas experiencing water scarcity. This is because it does not account for the avoided costs associated with more expensive, alternative water supplies that groundwater recharge helps to offset. In addition, values based on wholesale or retail water rates do not always reflect the true cost (or value) of water and are more reflective of the average, rather than marginal, price. In areas with plentiful water supplies (e.g., many of the eastern and midwestern portions of the country), particularly those that already rely on groundwater, these values may be more appropriate.

Communities in which water supplies are considered scarce, or are projected to be scarce in the future, are expected to have a higher value for groundwater. To estimate this value, common methods include the use of avoided costs and stated preference studies.

The “avoided cost” method places a value on the groundwater or potable water supply offsets equal to that of the infrastructure cost, or other cost, that would alternatively be incurred to provide a similar quantity and quality of water. Tetra Tech (2016) provides an example of the avoided costs associated with groundwater recharge in Tampa Bay, FL, where diminishing groundwater supplies led Tampa Bay Water to rely more on surface water and ultimately, desalination to meet peak demands in dry periods. The costs of supplying groundwater, surface water, and desalinated water are $358, $593, and $1,059 per acre-foot (2019 USD), respectively, providing perspective on the value of an adequate local groundwater supply (Tetra Tech 2016, based on personal communication with Tampa Bay Water representative).

The avoided cost approach is often used to value local water supplies in Southern California, where the cost of imported water ranged from $695 to $1,015 per acre foot in 2018 for untreated and treated wholesale water from the Metropolitan Water District, respectively. As reported by the Pacific Institute (Cooley and Phurisamban 2016), the cost of stormwater capture in California compares favorably to other potential sources of water supply including non-potable reuse, indirect potable reuse, seawater desalination, and brackish water desalination (in some cases). Based in part on the Pacific Institute report, as well as other sources, the Public Policy Institute of California compared the costs of alternative water supply sources in California (Figure C-1); this helps to understand the potential avoided water supply costs associated with groundwater recharge. However, these costs are highly variable, and in many cases the “cost of traditional supplies water rights, new transmission, reservoirs – are on the rise. In many cases, the most economical siting options have already been utilized” (Bluefield Research 2017).

The avoided cost approach likely underestimates the full value of having a more reliable water supply. For this reason, several studies have employed stated preference techniques to better estimate household willingness-to-pay (WTP) to avoid risk of water shortages across multiple locations and scenarios (e.g., CUWA 1994, Carson and Mitchell 1987, Howe and Smith 1994). In a national level study for the Water Reuse Research Foundation, Raucher et al. (2011) surveyed more than 2,000 households in 5 U.S. cities (including Austin, Long Beach, San Francisco, Orlando, and one anonymous city) to understand how much households would be willing to pay to avoid water supply shortages. Specifically, the authors used a stated choice experiment to elicit household WTP to avoid Level 1 and Level 2 drought restrictions for outdoor water use. Results of the analysis indicated that most customers are not willing to pay to avoid relatively minor water use restrictions (Level 1); however, household WTP to avoid one year of Level 2 restrictions ranged from $20.20 per household per year in Orlando to $37.16

per household per year in San Francisco. The authors provided guidance on how to interpret the results of the analysis to estimate a value to households per AF of water (see Figure C-2).

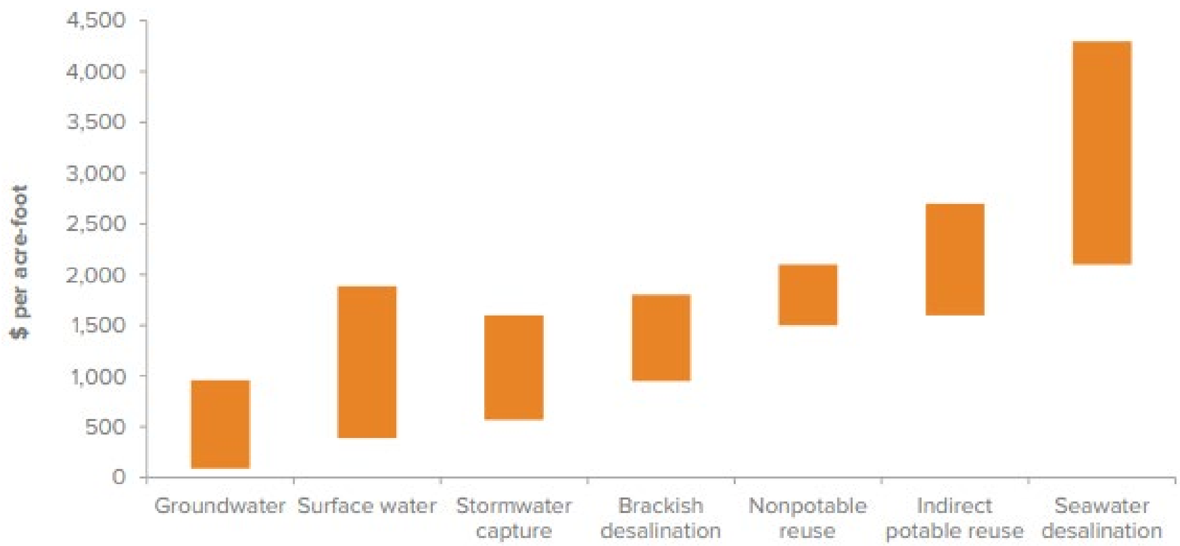

Figure C-1. Cost of Alternative Water Supplies in California ($/AF 2015 USD).
Source: McCann et al. 2018; figure reprinted with permission from PPIC.

Figure C-2. Translating WTP to Avoid Water Use Restrictions to $/AF Values.
Source: Adapted from Raucher et al. 2011.

1) In Orlando, mean WTP to avoid one year of Stage 2 drought restrictions is $20.20 per household.
2) The amount of additional water use reduction required from Stage 1 to Stage 2 restrictions is approximately 15%.
3) Average household water use for homes with a yard is 325 gallons per day, or 36% of an AF per year.
4) A 15% reduction under Stage 2 restrictions thus amounts to 5.4% of an acre-foot of water use foregone per household (15% x 36% of an AF).
5) Household WTP of $20.20 per year for 20 years has a present value of $250, when discounted at 6%.
6) This $250 represents household WTP to avoid losing use of 0.054 acre-feet in one future year.
7) Therefore, the implied value to the household for that water use is $4,630 per acre-foot (= $250/0.054 AF).

In addition to direct (consumptive) use of infiltrated stormwater (i.e., pumping and extraction of recharged groundwater for treatment and use), GSI practices that recharge aquifers can increase base flows in connected rivers and streams (i.e., in conjunctive use systems). This can provide benefits for electric power, fisheries, recreation, stream-dependent ecosystems, and can ultimately augment surface water supplies for downstream users. Autocase, a proprietary tool that allows users to estimate the benefits of GSI at the site level, values groundwater recharge based on this premise – that reusing stormwater increases the amount of water available in local streams. Autocase posits that the marginal value of increased streamflow is equal to the sum of the marginal value of all the possible instream and offstream uses of that streamflow on its journey to its end point (Impact Infrastructure 2017). Autocase monetizes this value based on marginal values published by Brown (2004) for different water use categories associated with increased streamflow in different water resource regions.[13] Brown's estimates, shown in Table C-8, are based on economic valuation studies and water market transactions for hydropower and instream and offstream uses.

Table C-8. Marginal Value of Instream Flow by Water Resource Region.
($ per AF per Year, 2019 USD)

Region	Offstream[a]	Hydro-electric	Instream[b]	Total
New England	0.86	2.40	6.96	10.23
Mid-Atlantic	4.29	1.43	6.82	12.55
South-Atlantic-Gulf	2.60	2.17	6.99	11.76
Great Lakes	8.75	7.70	6.78	23.24
Ohio	4.41	0.99	6.89	12.28
Tennessee	4.42	9.76	7.17	21.35
Upper Mississippi	5.67	1.00	6.92	13.59
Lower Mississippi	0.56	0.49	6.60	7.64
Souris-Red-Rainy	0.40	0.36	8.96	9.73
Missouri	29.17	5.96	23.37	58.51
Arkansas-White-Red	5.67	2.85	10.70	19.22
Texas-Gulf	18.41	0.75	10.41	29.57
Rio Grande	22.99	1.97	39.27	64.23
Upper Colorado	18.51	24.72	36.58	79.81
Lower Colorado	35.52	22.50	59.01	117.02
Great Basin	50.14	1.82	22.96	74.92
Pacific Northwest	2.02	13.12	12.98	28.11
California	15.22	14.79	32.06	62.06

a. offstream uses include municipal, agriculture, and industrial water use
b. instream uses include recreation, ecosystem functions, and waste dilution

Source: Brown 2004.

C.3 Tool Methodology for Quantifying and Monetizing Water Supply Benefits

The GSI TBL Benefit Cost Framework and Tool relies on methods and data presented in the literature review above, as well as inputs and calculations from the CLASIC tool This section describes how the Tool quantifies and monetizes the water supply benefits associated with rainwater harvesting and groundwater recharge through stormwater infiltration.

C.3.1 Rainwater Harvesting

The CLASIC tool includes three sizes of rainwater harvesting systems: 110 gallons (equivalent to two 55-gallon rain barrels), 1,000 gallons, and 10,000 gallons (the larger sizes we classify as cisterns). CLASIC uses U.S. EPA's SWMM to determine the volume of stormwater captured through these systems based on relevant local conditions. Users of CLASIC will be able to input the volume and associated number of rainwater harvesting systems, by size, into the Tool. Non-CLASIC users can select the use of rain barrels and/or cisterns as part of the GSI scenario they develop. To estimate the annual volume of stormwater captured and the associated water supply benefit associated with these practices, the Tool applies several assumptions and calculations, as detailed below. Users can also enter this information into the

[13] There are 18 water resource regions (WRR) in the contiguous 48 states. A WRR is a major watershed, such as the Missouri River basin, or large area of contiguous coastal watersheds, such as the California region (U.S. Water Resources Council, 1978, as cited by Brown 2004).

Tool manually.

C.3.1.1 Rain Barrels
The Tool assumes that rain barrels are used for residential purposes only and that two 55-gallon rain barrels are used per household (a total of 110-gallon storage capacity). This is consistent with the smallest unit for rainwater harvesting used in the CLASIC tool.

To estimate water supply benefits of rain barrels, the Tool applies findings from Litofsky and Jennings (2014, as shown in Table C-5) for the user's city or nearest/most similar reference city. As described above, this study estimates the percentage of irrigation demand met annually with a 62-gallon rain barrel from a 500 sq. ft. of roof area (one downspout) in 70 U.S. cities. While not directly reported in the study, the primary author provided the project team with additional results on the total volume of irrigation demand met by rain barrels in each of the 70 cities. We then scaled these results to estimate the total irrigation demand (gallons) met by two 55-gallon rain barrels, each servicing 500 square feet of roof area. This reflects the total volume of captured stormwater that could be used for irrigation, thereby resulting in a potable water supply offset.

Note that residential rain barrels will likely not be able to capture the design storm used as an input to develop the user's GI scenario. The Tool determines the number of rain barrels in a user's GSI scenario based on the total (annual) stormwater volume that is allocated to this practice for management divided by the annual total capture that rain barrels can provide (based on findings from Litofsky and Jennings).

C.3.1.2 Cisterns
The CLASIC tool includes two sizes of larger rainwater harvesting systems (i.e., cisterns): 1,000 gallons and 10,000 gallons. For users that are coming to the Tool without CLASIC inputs, we assume the following:

- The cisterns can handle the design storm input by the user as part of the GSI scenario for the equivalent amount of roof area. For example, to handle a 1" storm, a 1,000-gallon cistern could manage runoff from an approximately 1,600 square feet of roof.
- The amount of stormwater managed is based on the total precipitation that falls during the growing season (based on results for the 70 U.S. cities included in Litofsky and Jennings, 2014). We assume that cisterns do not operate in winter months with freezing conditions.
- Per CNT and American Rivers (2010), we apply an efficiency factor of 85% (meaning 15% of the captured water is not available for use) to account for water loss due to evaporation, inefficient gutter systems, and other factors.

To determine water supply benefits associated with cisterns, we assume that the stormwater captured is used for both outdoor irrigation and toilet flushing and that the total volume captured is used to meet household water demands for these purposes (minus the 15%/85% efficiency factor). Although this assumption may overestimate the total volume of captured stormwater that is used for water supply, we believe it serves as a reasonable approximation, particularly since the use of water for toilet flushing serves as a consistent source of demand.

C.3.2 Groundwater Recharge
Without extensive modeling, it is necessary to approximate the amount of groundwater that could be recharged through specific GSI practices. As a starting point, the Tool pulls the volume of stormwater managed by relevant GSI practices, as determined through the user's GSI scenario. GWI practices that allow for groundwater recharge include: bioretention and raingardens, street trees, wetlands, and permeable pavement.

Next, the Tool applies efficiency factors taken from NRDC (2014). As described above, in its 2014 evaluation of potential stormwater capture benefits in California, NRDC applied efficiency/adjustment factors to estimate groundwater recharge volumes from stormwater infiltration. Specifically, the authors assumed that in areas where conditions are considered favorable for infiltration (i.e., NRCS Hydrologic Soil group A or B), between 75% and 90% of the runoff could be infiltrated into the ground, with the remaining portion lost to evaporation or transpiration. Where soil conditions require a longer drawdown time for the water to infiltrate (e.g., NRCS group C soils), the authors assumed that 65% to 80% of the runoff could be infiltrated into the ground. The tool applies 77.5% adjustment factor (as an approximate average); however, the user can change this input within the 65% to 90% range.

As stated earlier, the applicability of this benefit depends on the extent to which the recharge area is hydrologically connected to aquifers used for water supply or that might be used for water supply in the future. Absent specific location data for GSI practices, this cannot be estimated in a national level tool and requires input from the user. As such, the user will need to input the percentage of their study area where this applies. As a starting point, users may want to reference the maps provided in Tetra Tech (2016) to determine whether their county falls within a groundwater use area.

C.3.3 Monetary Value of Water Supply Benefits

The benefits associated with potable water offsets through rainwater harvesting are valued separately from the potential water supply benefits of groundwater recharge. For potable water supply offsets, the Tool applies retail water rates, by state, as a baseline value. These estimates are taken from Tetra Tech (2016), which estimates average retail water rates by state based on published rates available on municipal and water supply company websites. While these estimates represent the direct market price of water, it is important to note that retail water rates do not always reflect the marginal price of water and are often more reflective of the average price. These estimates serve as a conservative value for potable water supply offsets.

To estimate the monetary value of groundwater recharge, the Tool incorporates annual average values for groundwater per AF, by state, also estimated in Tetra Tech (2016). As described earlier, these values also serve as lower bound estimates and are most appropriate for use in areas that are not experiencing water scarcity.

For both potable water offsets and groundwater recharge, the Tool provides guidance to users on how to determine that avoided costs of alternative water supplies and allows users to input these costs into the Tool. As a starting point, the Tool provides values from McCann et al. (2018). However, these costs are specific to California and are intended to provide a starting point for site-specific costs.

The Tool does not incorporate values associated with groundwater recharge and related increases in stream flow. This is because instream flow values are captured to some extent through the water quality model included in the Tool. The user can incorporate the percentage of stormwater volume that they expect to result in offstream uses into the groundwater recharge estimation.

C.4 References

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APPENDIX D

Air Quality and Associated Health Benefits

D.1 Introduction

Conventional air pollution is a persistent problem for most cities in the United States. Even after decades of concerted federal and state efforts to improve air quality, much of the U.S. population live in areas that exceed National Ambient Air Quality Standards (NAAQS). Trees and other vegetation associated with green stormwater infrastructure (GSI) can improve air quality in several ways, including:

- Reducing emissions (e.g., CO_2, SO_2, NO_x) associated with electricity generation by reducing energy use for heating and cooling, stormwater collection and treatment, and/or potable water supply treatment and distribution.
- Absorbing gaseous pollutants [e.g., ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), SO_2] through leaf surfaces
- Intercepting particulate matter (PM; e.g., dust, ash, dirt, pollen, smoke)

The public health and environmental impacts of specific air pollutants are well-documented (e.g., U.S. EPA 2018a). For example, NO_2 and SO_2 are both linked to respiratory illness, and NO_x and sulfur oxides (SO_x) contribute to an array of adverse respiratory and cardiovascular effects. Ground-level O_3 and PM are linked to premature deaths, chronic bronchitis, asthma, respiratory infections, and other illnesses. O_3 can also damage crops and increase the vulnerability of some tree species to various diseases, while PM can reduce visibility in urban areas (Clements et al. 2016; Massetti et al. 2017; U.S. EPA 2002).

The U.S. EPA and others have developed several tools and methods for estimating air quality improvements and linking these improvements to public health outcomes. These data and studies allow us to translate GSI inputs into total air pollutant reductions and to value these reductions based on established estimates of willingness-to-pay (WTP) to avoid specific health outcomes and/or avoided healthcare costs.

The following sections provide an overview of the air quality and related public health benefits associated with GSI and describes how these benefits are quantified and monetized in the GSI Cost Benefit Framework and Tool (Tool).

D.2 Findings from the Literature

This section provides an overview of findings from the literature related to air quality benefits associated with GSI, including energy-related emissions reductions, pollutant uptake and removal by trees and other vegetation, and the monetary value of related public health improvements.

D.2.1 Energy-Related Emissions Reduction

For air quality improvements resulting from reductions in electricity use, we are primarily concerned with emissions of SO_2, NO_x, and $PM_{2.5}$. Power plants directly emit other pollutants, [14] including greenhouse gases (GHGs). GHG emissions are addressed in Appendix L (Carbon Reduction) and are

[14] Electric utilities emit modest quantities of CO, VOC, and NH3. However, the contribution of electric utilities to total emissions of these pollutants is lower than 1% of the total (Massetti et al., 2017). Most VOCs are oxidized to form CO2; however, a portion of VOC emissions contribute to ambient PM2.5 levels as organic carbon aerosols. The understanding of how carbon aerosols contribute to human health effects is limited (EPA 2018b). Thus, VOCs are not included in this analysis.

therefore not described here.

$PM_{2.5}$ (which consists of particles 2.5 micrometers or smaller in diameter) [15] is known to be the leading cause of increased risk of morbidity and mortality from air pollution. Direct emissions of $PM_{2.5}$ from power plants can be relatively modest compared to SO_2 and NO_x (on a per ton basis, U.S. EPA 2018b). However, once they are emitted into the atmosphere, SO_2 and NO_x undergo chemical reactions to form $PM_{2.5}$. In addition, NO_x contributes to the formation of ground-level O_3 (the main component of smog), which can also be very damaging to human health.

Emission rates associated with electric power generation depend on several factors, including fuel resource mix (i.e., percentage of energy generated from coal, natural gas, wind energy, etc.), quality of the fuel, combustion technology, the efficiency of the electric generating unit, and the availability of pollution controls (Massetti et al. 2017). Most energy-related emissions come from the combustion of fossil fuels, including coal, natural gas, and petroleum products, although small amounts are also emitted from biomass and other energy sources (Massetti et al. 2017).

The U.S. EPA tracks emission rates for different pollutants (i.e., lbs of pollutant emitted per MWh) for almost all electric power generation in the United States (i.e., by plant/power company), across various grid regions and at other geographic scales. As described below, we apply this data to estimate total emission reductions associated with GSI-related energy savings in the Tool.

D.2.2 Pollutant Uptake and Removal from Added Vegetation

Trees and other vegetation improve air quality by absorbing gaseous pollutants and intercepting particulate matter. Ozone and other gaseous pollutants are absorbed into the leaves of trees and plants primarily through stomata respiration. Once inside the leaf, absorbed gases diffuse into intercellular spaces and react with inner-leaf surfaces (Nowak et al., 2006, 2014). This process effectively removes the gaseous pollutants from the atmosphere.

Additional ozone and particulate matter are removed from the air through direct interaction with the leaf surface (Stratus Consulting 2009). Some intercepted particles can be absorbed into the tree or plant, though most remain on the plant surface. Trees and plants retain only a portion of the atmospheric particles they intercept, as many particles are re-suspended into the atmosphere, washed off by rain, or dropped to the ground with autumn leaf fall (Nowak et al., 2014).

The U.S. Forest Service (USFS) and others have conducted various studies to estimate the pollution removal benefits provided by trees (e.g., Nowak et al., 2006, 2013, 2014). These studies attempt to capture the amount of pollutants, both gaseous and particulate, that accumulate on or within trees (known as dry deposition), accounting for re-suspension and subtracting out particles that return to the atmosphere through rainfall (known as wet deposition). Until relatively recently, most studies have assumed a re-suspension rate of 50%. However, this assumption is based on one study that was conducted in 1967. More recent studies indicate that re-suspension rates can vary considerably (and can be much lower than 50%) depending on wind speed, tree species and structure, and the size of the

[15] PM is the general term used to describe solid particles and liquid droplets found in the air. Some particles are large enough to be seen as dust or dirt, while others are so small they can only be seen using a powerful microscope. Two size ranges, PM10 and PM2.5, are widely monitored. PM10 includes particles that have aerodynamic diameters less than or equal to 10 microns (µm). PM2.5 is the subset of PM10 particles that have aerodynamic diameters less than or equal to 2.5 µm. PM can be emitted directly or formed in the atmosphere. “Primary” particles are those released directly to the atmosphere. These include dust from roads and black and/or elemental carbon from combustion sources. In general, PM10 is composed of primary particles. “Secondary” particles are formed in the atmosphere from chemical reactions involving primary gaseous emissions (e.g., SO2 and NOx). Unlike coarse PM, a much greater portion of fine PM (PM 2.5) contains secondary particles.

intercepted PM (NYC DEP, n.d.) For example, Nowak et al. (2013) found that re-suspension of $PM_{2.5}$ from trees ranged from 26% to 42%. Pullman (2009) reports re-suspension rates for $PM_{2.5}$ from conifers to be much lower, ranging from 6% to 23% depending on wind speed. Others have found that larger particles will re-suspend much more readily because of wind and mechanical jarring (Witherspoon and Taylor 1969, Gillette et al. 2004 as cited in NYC DEP, n.d.).

Much of the research on tree pollutant removal has been conducted by the USFS in support of the i-Tree model (formerly the Urban Forest Effects Model or UFORE), which allows users to quantify and monetize the ecosystem services associated with trees in various settings.[16] Hirabayashi (2014) describes how recent USFS research[17] has been applied (and integrated into i-Tree) to develop pollutant removal estimates based on tree canopy for rural and urban areas, and for each county, in the co-terminus United States. This research used computer simulations and local environmental data to estimate air pollutant removal and concentration change due to dry deposition from trees on an hourly basis. Table D-1 shows the resulting national average pollutant removal estimates, in grams per meter of canopy per year, for rural and urban areas, as well as by county.

Table D-1. i-Tree Average Annual Tree Pollutant Removal per Square Meter of Canopy Area, Rural and Urban Areas and by County in Co-terminus U.S.

Pollutant	Removal rate (g/m2/yr)		
	Rural	Urban	County
CO	0.100	0.127	0.101
NO2	0.545	0.700	0.551
O3	5.493	5.404	5.490
PM10	1.851	1.534	1.839
PM2.5	0.266	0.276	0.267
SO2	0.347	0.344	0.347

Source: Hirabayashi 2014, based on Nowak et al. 2014.

The estimates reported in Table D-1 represent national averages; however, Nowak et al. (2014) reports that removal rates by trees vary locally based on several factors, including:

- Amount of tree cover (increased cover increases removal)
- Ambient pollution concentration (increased concentration generally increases removal)
- Length of the growing season (longer growing seasons increase removal)
- Percent evergreen leaf area (increased evergreen leaf area increases pollution removal during leaf-off seasons)
- Meteorological conditions (e.g., humidity, wind speed can affect dry deposition pollution removal rates).

In addition, while most studies have found that trees generally improve air quality; trees can result in localized increases in pollutant concentrations under certain conditions (Nowak et al. 2014, Abhijith et al. 2017). For example, in street canyons (i.e., streets with tall buildings on either side of the road), trees can have a negative impact on air quality depending on aspect ratio (width of street relative to height of buildings), wind speed and direction, and vegetation density (Abhijith et al. 2017). Some studies have observed that air pollutants that would otherwise be aerodynamically ventilated from the road area can get trapped by the tree canopy, increasing pollutant concentration at the street level (NYC DEP, n.d.). Others report that trees can limit dispersion by reducing wind speeds (Nowak et al. 2006). These studies

[16] In addition, many of the studies that report pollutant removal from trees are based on the UFORE/i-Tree models and therefore employ the same assumptions.
[17] Studies include Nowak et al. 2006, 2013, 2014; Hirabayashi et al. 2011, 2012.

therefore do not recommend planting dense tree canopy in street canyons where emissions are actively produced (NYC DEP, n.d.). Alternatively, Abhijith et al. (2017) report that in open road conditions, dense and tall vegetation can considerably reduce air pollutant concentrations.

Compared to pollutant removal by trees, air quality removal data for shrubs and grasses and other types of GSI vegetation is relatively limited. In a 2002 study, Nowak et al. adapted the UFORE model to estimate removal rates for shrubs and herbaceous cover in Brooklyn. Results of this study indicate a removal efficiency of 80% compared to tree pollutant removal, depending on the pollutant (Table D-2).

Table D-2. Pollutant Removal Rates for Trees and Shrubs in Brooklyn.

Pollutant	Pollutant removal rate (g/m2/year)		Removal Rate of Shrubs and Herbaceous Cover Relative to Trees
	Trees	Shrubs	
CO	0.58	0.58	100%
NO2	2.54	1.92	75.6%
O3	3.06	2.42	79.1%
PM10	2.73	2.12	77.7%
SO2	1.32	1.13	85.6%
Total	10.23	8.17	79.9%

Source: Nowak et al. 2002.

Some studies have assessed the pollutant removal performance of green roofs (e.g., Currie and Bass, 2008; Yang et. al., 2008; Speak et al. 2012; Jayasooriya et al. 2017). Based on a review of these studies, Francis and Jensen (2017) and Abhijith et al. (2017) report that pollutant removal rates vary considerably based on wind conditions, seasonal variations, plant characteristics and species, and green roof location. Table D-3 summarizes pollutant removal rates and findings from individual green roof studies. Most of these studies are based on model simulations (as opposed to real-world data); some rely on the UFORE/i-tree model to estimate pollutant removal rates (e.g., Currie and Bass 2008, Jayasooriya et al. 2017).

D.2.3 Economic Valuation of Avoided Health Effects

Reductions in ozone, $PM_{2.5}$, and other pollutants can directly reduce the risk of adverse human health effects, including premature mortality and a broad array of respiratory and cardiovascular illnesses (U.S. EPA 2018a). The benefit of reducing these pollutants can therefore be valued based on associated reductions in health-related costs and/or willingness-to-pay (WTP) to avoid specific health outcomes.

The U.S. EPA's Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) currently serves as the most comprehensive source of information on air quality changes and related public health improvements. BenMAP-CE is a software package and database that allows users to estimate the health-related benefits of air quality improvements based on established health impact function (HIFs). The HIFs are derived from epidemiology studies that relate pollutant concentrations to specific health endpoints (e.g., premature mortality, chronic bronchitis, heart attacks, and other illnesses). BenMAP-CE applies that relationship to the population experiencing the change in pollution exposure to calculate health impacts. Using values from the literature, BenMAP-CE also applies WTP and avoided cost estimates to calculate benefits in monetary terms. The values used in BenMAP-CE are periodically updated by U.S. EPA based on reviews of economic studies.

Table D-3. Summary of Studies on Pollutant Removal Benefits of Green Roofs.

Study	Pollutant removal rate (g/m2/year)				Summary/Key Findings
	PM_{10}	NO_2	SO_2	O_3	
Deutsch et al., 2005	1.00	0.38	2.62	2.69	Conducted simulation of different planting scenarios of green roofs in Washington, DC, using the UFORE model. Estimated that 58 metric tons of air pollutants could be removed if all the roofs in the city were converted to green roofs. Analysis assumed 80% extensive green roofs and 20% intensive.
Currie and Bass (2008)	0.89 – 9.21	0.65 – 2.55	0.2 – 0.84	1.2 – 3.58	Evaluated air pollutant removal rates (dry deposition) for green roofs on two-story buildings in Toronto using UFORE model. Included various scenarios with different levels of vegetation and GSI, including trees, shrubs, and grass, assuming pollutant removal rates based on leaf surface area. Intensive roofs outperformed extensive green roofs; performance of intensive green roofs was greatest for PM_{10}. Benefits of extensive green roofs did not increase linearly for 20% and 100% building coverage scenarios. Overall, study demonstrated green roofs can supplement existing vegetation and improve air quality when installed in sufficient quantities.
Speak et al. (2012)	0.42 - 3.21				Conducted controlled field studies to evaluate PM10 reduction for four species of green roof vegetation in Manchester, UK (city center). Found that location of roof and species affected removal rates. Site directly downwind from larger PM_{10} concentrations had higher removal rates. Species with grooved leaf surfaces retained more PM10 than those with smooth surfaces; dense arrangements of blade like leaves also had higher removal rates compared to low-lying mats and species with radial arrangements.
Yang et al (2008)	1.12 - 2.16	2.33- 3.57	0.65 - 1.01	4.49 - 7.17	Evaluated pollutant removal for extensive, intensive, and semi-intensive green roofs in Chicago. Developed dry deposition model to evaluate pollution removal rates for short grass, herbaceous plants, and deciduous trees. Results showed removal was affected by air pollutant concentrations, weather conditions, and the growth of plants. The highest air pollutant removal occurred in May when leaves of plants were fully expanded and the concentration of pollutants was high. The lowest removal was in February when the vegetation was covered in snow.
Jayasooriya et al. (2017)	1.53	0.37	0.1	1.24	Estimated air quality improvements of GSI scenarios consisting of trees, green roofs, and green walls, in Melbourne, Australia using the i-Tree Eco software.

Source: Data from Currie and Bass 2008, Speak et al. 2012, Yang et al. 2008, Jayasooriya et al. 2017, and Francis and Jensen 2017.

According to economic theory, the best measure of the value of reducing the risk of an adverse health effect is the average that individuals are willing-to-pay to reduce the risk by a small amount. However, for certain endpoints, reliable WTP studies are not available. Alternative methods for valuing health outcomes include avoided medical costs and/or estimates of lost productivity; however, these methods result in lower-bound estimates of value because they only consider a portion of the total demand (i.e., WTP) for avoiding a health risk. For example, BenMAP-CE values hospital admissions based on the medical costs incurred during the stay in the hospital; this ignores the pain and suffering components of value that would be included in WTP. Heart attacks are valued using a combination of medical cost information plus the lost stream of income from people not able to re-enter the workforce (or who must work at a reduced level of income) after a heart attack. This ignores the pain and suffering components of WTP and does not include lost income for people assumed to be out of the workforce (e.g., retirees and unemployed adults).

Detailed information and sources of all values used in BenMAP-CE are available in the BenMAP documentation and technical appendices (U.S. EPA, 2018a). Table D-4 presents monetary values (per incident) for some of the health effects included in BenMAP-CE.

Table D-4. BenMAP-CE Values for One Case of Each Health Effect.

Health Effect	Value per Case (2018 USD)[a]
Premature mortality[b]	$9,222,609
Chronic bronchitis	$496,500 (WTP estimate) $16,388 - $245,736 (cost of illness and wage loss, varies by age)
Heart attack	$38,317 to $318,730 (varies by age)
Hospital admission	$18,195 to $49,128 (varies by cause of hospitalization and age)
Asthma-related emergency room visit	$474 - $566
Asthma attack	$63
Illness day	$22 to $87 (varies by illness)
Work loss days	$183
School absence	$112

Source: U.S. EPA 2018a.

a. Updated from 2015 prices/2015 income using Consumer price index, does not account for difference in changes in income v. CPI

b. Risk of premature mortality is valued based on U.S. EPA's methodology for estimating value of statistical life (VSL)

In 2018, U.S. EPA used BenMAP-CE to calculate the benefit-per-ton of reducing $PM_{2.5}$ and $PM_{2.5}$ precursor emissions in 17 industry sectors. Table D-5 shows the resulting benefit-per-ton values for the electricity generating sector (in terms of the monetary value of avoided mortality and morbidity risk) based on mortality risk reduction estimates from Krewski et al. (2009) and Lepeule et al. (2012). Table D-5 also shows the health outcomes (mortality and morbidity) associated with each ton of pollution. For example, results show that reducing one ton of $PM_{2.5}$ emissions from electricity generating units would result in a subsequent reduction of 0.0088 respiratory-related emergency room visits and 0.021 cases of acute bronchitis, per year, on average.

U.S. EPA (2018b) notes that care should be taken in applying the national average estimates reported in Table D-5 to emission reductions occurring in any specific location. Health outcomes and associated monetary values can range significantly based on the local population, geography, and power generation mix, among other factors (Massetti et al. 2017). For example, the marginal cost of emitting one unit of SO_2 in a remote area may be lower than the marginal cost of the same unit of pollution emitted in a densely populated area, because emissions in populated areas generate greater health damages. The health impact attributable to a ton of SO_2 will also depend in part on the propensity of SO_2 to form $PM_{2.5}$ and the baseline health status of the population living downwind, among other factors (Massetti et al. 2017). In addition, the national estimates do not capture important differences in marginal benefit per ton that may exist due to different combinations of reductions (i.e., all other sectors are held constant) or nonlinearities within a particular pollutant (U.S. EPA 2018b).

Results from U.S. EPA's Regulatory Impact Analysis (RIA) for the Clean Power Plan Final Rule demonstrate the geographic variability in benefit-per-ton estimates for the electricity generating sector. For the RIA, U.S. EPA assessed the health benefits in 2020 associated with reducing SO_2, directly emitted $PM_{2.5}$, NO_X as a precursor of $PM_{2.5}$, and NO_x as a precursor of ground-level ozone. Table D-6 shows the results of this analysis at national level and for three large representative regions, showing significant variation both by pollutant and by region.

Table D-5: Dollar Value (Mortality and Morbidity) per Ton of Directly Emitted $PM_{2.5}$ and $PM_{2.5}$ Precursors Reduced in 2016 From the Electricity Generating Sector.

(2018 USD, 3% discount rate[a,b])

Mortality risk estimate (source)	Benefit per ton[c]		
	NO_x	SO_2	Directly emitted $PM_{2.5}$
Krewski et al. (2009)	$6,400	$42,400	$148,300
Lepeule et al. (2012)	$14,800	$97,500	$349,600
Average	**$10,600**	**$69,900**	**$249,000**
Health endpoint			
Premature mortality			
Krewski et al. (2009)	0.000650[a]	0.004400	0.016000
Lepeule et al. (2012)	0.001500	0.010000	0.036000
Morbidity			
Respiratory emergency room visits	0.000320	0.002200	0.008800
Acute bronchitis	0.000850	0.005400	0.021000
Lower respiratory symptoms	0.011000	0.070000	0.270000
Upper respiratory symptoms	0.016000	0.100000	0.390000
Minor Restricted Activity Days	0.450000	3.000000	12.00000
Work loss days	0.076000	0.500000	1.900000
Asthma exacerbation	0.018000	0.120000	0.450000
Cardiovascular hospital admissions	0.000150	0.001000	0.003700
Respiratory hospital admissions	0.000140	0.001000	0.003500
Non-fatal heart attacks (Peters)	0.000600	0.004200	0.015000
Non-fatal heart attacks (All others)	0.000064	0.000460	0.001600

Source: U.S. EPA 2018b.

a. Values updated to 2018 from 2015 USD, using CPI
b. Discount rate is applied because health effects associated with one-ton reduction in emissions do not occur all within the same year. This study assumes is a "cessation" lag between changes in PM exposures and the total realization of changes in health effects as follows: 30% of mortality reductions in the first year, 50% over years 2 to 5, and 20% over the years 6 to 20 after the reduction in PM2.5.
c. Estimates for NOx and SO2 include a reduction in premature mortality. While these emissions are not directly linked to mortality risk, these estimates reflect the contribution of these gases to PM2.5 and ozone formation, and associated mortality risk.

Nowak et al. (2014) also used BENMAP to estimate the benefit per ton of pollutant removal from trees in urban and rural areas, and for each county in the U.S. (pollutant removal rates from this study were reported in previous section). Table D-7 presents the results of this analysis, including the monetary value per ton of emission, as well as the health effects reflected in that value. As shown, estimate for NO_2 and SO_2 do not include reductions in mortality risk. Therefore, the benefit per ton values for these pollutants in Table D-7 are much lower than those reported in Tables D-5 and D-6 for the electric generating sector (because the estimates for NO2 and SO2 reported in Tables D-5 and D-6 reflect the indirect contributions of these gases to premature mortalities caused by $PM_{2.5}$ and ozone).

Table D-6. The Health Impacts of Pollution from Electricity Generation Utilities in Three Regions of the United States in 2020.

(2018 USD)

Pollutant	Thousands $ per ton of emission			
	National	East	West	California
SO_2	37.2 – 84.4	7.0 – 15.8	106.9 – 236.4	180.1 – 360.2
NOx (as $PM_{2.5}$)	3.5 - 7.8	0.7 – 1.7	24.8 – 55.2	19.2 – 38.2
NOx (as O_3)	7.3 – 31.6	2.2 – 10.1	15.8 – 66.4	8.4 - 34.9
Directly emitted $PM_{2.5}$ (EC+OC)	157.6 – 360.2	30.4 – 67.6	416.6 – 934.3	315.2 – 641.7
Directly emitted $PM_{2.5}$ (crustal)	25.9 – 58.6	12.4 – 28.2	82.2 – 180.1	123.8 – 247.7

Source: Massetti et al. 2017.

Notes:

Updated from 2015 USD using CPI; values originally estimated using 3% discount rate

Includes separate benefits analysis for two categories of directly emitted particles: elemental carbon plus organic carbon (EC+OC) and crustal. Crustal emissions are composed of compounds associated with minerals and metals from the earth's surface, including carbonates, silicates, iron, phosphates, copper, and zinc.

Range of estimates reflects the range of epidemiology studies for avoided premature mortality for $PM_{2.5}$ and ozone.

Benefit per ton estimates do not include reduced health effects from direct exposure to NO2, SO2, ecosystem effects, or visibility impairment.

Monetized benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Benefit-per-ton estimates for ozone are based on ozone season NOX emissions.

Table D-7. Value of Pollutant Removal and Adverse Health Effects of Pollutants.

(2018 USD[a])

Pollutant	$ value per ton			Adverse health effect
	Co-terminus U.S	Urban areas	Rural areas	
SO_2	10	188	4	Acute respiratory symptoms, asthma exacerbating, emergency room visits, hospital admissions.
NO_2	34	553	9	Asthma exacerbation, hospital admissions, acute respiratory symptoms, emergency room visits
O_3	197	3,636	66	Mortality, acute respiratory symptoms, hospital admissions, school loss days, emergency room visits
$PM_{2.5}$	8,361	148,653	2,753	Mortality, chronic bronchitis, acute respiratory symptoms, acute myocardial infarction, asthma exacerbation, work loss days, hospital admissions (cardiovascular and respiratory), lower and upper respiratory symptoms, emergency room visits, acute bronchitis

Source: Nowak et al. 2014; data reprinted with permission.

a. Values updated from 2010 to 2018 USD using CPI; also converted from $/metric tonne to $/ton (U.S. ton)

The results of Nowak et al. (2014) again demonstrate the variability in benefits associated with emission reductions by geography, and specifically for rural vs. urban areas. Based on the results for individual counties, Nowak et al. (2014) developed regression equations to estimate benefit per ton values. These equations produce average values based on population density and do not account for specific population parameters (e.g., age class distribution). However, Nowak et al. (2014) reports that they provide rough estimates of values in areas where BenMAP cannot be applied.

D.3 Tool Methodology for Quantifying and Monetizing Air Quality and Associated Health Benefits

This section describes the methodology for quantifying and monetizing the air quality benefits associated with GSI practices including benefits from reductions in energy-related emissions, as well as benefits associated with pollutant removal through vegetation.

D.3.1 Energy-Related Emissions Reductions

The U.S. EPA maintains extensive data on electricity power generation and energy-related emissions through its Emissions & Generation Resource Integrated Database (eGRID). eGrid contains data on the environmental characteristics of almost all electric power generated in the United States, including emission rates (i.e., pounds of pollutant emitted per MWh or MMBtu generated) for three greenhouse gas gases (GHGs) - carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O); as well as for NOx and SO2. The most recent data, the thirteenth edition of eGRID (eGRID 2016), was published in March 2020. The Tool applies regional eGrid emission rates to previously calculated GSI-related energy savings (see Appendix C) to estimate the associated reduction in emissions/pollutants.

eGrid data is available at different levels of aggregation, including by state, eGRID subregion, and for the U.S. overall. To minimize issues associated with aggregation (see Rothschild and Diem, 2009), U.S. EPA recommends using emission rates by eGrid subregion, rather than state-level estimates. For electricity-generating emissions, U.S. EPA also recommends using non-baseload emission rates (rather than total output emission rates) to estimate the emission benefits of reduced energy use. The term “baseload” refers to plants that supply electricity to the grid no matter what the demand for electricity is at a given time; they generally operate except when undergoing routine or unscheduled maintenance. Non-baseload emission rates are a slice of the system total mix, with a greater weight given to plants that operate coincident with peak demand (Rothschild and Diem, 2009). Thus, they are representative of marginal reductions in energy use at times of peak demand and are generally more applicable for the current context.

In addition, the electricity-generating emission factors in eGRID represent those associated with the generation of electricity, not with the consumption of electricity. They do not account for transmission and distribution losses between the points of consumption and the points of generation. For example, because there are line losses, one kilowatt hour of electricity consumption requires a little more than one kilowatt hour of electricity generation. To account for transmission and distribution losses when applying eGRID output emission rates, U.S. EPA recommends multiplying the electricity consumption (or savings) by a transmission and distribution system loss factor (published in eGrid) and adding it to the base consumption (or savings) level.

Figure D-1 shows the 26 U.S. EPA eGrid subregions; Table D-8 shows the electricity non-baseload emissions rates (lbs/MWh) and natural gas input emissions factors (lbs/MMBtu) for each subregion, as well as the gross grid loss factors (CO_2 and GHG emissions are discussed in Appendix L).

While eGrid does not track direct $PM_{2.5}$ emissions associated with energy generation, U.S. EPA’s The AVoided Emissions and geneRation Tool (AVERT) publishes avoided (direct) $PM_{2.5}$ emissions associated with energy efficiency projects for 10 U.S. sub-regions (for electricity generation only). Based on 2017 data, U.S. EPA estimates that avoided $PM_{2.5}$ emissions associated with reductions in marginal electricity consumption range from 0.04 lb/MWh in the Rocky Mountain Region to 0.21 lbs/MWh in the Great Lakes/mid-Atlantic region, with an average emissions rate of 0.11 lbs/MWh for the U.S. overall (U.S. EPA 2018c). The Tool applies these emissions rates to the energy savings generated through implementation of GSI. To value the emissions reductions associated with energy savings, the Tool applies benefit per ton values from U.S. EPA (2018b) for the electricity generating sector.

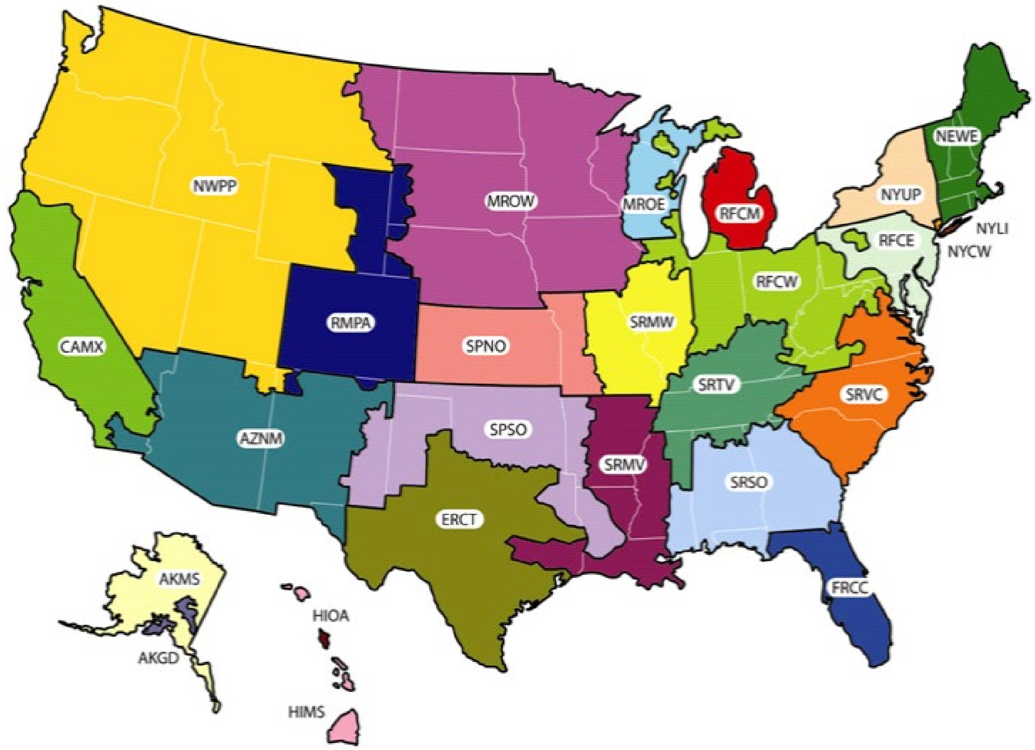

Figure D-1. U.S. EPA eGrid Subregions.

Source: U.S. EPA 2020.

Based on communications with U.S. EPA, eGrid only applies to electricity; it does not contain emissions rates for natural gas (i.e., input natural gas emissions rates published through eGrid should not be directly applied to reductions in natural gas to calculate avoided emissions, pers. comm. T. Johnson, 4/13/2020). Given the relatively low emissions rates for natural gas (cite), and the relatively low natural gas savings associated with most GSI, the Tool does not calculate air quality benefits associated with reductions in natural gas use due to building energy savings.

D.3.2 Pollutant Removal through Added Vegetation

To estimate the pollutant removal from trees associated with GSI improvements, the Tool relies on data provided by Dr. Nowak (USFS, developed for Nowak et al. 2014) on average pollutant removal rates for NO_2, O_2, $PM_{2.5}$, and SO_2 for trees in urban and rural areas, by state.

The pollutant removal rates published by Nowak et al. (2014) are based on area of tree cover (g/m2). To estimate pollutant removal from trees under the GSI scenario being analyzed, the Tool therefore needs to estimate the canopy area associated with the number and species of trees planted. To do this, we used the Urban Tree Database (McPherson et a. 2016) to identify the most common 15 to 20 street tree species in each of 16 U.S. climate zones used in i-Tree. Next, we used equations developed by McPherson et al. (2016) to estimate canopy size for individual species in each region, based on tree age. We calculated canopy size for each tree species across multiple years, allowing us to estimate per-tree pollutant removal benefits in each year of the 30-year analysis period.

Table D-8. eGrid 2018 Emission Rates and Transmission Loss Percentage, by eGrid Subregion.

eGRID subregion acronym	eGRID subregion name	Non-baseload output emission rates, electricity (lb/MWh)		Grid Gross Loss (%)
		Annual NO_x	SO_2	
AKGD	ASCC Alaska Grid	6.5	1.1	5.12%
AKMS	ASCC Miscellaneous	22.8	2.0	5.12%
AZNM	WECC Southwest	1.0	0.3	4.80%
CAMX	WECC California	0.8	0.0	4.80%
ERCT	ERCOT All	0.8	1.1	4.87%
FRCC	FRCC All	0.4	0.4	4.88%
HIMS	HICC Miscellaneous	11.8	5.0	5.14%
HIOA	HICC Oahu	4.2	8.4	5.14%
MROE	MRO East	0.9	1.0	4.88%
MROW	MRO West	1.5	1.8	4.88%
NEWE	NPCC New England	0.5	0.3	4.88%
NWPP	WECC Northwest	1.4	0.8	4.80%
NYCW	NPCC NYC/Westchester	0.5	0.1	4.88%
NYLI	NPCC Long Island	1.0	0.4	4.88%
NYUP	NPCC Upstate NY	0.5	0.5	4.88%
RFCE	RFC East	0.7	0.8	4.88%
RFCM	RFC Michigan	1.2	2.1	4.88%
RFCW	RFC West	1.4	1.4	4.88%
RMPA	WECC Rockies	0.8	0.4	4.80%
SPNO	SPP North	1.2	0.7	4.88%
SPSO	SPP South	1.3	1.9	4.88%
SRMV	SERC Mississippi Valley	0.9	1.4	4.88%
SRMW	SERC Midwest	1.1	2.7	4.88%
SRSO	SERC South	0.8	0.5	4.88%
SRTV	SERC Tennessee Valley	0.8	0.9	4.88%
SRVC	SERC Virginia/Carolina	0.9	0.5	4.88%
U.S.		**1.0**	**0.9**	**4.87%**

Source: U.S. EPA 2020.

Rather than having the user input specific tree species, we estimate pollutant removal based on the average canopy size for the most common street tree species in each region. While some tree species have much higher stormwater capture benefits than others (the primary benefit of interest for stormwater managers), site constraints can prevent planting of certain species (e.g., larger trees). Therefore, rather than focusing solely on trees that provide the greatest stormwater benefits, the average street tree better represents real world conditions. That said, we excluded some species from the estimate if they had particularly low stormwater capture benefits.

To estimate the pollutant removal rates for GSI practices that incorporate other types of vegetation (e.g., bioretention), the Tool applies the ratio of tree to shrub/herbaceous cover removal efficiencies reported in Table D-2 to the pollutant removal estimates reported by Nowak et al. (2014) for urban and rural areas, by state. For green roofs, the Tool applies the mid-point of the range of values reported in the literature to estimate pollutant removal per m^2 (as reported in Table D-3 above). These are intended to serve as order-of-magnitude estimates. Further, the studies evaluating pollutant removal from shrubs, herbaceous cover, and green roofs quantify removal of PM_{10} rather than $PM_{2.5}$.

Finally, to estimate the value per ton of pollutant removal from various practices, the Tool includes the regression equations developed by Nowak et al. (2014), where y = dollars per tonne (metric ton), and x = population density. These equations are as follows:

NO2: y = 0.7298 +0.6264x (r2 = 0.91)

O3: y = 9.4667 +3.5089x (r2 = 0.86)

PM2.5: y = 428.0011 +121.7464x (r2 = 0.83)

SO2: y = 0.1442 + 0.1493x (r2 = 0.86)

Once calculated, values are updated from 2010 USD to 2018 USD using the Consumer Price Index.

D.4 References

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APPENDIX E

Property Value Benefits

E.1 Introduction

Trees and plants improve urban aesthetics and community livability, which can result in increased sale prices and rental rates for homes and commercial space. Simply put, people are willing to pay more to live and work in places with more greenery. To measure this value, economists typically employ "hedonic pricing" methods, which use statistical analysis to estimate the effect of different factors on the price of a home or property. Hedonic models attempt to isolate the effect of a specific characteristic, such as proximity to green stormwater infrastructure (GSI), on a property's market value by controlling for all other factors. Developing hedonic models to assess property value benefits associated with GSI is outside of the scope of this project. To estimate property value benefits associated with different types and scales of GSI, the GSI TBL Benefit Cost Framework and Tool (Tool) applies findings from existing well-executed studies on this topic. This approach is known as benefits transfer.

As an important note, property value increases associated with GSI can reflect a willingness-to-pay (WTP) for a range of benefits, including many of the benefits incorporated in the Tool. In this sense, increases in property values related to GSI serve as a measure of the value of GSI rather than a stand-alone benefit. In theory, changes in property values linked to GSI can reflect associated differences in neighborhood aesthetics, air quality, water quality, energy usage, increased shade, and other benefits. A property in an area with good air quality should sell for a higher amount relative to another property in an area with low air quality, all else equal. Thus, to simply add property value benefits with the benefits from improved air quality would be double-counting (at least to some extent).

The following sections provide an overview of the property value benefits associated with GSI and describes how these benefits are quantified and monetized in the Tool.

E.2 Findings from the Literature

The effect of GSI or similar neighborhood greening on property values has been relatively well-documented for single family properties; less work has been conducted with respect to multi-family, commercial, or industrial properties. Studies show that property value benefits vary by GSI practice, with trees and green roofs garnering some of the highest increases.

E.2.1 Single-Family Residential Property Value Benefits

Some studies have found that GSI or similar landscaping improvements can increase residential property values by as much as 7% to 12% (Been and Voicu 2007; Wachter and Wong 2008, SBN 2016), depending on the type of improvement. However, most estimates seem to range from 1% to 5%. Ward et al. (2008) evaluated the effect of GSI projects on property values for adjacent properties in King County, Washington (Seattle area). The authors found that compared to similar houses in the same zip-code, houses located in the Street Edge Alterative, Broadview Green Grid, Pinehurst Green Grid, and High Point project areas sold for 3.5 – 5% more during the period after the adjacent streets were treated with GSI. While the authors did not use hedonic modeling for this study, they report that prior to the introduction of GSI, the houses affected by these projects did not command a premium over their neighbors.

An extensive study on the triple bottom line (TBL) benefits of combined sewer overflow (CSO) control alternatives in Philadelphia also explored the effect of GSI and similar landscaping improvements on residential property values (Stratus Consulting, 2009). In this study, the authors reviewed existing literature relevant to the types of improvements planned for Philadelphia, finding increases ranging from 0– 7% (Table E-1).

Table E-1. Studies Used to Estimate Property Value Benefits in Philadelphia's Study of the Benefits of GSI-Based Alternatives for CSO Control.

Study	Summary of Study	Estimate (% increase in value)
Ward et al. (2008)	Estimates effect of LID on adjacent properties relative to those farther away, in King County (Seattle), WA.	3.5–5.0%
Shultz and Schmitz (2008)	Proxies LID effects by looking at differentials for neighborhoods with clustered open spaces and greenways, etc., in Omaha, NE.	Greenways: 1.1–2.7%; clustered open space: 0.7–1.1%
Braden and Johnston (2003)	Uses meta-analysis of studies to estimate several benefit categories related to on-site stormwater retention (green approach/LID) for managing stormwater.	0–5%
Wachter and Wong (2008)	Estimates the effect of tree plantings on property values for select neighborhoods in Philadelphia.	2% (intrinsic value of trees)
McPherson et al. (2006)	References an uncited study that looks at the differentials between properties with ample trees vs. none or few trees (few details).	3–7%
Anderson and Cordell (1988)	Uses sales data from Athens-Clarke County (GA) to estimate the value of trees on residential property. Looks at differences between houses with five or more front yard trees and those that have fewer.	3.5–4.5%

Source: Stratus Consulting 2009.

Note: About half of these studies focused on property value benefits associated with trees because at the time the study was conducted, street tree projects and tree plantings constituted a significant portion of Philadelphia's planned GSI portfolio.

In 2016, the Sustainable Business Network (SBN) of Greater Philadelphia GSI Partners published a report documenting the economic impacts and benefits associated with the first five years of Philadelphia Water's Green City Clean Waters (GCCW) Program (SBN 2016). GCCW is Philadelphia's large-scale CSO control plan that focuses on GSI implementation. The study included an original hedonic analysis that estimated the effect of the City's completed GSI projects (through 2014) on nearby residential property values. These projects primarily consist of stormwater bump outs in the public right-of-way, stormwater planters, rain gardens, and stormwater tree trenches.

In developing the hedonic regression model, the authors controlled for various factors including whether the GSI project was on private or public land and whether public projects occurred at a park, school, or recreation center. Results of the analysis indicated that public projects that are not located at a park, school or recreation center increase nearby (i.e., within a quarter mile) residential property values by 12.7%, while being located near a public project that occurred at a park, school, or recreation center results in an 11.5% increase. The authors posit that the larger impact from being located near a public project that did not occur at park, school or recreation center is likely due to the fact that these projects are adding green features to a neighborhood that otherwise did not have much.

SBN (2016) also found that being located near a private GSI project increases nearby residential property values (for properties within an eighth of a mile) by 1.7%. The smaller impact of private investment is likely due to the fact that these investments occur on private property and may not be visible to nearby properties. Overall, the authors estimate that the average effect of GSI projects on residential property values is 10.3%. In other words, all else being equal, an identical house is worth 10.3% more if it is located near a GSI project, compared to not being located near a GSI project.

Some studies have found smaller increases in residential property values due to GSI improvements. For example, Mazzotta et al. (2014) conducted a meta-analysis of 35 studies to evaluate the property value benefits of practices that reduce impervious surfaces and increase vegetated areas in developments (focusing on small, dispersed open spaces). The authors applied their meta-analysis model to a hypothetical policy case for a HUC-12 watershed in Illinois, assuming future construction projects would provide increased open space relative to "conventional" development. Results show that a perceived increase in open space of 7.8% would result in a 0.9% to 1% increase for homes located within 250 meters, depending on whether the open space included recreational amenities. Homes located 250 to 500 meters would see an increase of 0.25% and 0.33% for open space with and without recreational amenities, respectively. The meta-analysis found that larger lots showed a smaller price response, as do homes with higher values and homes located in areas with less density (which included the policy case). In addition, percent increases were larger for open space in trees and riparian areas, compared to general open space.

Madison and Kovari (2013) used hedonic regression models to evaluate the effect of property value increases associated with a large-scale GSI project in a lower-income neighborhood in Milwaukee's Lincoln Creek watershed. Designed to reduce flooding, the project had multiple components, including channel and habitat restoration, naturalization, concrete removal, the addition of adjacent stormwater detention basins, and a bridge replacement. Approximately two miles of concrete were removed during the project. Results indicate that holding all other variables constant, in any given year, the assessed values of the residential properties in Lincoln Creek were 20.4% higher than they otherwise would have been without the GSI. The authors not that while this figure may seem high, the average property value of a single-family home in Lincoln Creek was only $56,900 in 1999 (in 2011 dollars); thus, any sizeable infrastructure project should have increased the value significantly.

As reported by Stratus Consulting (2009), several studies have specifically focused on the effect of trees on residential property values. For example, Donovan and Butry (2010) found that street trees increased the sale prices of houses in east Portland neighborhoods by an average of $8,870 and reduced time on the market by an average of 1.7 days (though the authors did not report increases in percentage terms, based on data reported in the study, we estimate that the $8,870 was equivalent to a 3% increase in sales price). The tree's benefits spilled over to houses within a 100-foot radius, increasing their combined value by $12,828. Wolf (2007) reports that trees have been found to increase property values by as much as 15%, while the trend across studies shows a price increase of about 7%. However, the magnitude of increase depends on the size and type of tree, as well as the overall tree canopy. Table E-2 shows Wolf's (2007) findings from a review of literature on this topic.

Table E-2. Wolf (2007) Summary of Findings of Studies Assessing the Effects of Trees on Residential Property Values.

Condition	Price increase
Mature yard trees (greater than 9-inch dbh)	2%
Trees in front yard landscaping	3 to 5%
Good tree cover in a neighborhood	6 to 9%
Mature trees in high-income neighborhoods	10 to 15%

Source: Wolf 2007.

While it is generally agreed that trees can have positive effects on property values, studies have found that the level of increase depends on the existing tree canopy. For example, in a study the value of urban trees in Minnesota, Sander et al. (2010) found that tree cover increases residential property values in areas with less than approximately 40 to 60% total tree cover. Beyond this point, increased tree cover contributes to lower price. Siriwardena et al. (2016) report a similar finding in a meta-analysis on the impact of tree canopy cover on residential properties. Specifically, the authors suggest that property-level tree cover of about 30%, and county-level tree cover of about 38%, maximize the implicit price of tree cover in property values.

Boyer and Polasky (2004) identified three studies that applied the hedonic method to estimate the value of wetlands to nearby property owners in urban areas (Lupi et al. 1991, Doss and Taff 1996, Mahan et al. 2000). All three studies find a positive impact from wetlands on property values:

- Mahan et al. (2000) analyzed data on over 14,000 home sales in the Portland, Oregon metropolitan area, along with detailed information about housing and neighborhood characteristics and GIS information on the location of wetlands, lakes, rivers, streams, and other environmental amenities. They found that closer proximity to a wetland increased property value. Decreasing the distance to the nearest wetland by 300 meters from an initial distance of 1.6 kilometers resulted in an estimated increase in property value of $752 (2019 USD).
- Lupi et al. (1991) used data from Ramsey County, Minnesota, where St. Paul is located. They estimated that an increase in wetland area within the survey section in which a home is located increased its value by $39 per hectare of increased wetlands (2019 USD). The increase in value for wetland area tended to be greater in areas where there were few nearby wetlands.
- Doss and Taff (1996) also found a positive value from nearby wetlands using data from Ramsey County, Minnesota. They found a preference for open-water wetlands and scrub-shrub wetland types over emergent-vegetation and forested wetlands.

Tapsuwan et al. (2009) applied hedonic models to value urban wetlands in Perth, Australia. The authors found that distance to the nearest wetland and the number of wetlands within 1.5 km of a property significantly influences residential sales price. For a property that is 943 m away from the nearest wetland, which is the average distance to the wetland in this study, reducing the wetland distance by 1 m will increase the property price by AU$42.40 (approximately $40 2019 USD[18]). Similarly, the existence of an additional wetland within 1.5 km of the property will increase the sales price by AU$6976 (approximately $8,313 2019 USD). For a randomly selected wetland, assuming a 20 ha isolated circular wetland surrounded by uniform density housing, the total sales premium to surrounding properties was estimated to be around AU$140 million ($130 M 2019 USD).

Across all GSI practices, Wolf (2007) reports that socioeconomic condition of a residential area makes a difference. For instance, greater increments of value are seen for tree planting and landscape improvements are often seen in lower-income neighborhoods. This study is confirmed by Wachter (2004), who used hedonic analysis to assess community revitalization potential from the construction of gardens in vacant lots and planting of street trees in a semi-blighted neighborhood in Philadelphia. The study found that planting street trees where none previously existed increased house prices by approximately 9%. Been and Voicu (2007) report that well-designed (and maintained) community gardens located in previously vacant lots in New York City increased property values for surrounding homes by over 9% in low-income neighborhoods within 5 years of opening.

E.2.2 Multi-Family and Commercial Property Value Benefits

Just as with single-family residences, the value of a commercial property in urban areas is determined by various factors, including characteristics of the land (e.g., lot size) and the structure (e.g., square footage), the closeness to natural amenities (e.g., parks, trails, waterways, open space), and other attributes (e.g., crime rate, population, location relative to business and transportation centers). Making green infrastructure improvements to commercial sites can make them more appealing to potential

[18] Dollars converted to USD based on US/AU exchange rate in 2009 and updated to 2019 USD using CPI.

customers, tenants, or buyers and improve a site's economic vitality (Bisco Werner et al. 2001).

Various studies of the value of natural spaces in urban and suburban environments have found that commercial office space, retail locations, and multifamily housing may fetch higher rents as a result of on-site landscaping decisions. For instance, Laverne and Winson-Geideman (2003) find that well-designed landscaping added approximately 7% to the average rental rate for office buildings. Shade also increased rental rates for office buildings by about 7%. Conversely, excessive tree cover that created a visual screen decreased rental rates 7.5% (Laverne and Winson-Geideman, 2003). Tyrväinen and Miettinen (2000) found that units in multifamily buildings with views of trees or forest cover can increase rents by as much as 4.9% (Wolf 2007).

While little quantitative research has been conducted in relation to the impact of vegetation and trees on retail rents, there is evidence that retail rents increase with urban quality improvements. For example, Whitehead et al. (2006) report that creating pedestrian-only zones and related improvements in retail areas increase rents by about 22%, on average.

The construction of wetlands can benefit commercial office property owners as well. In the Washington, D.C., metropolitan area, several studies identify rent premiums for office spaces with views of constructed wetlands or ponds. Benefits of these desirable views range from a 5.7 to 7.5% increase in rents (U.S. EPA 1995). Additionally, these properties may be easier to rent, with higher occupancy rates and shorter periods between leases (U.S. EPA 1995). However, construction of retention ponds that lack attractive vegetation or recreation opportunities, for instance, may decrease property values, as is the case in the residential sector (Lee and Li 2009).

To our knowledge, only a few studies have assessed the effect of green roofs on multifamily residential and commercial building values (Figure E-1). Few studies also document the property value benefits of trees for larger commercial or industrial property types. However, the U.S. Forest Service (USFS) National Street Tree Benefit Calculator (NSTBC) estimates that multi-family residential properties realize approximately 70% of the increase in value that single-family residential properties gain from street trees, while small commercial businesses realize approximately 66%. NSTCB also assumes Industrial properties, large commercial businesses, and vacant lands see only about 40% of the increase that single-family residential properties experience.

These additional amenities, such as green roofs, parks, and water features, can lead to rental increases. A 200-unit apartment complex at 1330 Boylston in Boston garnered an additional $300 to $500/month in rent for units that overlooked the green roof. The green roof cost $113K to build and the extra rent nets $120K/year, according to ULI.

E.3 Tool Methodology for Quantifying and Monetizing Property Value Benefits

Using benefits transfer to estimate property value increases associated with GSI can be a relatively straightforward exercise. However, as described above, the actual magnitude of increase depends on several factors. As a first step in calculating property value benefits, the Tool leads the user through the following steps:

1. **Estimate the property value baseline for single family residential, multi-family, and commercial (if available) properties.** For single family and multi-family residential, this information can be obtained from the American Community Survey (ACS), at the city or even Census tract level. The Tool guidance leads users through the steps associated with accessing this data from the Census

website. Alternatively, many utilities may have access to more comprehensive local databases, such as through the County Assessor's office that will allow them to calculate baseline residential and commercial property values.

2. **Determine the percentage of properties affected by different types of GSI.** In this step, the user calculates the percentage of properties that will realize an increase in value due to GSI projects based on the increase in greened acreage and/or number of BMPs added. Users may opt to exclude certain areas where GSI improvements will not likely result in additional property value benefits (e.g., higher income, well-vegetated neighborhoods). Further, the Tool allows users to apply a lower percentage increase to properties that are not directly adjacent to GSI improvements. The Tool assumes that green roofs only result in property value increases for the buildings on which they are located.

Figure E-1. Summary of Findings from Studies on the Property Value Benefits of Green Roofs.

Studies of green roofs have generally found greater increases in property values relative to studies that have assessed ground-level green infrastructure improvements, although additional research is needed. For example, **Abbot and Lewis (2013)** examined average weighted rent for commercial buildings with and without green roofs in Washington D.C. Results of the study indicated that the average weighted rent for buildings without green roofs amounted to $44.08 per square foot, while the average for buildings with green roofs was $48.12/square foot (a 9% relative increase). The model showed that green roofs could increase rents for commercial buildings by up to 15%, after controlling for other factors.

Ichihara and Cohen (2011) report similar findings in a study examining the effect of green roofs on rental prices in high-end multi-family buildings located in the Battery Park area of New York City. Specifically, results indicate a rental premium of 16.2% for buildings with green roofs compared with those lacking them, after controlling for apartment size (number of bedrooms and bathrooms) and distance to parks and transit. Based on these findings, the authors posited that if this percent increase were applied to the 41 buildings in the sample that did not have a green roof, the added value would amount to approximately $2.1 billion per month. While these results show a strong preference for green roofs, only three of the 44 buildings included in the study had green roofs (however, the number of apartments in these three buildings did account for 27% of the apartments in the sample). In addition, the three buildings were built post 2003 and are outfitted with numerous other 'green' amenities, such as energy efficiency measures and LEED certification. These characteristics were not controlled for in the final model.

A 2010 Canadian report **(Tomalty and Komorowski 2010)** measured the benefits of green roofs based on 5 case studies selected from the US and Canada. Using a hedonic pricing model, their results indicated that a recreational rooftop garden increased property values by approximately 11%, while rooftop vegetable gardens may increase it by 7%. The authors also found that these benefits even confer on surrounding properties, potentially raising property values of those within 500 feet of the garden by 5% and by 2% for properties up to 1,000 feet.

While several other studies have cited property value or rental rate increases associated with green roofs (e.g., ARUP, 2016; Green Roofs for Healthy Cities and the Green Infrastructure Foundation, 2017), most of these studies rely on existing estimates from studies that have assessed these benefits for other types of green infrastructure, open space, community gardens, or green certifications (e.g., LEED). While these studies support the idea that green roofs positively influence property values and rental rates, more research is needed to better understand the magnitude of this effect, as well as variations across building, neighborhood, and green roof characteristics.

3. **Apply property value increases from the literature to the aggregate value of affected properties to determine total potential property value benefits from GSI.** The Tool applies a range of property

value increases based on user inputs, as well as the mix of GSI practices included in the scenario being analyzed:

- ***Mix of GSI practices.*** The Tool guidance includes a table that provides low, medium, and high estimates from the literature for the percentage increase in property values associated with different types of GSI practices. As a default, the Tool includes the mid-point (i.e., medium) estimates from the table; however, the user can change these values if desired. The Tool applies a weighted average property value increase based on the types of GSI practices that make up the user's GSI scenario.
- ***Larger percentage increases in lower-income areas.*** As described previously, research suggests that property value benefits associated with GSI and related amenities can be greater in low-income areas. The Tool guidance describes how to use data from U.S. Census ACS to identify applicable areas. The user can then input the percentage of the study area that is made up of lower-income areas into the Tool. The Tool then applies higher increases to the relevant percentage of parcels. However, the user should only apply this option if location-specific data on property value is utilized. For example, if the average city-wide residential property value is used (rather than property values that reflect values in the lower-income areas of a specific study region or neighborhood), this option should not be utilized as it would result in an overestimation of value.
- ***Level of existing vegetation/tree cover and or high-income areas.*** The literature also suggests that there is a threshold at which increased vegetation (particularly trees) may result in diminishing returns (or in the case of trees, can result in decreased home values). Based on the literature, this threshold seems to hover around 35% to 40% for trees; however, it is not clear how this might apply to other types of GSI. Further, installing GSI in wealthy neighborhoods often will not yield further property value increases. The Tool allows users to exclude certain portions of their GSI management area from the property value analysis if they believe that GSI projects will not result in further increases in value due to existing levels of vegetation or high baseline property values.
- ***Commercial properties.*** As described in the previous section, the literature does include some data for the effect of GSI on property values/rental rates for some types of commercial properties. The Census does not include information on commercial property values (other than for multi-family residential, which is sometimes classified as commercial). Thus, users can only estimate the value of increases for commercial properties if they can provide baseline commercial property value data. However, the Tool assumes that half of all green roofs are installed on commercial buildings, while the other half are installed on multi-family buildings. The Tool assumes that the value of commercial properties that install green roofs is equivalent to the value of multi-family properties. Thus, some of the property value increases associated with green roofs is classified as commercial.
- ***Industrial properties.*** The Tool does not estimate any potential property value increases for industrial properties, as the value of these properties is often based on several factors that cannot be controlled for and likely outweigh the value of GSI. The project team did not find any literature that would support including these properties in the Tool.
- ***Proximity to GSI projects.*** In its TBL study of GSI in Philadelphia, Stratus Consulting (2009) applied a slightly smaller property value increase (1.5%) to a percentage of properties located outside of the directly affected areas. This is consistent with literature findings showing a "decay" of benefits for properties located a certain distance from amenities, most recently Mazzota et al. (2014). Based on findings from the literature, the Tool allows users to apply a lower percentage property value increase estimates to properties located between 200 to 500 meters from GSI projects.

As described earlier, the property value increases associated with GSI can reflect WTP for a range of benefits. Thus, property value estimates are intended to measure benefits not already captured in the Tool, such as those stemming from aesthetic improvements, reduced crime, or other characteristics. In the Philadelphia TBL study, Stratus Consulting (2009) included 50% of the property value benefits in total benefit-cost ratios for GSI scenarios. The Tool currently applies this same assumption; however, future research may indicate that a higher or lower percentage might be more applicable.

Finally, increased property taxes will result in increased revenues for local governments. Property taxes do not represent additional benefits of green infrastructure, but rather a transfer or redistribution. However, based on local milling rates, users can determine associated increases in tax revenues, if desired.

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APPENDIX F

Urban Heat Stress Reduction

F.1 Introduction

Many green stormwater infrastructure (GSI) practices (e.g., trees, green roofs, permeable pavement, and bio-retention areas) create shade, reduce the amount of heat absorbing materials, and emit water vapor, all of which cool hot air and reduce the urban heat island (UHI) effect. For example, Sailor (2003) linked 10% increases in urban vegetation to reduction in average and maximum temperatures for nine cities, finding potential reductions of between 0.16 F (Charlotte, NC) to 0.72 F (Detroit, MI). In many areas, this cooling effect is enough to reduce heat stress-related fatalities and illnesses during extreme heat wave events.

Extreme heat events (EHEs) have a well-documented history of causing adverse public health effects. Kalkstein et al. (2013) reports that extreme heat contributes to more than 1,500 deaths annually in the United States, more than any other weather-related event (U.S. EPA 2008). Demonstrations of this heat-health relationship include the loss of roughly 15,000 lives in France during the 2003 European EHE and over 700 deaths in Chicago in a July 1995 EHE.

In addition to causing increased mortality (i.e., premature fatality), EHEs have also been associated with a range of morbidity (e.g., illness) impacts, many of which result in emergency room visits and/or hospitalizations. Climate change is expected to exacerbate the occurrence of heat-related deaths and illnesses, as extreme temperatures are projected to rise in many areas, bringing more frequent and intense heat waves (U.S. EPA 2017).

The U.S. EPA and other researchers have extensively studied the effects of EHEs and warming temperatures on increased mortality and morbidity, as well as the effectiveness of alternative strategies for reducing urban temperatures, including urban greening and increasing the albedo (i.e., surface reflectivity) of urban surfaces. This appendix provides an overview of this research and describes the how the GSI TBL Benefit Cost Framework and Tool quantifies and monetizes the heat-stress reduction benefits associated with GSI.

F.2 Findings from the Literature

This section provides an overview of findings from the literature related to mortalities and illnesses associated with extreme heat, as well as the effectiveness of GSI in reducing urban temperatures and mitigating public health effects associated with extreme temperatures.

F.2.1 Urban Heat Island Background

Urban areas are particularly susceptible to EHEs because they experience elevated temperatures compared to surrounding rural areas. This "urban heat island (UHI) effect" occurs for several reasons (Kalkstein et al. 2013, U.S. EPA 2008, The Trust for Public Land 2016):

- On average, more than half of urban landscapes have been converted to dark, impermeable surfaces that become hotter in the sunlight than natural and more reflective landscapes.
- Cities have less vegetation than rural areas. Vegetation keeps temperatures lower by providing evaporative cooling and shade.
- The geometry of high-density urban environments (e.g., urban canyons) traps solar radiation.

- Urban areas serve as concentrated hubs of human activity, many of which generate heat (e.g., air conditioning exhaust, vehicles, industrial processes).

Until relatively recently, the principal adaptive measure for reducing heat exposures in U.S. cities has been mechanical air conditioning (Anderson and Bell 2011). While expanded access to air conditioning among urban residents has been found to lower the risk of heat-related illness and mortality, this adaptation fails to address outdoor exposures to heat for urban populations, indoor exposure for those lacking continuous access to air conditioning, or potential exposure during electrical grid failure events.

As such, many communities are exploring the implementation of more passive cooling strategies, including increasing the reflectiveness (i.e., albedo) of urban surfaces and/or increasing the amount of urban vegetation (e.g., Sailor 2003; U.S. EPA 2008; Kalkstein et al. 2013). These strategies can help to reduce the effect of extreme temperatures among groups that are particularly vulnerable to high heat, including those who are living below the poverty line, are elderly, or are socially isolated, without reliance on electricity.

F.2.2 Heat-Mortality Relationship

The heat-mortality relationship has been particularly well-studied and applied across multiple locations. Recently, as part of the Fourth National Climate Assessment, U.S. EPA's Climate Change Impacts and Risk Analysis (CIRA) projects the number of deaths attributable to extreme temperatures in 49 U.S. cities under various future climate scenarios. The CIRA study (U.S. EPA 2017) is based on previous research (Medina-Ramon and Schwartz 2007; Mills et al. 2015) that established city-specific relationships between deaths and extreme temperatures using historical (daily) mortality and weather data. These studies define extremely hot days as those with a daily *minimum* temperature that is warmer than 99% of the days in the historical reference period and is at least 20°C (68°F). Statistical analysis is then used to estimate deaths that can be attributed to weather on those days.

While at first perhaps counterintuitive, extremely hot days are defined based on minimum temperatures because the UHI is often driven by days when hot temperatures do not cool off at night. During a heat event, people need the relief of lower nighttime temperatures to recover from compounding heat stress that builds throughout the day (Moriyama and Matsumoto 1988, as cited by The Trust for Public Land 2016). However, the UHI effect often becomes more pronounced after sunset due to the slow release of heat from urban infrastructure (U.S. EPA 2008); thus, this relief does not always occur.

To our knowledge, Medina-Ramon and Schwartz (2007) were the first to apply this methodology to develop heat-mortality relationships for a large number of municipalities. In this study, the authors used daily mortality and weather data from 1989-2000 to estimate the increase in mortality associated with extreme hot and cold temperatures in 50 U.S. cities. Results indicated that on average, baseline mortality levels increase by 5.7% on extremely hot days; these deaths are especially linked to myocardial infarction and cardiac arrest. Heat effects varied across cities, with the largest increase in mortalities in areas with milder summers, less air conditioning, and higher population density. Extreme cold temperatures also showed an increase in mortality risk, but this was less pronounced compared to extreme heat. The authors reason that the U.S. population is likely fully acclimatized to cold temperatures but not to heat, reflecting the near universality of central heating as opposed to air conditioning. Likewise, residents in the hottest cities are likely more fully adapted to extremely hot temperatures, thus explaining the lower rate of heat-related mortality in these areas.

Mills et al. (2015) applied the city-specific mortality relationships from Medina-Ramon and Schwartz (2007) to develop mortality projections for 33 U.S. Metropolitan Statistical Areas (MSAs) under baseline conditions and potential future climate scenarios. Specifically, the authors combined the city-specific relationships with updated temperature data and projections of extremely hot and cold days (average of three years centered on 2050 and 2090) to project increases in future deaths related to extreme temperatures. The study, which covers roughly 100 million of 310 million U.S. residents in 2010, found that projected mortality from extremely hot and cold days increases significantly over the 21st century because of the overwhelming projected increase in extremely hot days.

For the updated CIRA analysis (U.S. EPA 2017, referenced above), U.S. EPA analyzed the 49 of the 50 cities originally included in Medina-Ramon and Schwartz (2007), using updated mortality rate and population data (U.S. EPA 2017). This analysis followed the same methodology as Mills et al. (2015) to estimate future increases in heat-related mortality under various climate scenarios. Results of the analysis indicated that changes in extreme temperatures are projected to result in a net average increase of approximately 9,300 premature deaths per year by 2090 in the 49 modeled cities under a "high-end emissions scenario."[19] Under the "low-end emissions scenario," more than 5,000 deaths would be avoided each year.

To monetize the effects of changing mortality, U.S. EPA (2017) applied the agency's estimate for the value of statistical life (VSL, $10.0 million for 2015, in 2015 USD), adjusted to future years by assuming an elasticity of VSL to GDP per capita of 0.4 (VSL is discussed in more detail below). Annual damages associated with additional deaths related to extreme temperature amounted to $140 billion under the more aggressive climate change scenario and $60 billion under the lower intensity scenario by the end of the century. The authors report that the results represent low-end estimates for several reasons, including that the analysis was limited to the home county rather than the MSA associated with each city, and the study only considers approximately 1/3 of the total U.S population. In addition, the studies only consider mortality, and therefore do not consider the effect of worsening long-term health conditions, or the increase in morbidity as evidenced by increased hospital visits associated with EHEs.

Anderson and Bell (2011) used daily weather and mortality data (1987 – 2005) to analyze mortality risk for heat waves in 43 U.S. cities. For this study, the authors defined heat waves as two or more consecutive days with daily mean apparent temperatures higher than the community's 95th percentile mean temperature for the warm season (May through September), rather than using minimum temperatures. For each community, the authors estimated mortality risk during heat wave events compared with non-heat wave days, controlling for potential confounding variables. Results indicated that nationally, mortality increased 3.74% during heat waves. In addition, heat wave mortality risk increased by 2.5% for every 1°F increase in heat wave intensity and 0.4% for every 1-day increase in heat wave duration. An important finding of the study was that heat waves occurring earlier in the summer had greater impacts - mortality increased 5.0% during the first heat wave of the summer versus 2.7% during later heat waves. Table F-1 presents the results of study by region, showing that mortality impacts were more pronounced in the Northeast and Midwest compared with the South.

Table F-1. Increase in Non-accidental Mortality Risk for Heat Wave Days Compared to Non-Heat Wave Days, by Region.

U.S. Region	% increase in non-accidental mortality risk
National	3.74%
Northeast	6.76%
Midwest	5.62%
South	1.84%

Source: Anderson and Bell 2011.

[19] The four scenarios analyzed in the reported are based on four "representative concentration pathways" (RCPs) that capture a range of plausible emission futures.

In another body of research, Kalkstein, Sheridan, and others, have determined that certain very hot, dangerous “oppressive air masses” are associated with statistically significant increases in heat-related mortality, especially from cardiac arrests, strokes, and other heat-related causes (e.g., Kalkstein et al., 2011, Kalkstein et al. 2013, Kalkstein and Sheridan 2005). In these studies, the researchers use daily weather data to classify each day in a given location into an air mass category.[20] Total mortality is summed for each day and standardized to account for factors that cause changes in overall deaths rate for reasons unrelated to weather. The number of deaths above what would normally be expected is then calculated for each day and air mass type. Next, step-wise regressions are used to estimate location-specific mortality algorithms that account for the impact of the EHEs’ duration, severity, and timing.

Kalkstein et al. (2013) reports that in most cities the air mass types associated with the greatest increase in mortality over baseline levels include very hot, dry tropical (DT) and moist tropical (MT+, MT++). Table F-2 shows the estimated increase in mortality attributed to extreme heat on days with offensive air masses (DT and MT+) in different cities. For example, the table shows that in Washington D.C., offensive air masses (DT and MT+) occur, on average, 11% of the time during the summer (June–August). During a typical MT+ air mass day, mortality increases by approximately 7% in the District, or approximately 1.7 deaths above the average death rate. In Seattle, however, the presence of an MT+ air mass day results in a 10% increase in baseline mortality, or approximately 4.7 deaths.

Table F-2. Mortality Responses in Different Cities When DT and MT+ Air Masses Are Present.

City	% Frequency (Jun, Jul, Aug)[a]	DT Mortality (% inc)	MT+ Mortality (% inc)
Washington D.C.	11%	0.9 (4%)	1.7 (7%)
Seattle[b]	6%	3.7 (8%)	4.7 (10%)
New York	11%	16.6 (7%)	16.9 (7%)
New Orleans	2%	none	3.7 (9%)
Phoenix[c]	1%	2.7 (7%)	none
Rome	11%	6.2 (14%)	5.0 (12%)
Shanghai	11%	none	42.4 (10%)
Toronto	7%	4.2 (11%)	4.0 (10%)

Source: Kalkstein et al. 2013.

a. June, July, and August are consistently summer months for the cities in this table and chosen to improve comparisons across cities.

b. MT+ does not occur in Seattle; the moist air mass that is present is mt.

c. DT+ air mass for Phoenix.

Kalkstein et al. (2011) employed this same general approach to estimate the excess mortality attributable to EHEs in 40 major U.S. cities during 1975–1995 and 1975–2004. The goal of the study was to evaluate whether progress has been made in reducing mortality attributable to EHEs since 1995. Results indicated that most cities included in the study with a population of at least 100,000 (year 2000) experienced reductions in EHE-attributable to excess mortality during the 1996–2004 period, even after accounting for the change in average number of EHE days. The authors hypothesized that these reductions are attributable to improvements in EHE forecasting/recognition combined with an increased interest and commitment of public and private resources to EHE education, notification, and response measures. The decrease in heat-related mortalities (because of increased acclimatization/adaptation) is consistent with other research, as reported in a literature review on trends in human vulnerability to

[20] Days are classified into air mass categories using spatial synoptic classification (SSC; Sheridan, 2002) SSC evaluates a broad set of meteorological conditions (e.g., temperature, humidity, wind speed, cloud cover) to place each day into one of several air mass categories.

excessive heat by Sheridan and Allen (2018).

F.2.3 Heat-Related Morbidity Impacts

Extreme heat and heat waves can cause and/or contribute to a range of non-fatal human health effects, including general discomfort, respiratory difficulties, heat cramps and exhaustion, cardiovascular stress, kidney or liver failure, and blood clots (U.S. EPA 2008, Kleerekoper et al. 2012). In addition, high temperatures have been associated with increased mental health-related emergency room visits, including for violence and self-harm, and with premature births and stillbirths (CA OEHHA 2019).

Several studies have used daily weather data and information on hospital admissions and emergency room visits to examine the effect of extremely hot days and/or heat wave events in specific locations. Knowlton et al. (2009) reports that across these studies, the relationship between heat and morbidity varies based on local demographics, economic well-being, underlying disease risk, the presence of vulnerable subpopulations, weather variability, physiologic acclimatization, and locally available adaptations. For example, several studies have shown that heat waves take a disproportionate toll on people of color and low-income urban populations who often live in neighborhoods that have older, lower quality building stock, less tree cover, and fewer buildings with air conditioning (Kalkstein et al. 2013).

Knowlton et al. (2009) found that hospitalization rates and emergency room visits for illnesses linked to extreme heat increased significantly in California during a 2006 heat wave, including in areas with relatively modest temperatures. Specifically, the authors report that during the heat wave, there were 16,166 excess emergency room visits (a 3.3% increase from the reference period) and 1,182 excess hospitalizations statewide (a 0.62% increase from the reference period). Results showed that children (0-4 years of age) and the elderly (> or = 65 years of age) were at greatest risk.

Zhang et al. (2015) used a similar approach to estimate morbidity and mortality caused by an exceptional heat wave in Houston (TX) in the summer of 2011. The authors developed a distributed lag regression model to estimate associations between the heat wave and all-cause mortality and emergency room visits during the summer (May through September) for the five-year period 2007-2011. Results of this study showed that the 2011 heat wave in Houston was associated with a 3.6% excess risk in emergency room visits and a 0.6% increase in mortality risk. Elderly residents were found to be at greatest risk for emergency room visits.

Some studies have found that morbidity impacts have decreased over time, likely due to increased resilience and adaptation strategies. For example, Wang et al (2016) conducted a national study of heat-related illnesses among 23.5 million Medicare fee-for-service beneficiaries per year residing in 1,916 US counties between 1999 and 2010. The authors developed models to estimate the relative risk of heat stroke admissions on a heat wave day[21] compared to a matched non-heat wave day. Results indicated that heat stroke hospitalizations declined dramatically over time (from a relative risk of 71.0 in 1999 to 3.5 in 2010) and was highest in the northeast region of the United States. While the study found significant declines in heat-related illness over time, the authors caution that considerable risks remain.

While the UHI is often the focus of heat-related morbidity studies, some researchers have found that rural areas have higher rates of heat-related illness. For example, Fechter-Leggett et al. (2016) used county-level data on heat-related illness from the Center for Disease Control (CDC) to investigate temporal and geographic trends in heat-related emergency room visits in 14 states. The authors report

[21] For this study, heat wave days were defined as a period of at least two consecutive days with temperatures exceeding the 97th percentile of that county's temperatures.

that over the study period (2005 to 2010), there were 98,462 heat-related emergency room visits in the 14 states. A surprising finding was that age-adjusted incidence rates of heat-related emergency room visits were higher for rural areas compared to the most urban areas. This pattern was observed in all six climate regions. Consistent with Wang et al. (2016), the authors also found that emergency room visits decreased by 3.0% per year, on average, over the study period.

The CDC reports data on heat-related illnesses, including emergency room visits and hospitalizations, for states that participate in the National Environmental Health Tracking Network (NEHTN). Heat-related illnesses are identified using primary and other diagnosis codes. While this database serves as an important resource, CA OEHHA warns that heat-related illnesses are often unrecognized or misclassified as another underlying cause. Because of this, the number of heat-related illnesses reflected in the CDC data likely underestimate the full impact of exposure to periods of high temperatures. Table F-3 shows rates of heat-related emergency room visits and hospitalizations. per 100,000 in population, in the states that participate in the NEHTN program. Average results are shown for the period 2000 – 2016; however, not all states have reported data every year.

Table F-3. Heat-Related Emergency Room Visits and Hospitalizations per 100,000 Residents, Average 2000 – 2016, by Participating NEHTN State.

State	Heat-Related ER visits (per 100,000 people)	Heat-Related Hospitalizations (per 100,000 people)
Arizona	28.4	5.9
California	11.9	2.7
Florida	22.4	2.2
Iowa	26.9	2.7
Kansas	28.5	2.6
Kentucky	29.3	3.2
Louisiana	54.8	3.3
Maryland	14.3	1.0
Michigan		1.1
Minnesota	13.5	1.5
Missouri	35.6	1.6
New Jersey	10.6	1.1
New Mexico	11.7	1.3
New York	10.7	1.1
Pennsylvania		1.6
South Carolina	31.0	1.7
Tennessee	31.1	1.3
Washington		0.9
Wisconsin	14.7	0.6

Source: CDC 2019.

F.2.4 Effect of GSI on Urban Temperatures and Related Health Outcomes

Vegetated and reflective GSI practices create shade, reduce the amount of heat absorbing materials, and emit water vapor, all of which cool hot air and reduce the UHI effect. In addition to increasing albedo of urban surfaces (depending on the type installed), permeable pavement can provide evaporative cooling benefits because they allow water to pass through them more easily than traditional pavements and can release some of that water back into the air (Kalkstein et al. 2013). When implemented at scale, the cooling effect of GSI improvements can be sufficient to reduce heat stress-related fatalities and morbidity during EHEs.

Complex spatial models have been used to estimate how increasing urban vegetation or reflective surfaces can affect solar energy absorption and ultimately local meteorological values such as temperature and humidity. In these applications, the study area is first divided into grid cells. Each grid cell is then assigned to a land category class that has its own unique combination of attribute values (e.g., solar reflectivity/absorption, moisture, roughness). The impact of a program that increases urban vegetation or reflectivity is then accounted for by recalculating and reassigning attribute values in cells where the policy would be implemented (Stratus Consulting 2009).

This approach has previously been used to estimate the impact of increased urban vegetation on temperatures in several U.S. cities. For example, Sailor (2003) modeled the effect of a 10% increase in urban vegetation on average and maximum temperatures during multi-day heat wave events that occurred in various cities from June through August 1991–2001. Table F-4 presents the results of this study; while temperature reductions may seem relatively small, Kalkstein et al. (2013) note that even small changes in temperatures can reduce heat-related deaths and illnesses.

Table F-4. Modeled Temperature Reductions Associated With a 10 Percentage-Point Increase in Vegetated Area in 9 U.S. Cities.

City	Reduction in temperature (F)	
	Average Temperature	Maximum Temperature
Washington D.C.	0.31	0.32
Baton Rouge	0.22	0.18
New Orleans	0.13	0.27
Atlanta	0.50	0.58
Charlotte	0.04	0.16
Detroit	0.50	0.72
Grand Rapids	0.25	0.27
Baltimore	0.40	0.23
Philadelphia	0.38	0.49

Source: Sailor et al. 2003.

A similar study (Columbia University Center for Climate Systems Research et al., 2006) evaluated several potential changes to the urban landscape in New York City. The study estimated that there would be a 0.40°F reduction in temperature at 3 p.m. in New York City if 6.7% of the total city area represented were to receive shading by adding trees along streets. The study also estimated a potential 1.10°F reduction at 3 p.m. if 31% of the city area were converted from its current mix of grass areas, streets without trees, and impervious roofs to areas with trees and living (i.e., vegetated) roofs.

Building on previous research (Taha and Sailor, 1997; Akbari and Konopacki, 2003; Sailor, 2003), Sailor and Dietsch (2007) worked with U.S. EPA to develop a screening tool that allows users to estimate changes in temperature associated with incremental increases in vegetation or surface albedo. To develop the Tool, known as the Mitigation Impact Screening Tool (MIST), the authors created a suite of detailed meteorological model simulations for a set of 20 test cities within the U.S. The suite of simulations consisted of control runs, as well as mitigation scenario runs for several different levels of albedo and/or vegetation mitigation. The atmospheric effects of mitigation strategies were then extrapolated to 170 U.S. cities through regression analysis. Six city-specific variables were considered for the extrapolation process, including: population, physical area, population density (resident population/area), latitude, and underlying climate as measured by Cooling and Heating Degree Days. The population of the Metropolitan Statistical Area was found to be the single most statistically significant determinant of changes in temperature associated with incremental changes in vegetative cover and/or surface albedo in the model cities. The authors therefore developed the following equations to extrapolate results to other cities:

$$Temp\_Albedo = -2.8\text{E-}8 \times Population - 0.389$$

$$Temp\_Vegetation = -1.6\text{E-}8 \times Population - 0.279$$

where:

- *Temp_Albedo* is equal to the change in temperature (in degrees Celsius) associated with a 0.1 percentage increase in surface albedo, and
- *Temp_Vegetation* is equal to the change in temperature (in degrees Celsius) associated with a 0.1 percentage increase in vegetative cover.

Vanos et al. (2016) estimated reductions in heat-related mortality in three cities: Baltimore (MD), Los Angeles (CA), and New York (NY). The authors identified four actual multi-day extreme heat events in each city and modeled the impact of increased surface reflectance and increased vegetative cover on meteorological conditions under three scenarios:

- Increase urban surface reflectance by 0.10 (0.15 to 0.25)
- Increase surface vegetation by 0.10 and reflectance by 0.10
- Increase surface reflectance by 0.20 (0.15 to 0.35).

The authors state that reflectivity and vegetated cover were equally effective urban cooling strategies. While changes in air temperature and humidity in all cities were small (generally less than 1°F), results found a corresponding decrease in heat-related mortalities. Specifically, deploying the UHI mitigation strategies under Scenario 2 described above (including the 0.10 increase in surface vegetation) would save up to 12 lives in Baltimore and 197 lives in New York over a 10-year period. In Los Angeles, the mortality reduction was estimated at 2 lives over 10 years.

Kalkstein et al. (2013) found that a 10-percentage point increase in urban surface reflectivity in Washington D.C. could reduce the number of deaths during heat events by an average of 6%. Adding a 10% increase vegetative cover to the increases in reflectivity yielded an average 7% reduction in mortality during heat events. During the decades between 1948 and 2011, an average of 285 people died of heat-related causes in Washington D.C. (Kalkstein et al., 2011). A 6–7% decrease in mortality would save approximately 20 lives per decade. In addition, an even larger reduction would be expected in hospital admissions from heat-related illness, although the authors did not quantify this outcome.

Stone et al. (2014) paired global and regional climate models with human health effects models (including those from Median-Ramon et al. 2007, described above) to estimate changes in the number of heat-related deaths in 2050 resulting from modifications to vegetative cover and surface albedo across three U.S. metropolitan areas: Atlanta (GA), Philadelphia (PA), and Phoenix (AZ). Employing health impact functions for average warm season and heat wave conditions in 2050, the authors found that combinations of vegetation and albedo enhancement would offset projected increases in heat-related mortality due to climate change by 40% to 99% across the three metropolitan areas. Vegetation enhancement or a combination of vegetation and albedo enhancement resulted in the greatest reductions in mortality in Atlanta and Philadelphia, while albedo enhancement in Phoenix was found to have the most significant effect on heat-related mortality. The average reduction across all heat reduction strategies in the three cities was 57%. This decrease was associated with relatively aggressive green scenarios, for example, achieving 80% green on residential properties and 50% green on commercial properties.

Finally, Graham (2012) used regression models (rather than the more complex spatial models) to examine the effect of increased trees and vegetation on the number of heat-related ambulance calls from different neighborhoods within Toronto (ON). The findings of this analysis indicated that areas of the City with more trees had fewer emergencies during extreme heat events. Specifically, based on an evaluation of two Toronto neighborhoods, Dr. Graham found that increased trees and vegetation would result in an estimated 40 to 50% reduction in heat-related ambulance calls. He reports that if tree canopy cover is increased to 10% in areas that currently do not have many trees, the City would see an immediate and dramatic drop in the number of heat-related ambulance calls. Beyond 10%, Graham indicates the City would still see a decline in the number of calls, but it would be less dramatic.

F.3 Tool Methodology for Quantifying and Monetizing Urban Heat Stress Reduction Benefits

F.3.1 Quantifying Reductions in Heat-Related Mortalities

The Tool allows users to estimate the percent reduction in heat-related mortalities and morbidities associated with city- or neighborhood-scale GSI implementation. Within the Tool, the first step is to understand the relationship between extreme heat and fatalities in a given location. As detailed above, U.S. EPA (2017), building on Medina-Ramon and Schwartz (2007) and Mills et al. 2015, has developed these relationships for 49 U.S. municipalities. U.S. EPA provided the authors with this data, which includes the following information for each location:

- Estimated increases in mortality on extremely hot days, defined as days on which the daily minimum temperature is greater than or equal to the 99th percentile value from the distribution of daily minimum temperatures for that location, and is greater than 68 degrees F.
- The relevant minimum temperature threshold (i.e., the 99th percentile value)
- Number of days between 1986 and 2005 on which temperatures did not fall below the threshold (i.e., the number of extremely hot days), and the minimum temperature on those days
- Daily temperature projections for 2050, including number of days where temperatures do not fall below the minimum temperature threshold

Tool users will need to select a city from the list of 49 cities for which mortality data are available. The choice is self-evident if the analysis is being conducted in one of the 49 cities included in the U.S. EPA analysis. If the location is different from the 49 cities, practitioners will need to choose an analogue city. One way to do this is to consider the average warm season minimum daily temperature for the tool user's location compared to the average minimum daily temperatures listed in the tool for the 49 cities. The tool will also average this information by climate region.

The next step is to link planned increases in GSI to reductions in urban temperatures. For this step, the Tool relies on estimates from Sailor (2003) to estimate reductions in average daily temperatures from increased vegetation. Because only nine cities were included in Sailor (2003), the Tool averages results from the study by climate region. The reduction in temperatures are scaled depending on percentage increase in vegetated acreage under the GSI scenario being analyzed. The Tool relies on results from Sailor and Dietsch (2007) to estimate reductions in average daily temperatures associated with increases in surface albedo due to permeable pavement. Specifically, the equations developed for this study indicate that increasing albedo in urban areas by 0.10 percentage points results in an approximately 44% greater temperature reduction compared to increasing vegetative cover by 0.10. The Tool applies this difference to the Sailor (2003) results to estimate cooling effects associated with changes in surface reflectivity due to implementation of permeable pavement.

To apply the estimates from the studies referenced above, the Tool accounts for the following factors:

- First, the Tool requires a minimum increase of 0.05 percentage points in terms of increased vegetative cover or surface albedo. This is initially calculated based on the area of relevant GSI practices compared to the overall study area. However, the user has the option of indicating that GSI practices will be concentrated such that a 0.05 or greater increase will be achieved. This effectively decrease the area over which the cooling effect occurs to a subset of the overall study area.
- Second, the cooling effect associated with permeable pavement is based in part on the assumption that permeable pavement will increase surface reflectivity/albedo. However, this depends on the type of permeable pavement installed relative to a baseline. For example, replacing traditional black asphalt with black permeable asphalt does not change the surface albedo. The Tool includes questions related to permeable pavement (and what it is replacing) to determine this benefit.

Finally, to link temperature reductions to decreased mortalities, the Tool:

- Calculates the change in the days each year when the city is over the minimum mortality temperature (MMT) by subtracting the change in temperature from Sailor et al. 2003 and/or Sailor and Dietsch (2007) from the minimum daily temperature for the historical reference period.
- Uses the change in days over MMT and the change in the temperature for days over the MMT to calculate a new average annual mortality rate
- Calculates annual lives saved from the project based on population of the GSI management area.

F.3.2 Quantifying Reductions in Heat-Related Emergency Room Visits and Hospitalizations

To calculate the reduction in heat-related illnesses, we determined the ratio of heat-related mortalities to heat-related emergency room visits and hospitalizations using data from the CDC's NEHTN (Table F-5). This includes data for only 19 states; thus, the Tool applies ratios for non-Tracking states by using averages from states within the same climate region. To calculate heat-related illnesses, the Tool multiplies the relevant ratio (based on data from Table F-5) by the number of heat-related fatalities determined in the previous step.

F.3.3 Monetizing Avoided Heat-Related Mortalities and Illnesses

When conducting a benefit-cost analysis of new environmental policies, the U.S. EPA uses estimates of how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution. These estimates of willingness to pay (WTP) for small reductions in mortality risks are often referred to as the "value of a statistical life" (VSL). This is because these values are typically reported in units that match the aggregate dollar amount that a large group of people would be willing to pay for a reduction in their individual risks of dying in a year, such that we would expect one fewer death among the group during that year on average (U.S. EPA 2019). To estimate the value of avoided heat-related fatalities associated with GSI implementation, the Tool applies the current VSL dollar value of $9.2 million per avoided death (2018 USD).

Table F-5. Ratio of Heat-Related Emergency Room Visits and Hospitalizations per Heat-Related Mortality for NEHTN States, Average 2000 – 2016.[a]

State	ER visits per mortality	Hospitalizations per mortality
Arizona	7.1	2.0
California	53.0	9.5
Florida	146.1	27.5
Iowa	0.0	0.0
Kansas	11.7	6.6
Kentucky	69.5	13.2
Louisiana	90.8	12.0
Maryland	29.0	5.0
Michigan	N/A	11.4
Minnesota	38.6	6.0
Missouri	87.6	10.1
New Jersey	44.5	8.4
New Mexico	15.5	2.4
New York	31.5	7.7
Pennsylvania	N/A	7.8
South Carolina	103.8	11.9
Tennessee	95.0	11.0
Washington	N/A	30.7
Wisconsin	50.6	6.2

Source: Data from CDC 2019.

a. Estimates reflect annual average for 2000 – 2016; however, data is not available for most states for every year.

To estimate the monetary value of avoided heat-related emergency room visits and hospitalizations, the tool applies the corresponding avoided health care costs, using estimates from U.S. EPA's Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE, see Appendix E for a detailed description of BenMAP-CE). According to economic theory, the best measure of the value of reducing the risk of an adverse health effect is the average that individuals are willing-to-pay to reduce the risk by a small amount. However, for certain endpoints, reliable WTP studies are not available. Alternative methods for valuing health outcomes include avoided medical costs and/or estimates of lost productivity. These methods result in lower-bound estimates of value because they only consider a portion of the total demand (i.e., WTP) for avoiding a health risk. For example, BenMAP-CE values hospital admissions based on the medical costs incurred during the stay in the hospital; this ignores the pain and suffering components of value that would be included in WTP. Heart attacks are valued using a combination of medical cost information plus the lost stream of income from people not able to re-enter the workforce (or who must work at a reduced level of income) after a heart attack. This ignores the pain and suffering components of WTP and does not include lost income for people assumed to be out of the workforce (e.g., retirees and unemployed adults).

Detailed information and sources of all values used in BenMAP-CE are available in the BenMAP documentation and technical appendices (U.S. EPA, 2018). Table F-6 presents monetary values included in BenMAP-CE (per incident) for mortalities, hospital admissions, and emergency room visits.

Table F-6. BenMAP-CE Values for One Case of Each Health Effect.

Health Effect	Value per Case (2018 USD)
Premature mortality (VSL)	$9,222,609
Hospital admission	$18,195 to $49,128 (varies by cause of hospitalization and age)
Emergency room visit	$474 - $566

Source: U.S. EPA 2018a.

F.3.4 Limitations and Uncertainties

The methodologies described above are based on several assumptions that allow the user to understand and estimate the potential UHI reduction benefits (in terms of decreased heat-related deaths and illnesses) associated with the implementation of GSI at the city- or neighborhood-scale. Because of limitations associated with existing studies and availability of data for many municipalities, these estimates should generally be interpreted as order-of-magnitude estimates. For example, the analysis and assumptions built into the Tool assume that GSI is located in areas where increased vegetation will result in UHI benefits (e.g., GSI located in highly affluent, well-vegetated areas will not make as much of a difference). In addition, this methodology does not account for changes in sensitivity over time as humans adapt to a changing climate, whether due to increased availability of air conditioning or how the human body can become accustomed to high temperatures over time. Further, the actual number of heat-related illnesses (and associated monetary values) likely represent an underestimate, as heat-related illnesses are often misclassified or not identified as being related to extreme temperatures. The authors feel that the estimated impacts included in the tool represent reasonable estimates of value that help practitioners understand the value of well-located and well-designed GSI implemented at the city- or neighborhood-scale.

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APPENDIX G

Recreation

G.1 Introduction

Implementation of green stormwater infrastructure (GSI) can result in increased recreational opportunities and enjoyment of green space for residents in several ways:

- Substantial increases in vegetated acreage, tree canopy, and enhanced urban aesthetics can increase enjoyment and participation in neighborhood activities such as walking, biking, or jogging on sidewalks, bench sitting, and/or other general outdoor recreation.
- Some GSI projects are specifically designed to include recreational amenities. For example, several cities across the U.S. have created “stormwater parks;” others have developed large infiltration areas, such as wetlands, that provide active and passive recreation opportunities.
- Stream restoration and riparian buffer improvements can increase recreational opportunities in areas along and adjacent to waterways.
- Projects that make substantial improvements to water quality may also increase opportunities for water-based recreation.

Individuals value outdoor recreation for several reasons, including for physical activity and associated health benefits, improved mental health, and for building social capital. Because recreational activities associated with GSI projects are not traded in the market (i.e., there is no fee for participation), it can be difficult to establish the values associated with them. However, many researchers have conducted willingness-to-pay (WTP) surveys to estimate the value of a recreational experience across a range of activities. These studies yield what economists refer to as *direct use values*. Direct use values reflect the amount that individuals would be willing to spend to participate in a recreational activity if they had to pay for it.

Total recreational benefits associated with GSI are a function of direct use values and the additional recreational trips (often referred to as “user days”) taken as a result of the GSI improvements. However, these variables can range significantly depending on the availability of existing (i.e., baseline) outdoor recreation opportunities, the type of recreational activities facilitated by GSI improvements, the amount and quality of the recreational space, and other local conditions. Based on these factors, the GSI TBL Benefit Cost Framework and Tool (Tool) includes a series of questions to help guide users toward some basic assumptions for estimating recreational benefits. This includes separately estimating the recreational benefits associated with general urban greening and those associated with larger scale GSI projects that intentionally incorporate recreational amenities (e.g., stormwater parks, pocket parks).

As an important note, the recreational benefits associated with projects that results in increased opportunities for water-based recreation are not valued within the Recreation Module of the Tool. Rather, these benefits are valued as part of the methodology included in the Water Quality Module (see Appendix K). In addition, the value of recreational benefits included in the Tool (i.e., direct use values) reflect benefits for individuals who recreate; they do not reflect benefits associated with having views of green space or living in green environments. These benefits are captured to some extent in the property value estimates described in Appendix F. However, the benefits reflected in increased property values also likely capture the value that residents place on having access to recreational sites. The methodology included in the Tool accounts for this potential double-counting.

The following sections provide an overview of findings from the literature related to the potential recreational benefits of GSI, as well as methodologies economists use to value these benefits. We also provide an overview of the assumptions and methodology included in the Tool to help users quantify and monetize recreational benefits associated with their GSI scenario.

G.2 Findings from the Literature

G.2.1 Linking GSI Projects to Recreational Benefits

As noted above, there are several ways that GI projects can provide recreational benefits. In some cases, GSI installations and related aesthetic improvements can encourage additional outdoor activity by nearby residents. For example, the former Commissioner of Parks and Recreation in New York City notes that many properly designed, constructed, and managed GSI installations can serve as parks (Benepe 2015). He cites NYC's 2,000 Greenstreets (i.e., greened traffic islands), which were considered "parks" by the Parks Department. While these installations were mostly very small properties, they had plants, trees, and often sidewalks and sitting areas or benches; they created community spaces where there had previously been relatively bleak landscapes. These types of GSI installations have also resulted in the creation of small "pocket parks," which provide neighborhood open spaces and play areas.

In its 2009 study on the triple bottom line (TBL) benefits of GSI-based alternatives for combined sewer overflow (CSO) control, the City of Philadelphia estimated the recreational benefits associated with its' significant planned increase in urban vegetation and tree canopy throughout the city (i.e., general urban greening). Based on an estimated number of trips per greened acre, the authors of the study estimated that under the "50% GI" alternative, under which 50% of stormwater runoff from impervious area would be managed through GSI, the recreational benefits associated with this increase would result in approximately 2.7 million additional recreational trips per year; this would amount to approximately $86.3 million in direct use value (present value) over the 40-year study period (Stratus Consulting 2009). Autocase, a proprietary tool designed to monetize the benefits of GSI, follows the same methodology to estimate the recreational benefits associated with targeted GSI installations and related urban greening (Parker and Meyers 2015).

In more recent years, several cities across the U.S. have developed stormwater parks, which include larger-scale GSI solutions that capture and reuse or infiltrate stormwater, but also provide public open spaces and/or recreational amenities. For example, in Atlanta, the Old Fourth Ward Park is a major GSI installation that addresses local flooding and stormwater issues; the City had originally planned to address these issues using a much more expensive gray infrastructure solution. Other examples include the Los Angeles Wetland Park (CA), the Main Terrain Park in Chattanooga (TN), and the City Meadow park in Norfolk (CT).

Existing parks can also have new GSI elements added to them that create additional recreational opportunities and associated value. For example, as part of the Green City, Clean Waters Plan, the City of Philadelphia has transformed several traditional asphalt schoolyards and playgrounds into "green playgrounds." The new playgrounds include state-of-the-art play equipment, playing fields, and large new planting areas designed to capture stormwater runoff generated onsite, as well as from surrounding sidewalks and streets. The City's plan also includes a comprehensive stream restoration component that will transform creeks within the City's park system. Philadelphia's TBL Study (Stratus Consulting 2009) estimated that these projects would generate close to $539 million in recreational benefits (i.e., direct use values) over the 40-year study period (2019 USD).

Finally, significant improvements in water quality can also result in additional value for water-based recreational activities. For example, in many cities, untreated stormwater runoff and/or combined sewer overflows (CSOs) result in elevated levels of bacteria and other pathogens at beaches and in other waterbodies (Dorfman and Haren 2014). In a study on the value of clean water in Northeast Ohio's Lake Erie region, Clements et al. (2015) report that in 2013, 39% of the beach monitoring samples collected at local beaches on Lake Erie exceeded the Beach Action Value (BAV) safety threshold for *E. coli* bacteria[22]. Further, the authors report that beaches in the Northeast Ohio study area were closed and deemed unsafe for swimming approximately 20% of the time in 2012. Using just one beach as an example (Headlands Lake State Park), the authors conclude that in the absence of these closures, total recreational use value would have increased by $950,000 per year, from $4.8 to $5.7 million. This estimate was derived from baseline visitation in 2012 and associated direct use values. The changes in recreational use that result from improvements in water quality are site-specific and difficult to quantify in the absence of locally available data. Rather than value these services based on changes in recreational use, the value of recreational benefits associated with water-based recreational benefits is measured based on willingness-to-pay by recreators for specified improvements in water quality. For more information see Appendix K.

G.2.2 Social Benefits of Parks and Urban Green Spaces

Individuals value outdoor recreation for several reasons, including for physical activity and associated health benefits, improved mental health, and building social capital. The following sections provide examples from existing studies on how these benefits are realized through recreational activities similar to those that GSI projects typically support. In addition, we provide an important precursor related to park access, use, and equity.

G.2.2.1 Park Access and Equity

The use of greenspace and parks depends on several factors, chief among them being proximity (i.e., people who use parks regularly usually live nearby, Croucher et al. 2007, Grahn and Stigsdotter 2003). Ease of access, safety, quality, and connectivity to other greenspaces have also been found to influence the use of greenspace for different purposes (Croucher et al. 2007; Hartig et al. 2014, Lee and Maheswaran 2010). Some studies have found that the relationship between access and use of green space is stronger in children, the elderly, and those with lower incomes, most likely because they spend more time closer to home and in their neighborhoods (Maas, van Dillen, et al. 2009, Lee and Maheswaran 2010).

It is important to consider recreational benefits and access to greenspace from an equity standpoint. In short, benefits will be maximized in areas where green space and opportunities to recreate are relatively scarce. In urban areas, this most often occurs in neighborhoods with higher concentrations of low-income and/or minority or ethnic populations (Jennings et al. 2016). Research shows that adding green space or recreational amenities in traditionally underserved neighborhoods can increase outdoor activity among residents, resulting in associated physical and mental health benefits and other social outcomes (NRPA 2016). These gains will not be as large in areas that already have a significant amount of green space or recreational opportunities. Thus, recreational benefits will not be achieved solely through greater abundance of GSI projects, but through more equitable distribution.

G.2.2.2 Physical Activity and Related Health Outcomes

Multiple studies have established a link between greener environments and higher levels of physical activity (e.g., Kaczynski and Henderson 2007, Hartig et al. 2014, Mullenbach et al. 2018). By creating environments conducive to outdoor exercise and play, GSI can contribute to positive health outcomes.

[22] The U.S. Environmental Protection Agency provides the BAV to states as a conservative, precautionary value for making beach notification decisions in order to provide an early alert to beachgoers.

For example, Sallis et al. (2016) studied environmental determinants of physical activity in adults aged 18 to 66 years from 14 cities in ten countries worldwide. Results of the study found that four of six environmental attributes were significantly and positively related to physical activity, including the number of parks within a one-kilometer radius of a participant's residence. The difference in physical activity between participants living in the most and least activity-friendly neighborhoods ranged from 68 minutes per week to 89 minutes per week; this represents 45% to 59% of the 150 minutes per week of physical activity recommended by most governmental guidelines.

Researchers have also linked access to green space directly to physical health outcomes, including reductions in obesity levels. Ellaway et al. (2005) showed that higher levels of neighborhood greenery in Europe were associated with more physical activity and reduced levels of self-reported overweight and obesity. Nielson and Hansen (2007) found that for individuals under 25 years of age, the further they lived from green space, the more likely they are to be obese. In a review of literature on greenspace and obesity-related health indicators, Lachowycz and Jones (2011) report that most studies found a positive association. However, the authors note that the relationship varied by factors such as age, socioeconomic status, and amount of greenspace in a given area.

Several studies have demonstrated strong associations between physical activity and access to green space among specific groups, including senior citizens, children, and other subpopulations. Some of these studies also report associated health outcomes. For example:

- Broekhuizen et al. (2013) showed a significant positive association between a "green living environment," physical activity, and (perceived) health among older adults, including morbidity, mortality, and survival.
- Takano et al. (2002) found that after controlling for age, sex, living arrangement, and living expenses, five-year survival for senior citizens improved for those that had space for taking a stroll near their home, and particularly when that space provided access to parks and tree lined streets.
- Almanza et al. (2012) used satellite images and GPS and accelerometer data from children in several communities in California to demonstrate that increased residential greenness was positively associated with moderate to vigorous physical activity.
- Bell et al. (2008) found neighborhood greenness to be associated with lower BMI in children, regardless of residential density. Results of this study also indicated that more greenness reduced the odds of children increasing their BMI over a two-year period.
- Cohen et al. (2014) studied the effect of three new pocket parks on physical activity in inner city, low-income neighborhoods. Results showed that the pocket parks were used more than comparable playground areas in larger neighborhood parks. However, comparison playground users were more likely to be walking or engaged in vigorous physical activity while in the playground area. The authors note that pocket parks encourage residents to be physically active simply by being a valued community destination (e.g., an individual who walks a quarter to half mile to and from the local pocket park several times each week could be close to meeting physical activity recommendations).

G.2.2.3 Mental Health

It has been well-documented that spending time in natural environments can improve overall mental health, reduce stress, and increase cognitive functioning. Physical activity is at least partially responsible for this relationship. For example, Mitchell (2013) found that people who use the natural environment for physical activity at least once per week have about half the risk of poor mental health compared with those who do not; and each additional weekly use further reduces the risk of poor mental health by 6%. Results of this study also indicate that physical activity in natural environments is better for mental health than activity elsewhere. In a study conducted in Palo Alto, California, Bratman et al. (2015) found that walking 50 minutes in a city park boosted people's moods, as well as their working memories and attention. A 90-minute walk yielded changes to their brains in a way that can protect against depression.

Many individuals visit parks and greenspaces to sit and relax, be closer to nature, and/or undertake passive recreational activities (NRPA 2015). These activities also yield important mental health benefits. In a comprehensive review of literature relating health and greenspace, Wolf and Flora (2010) reference substantial research showing that natural scenes and contact with nature evoke positive emotions and provide other mental health benefits.

Wolf and Flora (2010) also report that more than 100 studies have shown that spending time in nature can significantly reduce stress. In one study, Grahn and Stigsdotter (2003) surveyed almost 1,000 randomly selected individuals in nine Swedish cities about their health and use of urban greenspaces. Individuals who visited urban greenspaces more frequently reported fewer stress related illnesses. The same relationship was also reported for length of time spent in greenspaces. The link between use of greenspace and reduced stress levels held regardless of age, gender, and socioeconomic status. The authors suggest that several experiences associated with greenspace likely influence stress levels, including outdoor activity and exercise, natural daylight, stimulation of the senses (sight, sound, scent, temperature, touch, balance, and hearing), and pleasing aesthetics).

Multiple studies have also shown that experiences in nearby nature improve cognitive functioning and increase one's capacity to be productive. In an article for NRPA's monthly magazine, Wolf (2017) notes that brief experiences in nature help to restore the mind from mental fatigue, as natural settings provide respite from the highly focused attention needed for most tasks in school or at work. Increased time in nature (up to 1.5 hours) increases the restorative effect. In addition, outdoor activities that involve a natural environment have been shown to reduce symptoms of attention deficit disorder (ADD) and attention deficit hyperactivity disorder (ADHD) in children who had been medically diagnosed (Kuo and Taylor 2004). Greener play areas have also been shown to attenuate ADD symptoms, improve concentration, and reduce aggression and bullying (Taylor, Kuo and Sullivan 2001).

Importantly, natural spaces do not have to be pristine or beautiful to provide emotional and cognitive benefits. For example, Tyrvainen et al. (2013) measured people's well-being in three different environments in Finland: urban streetscapes, busy city parks, and wilder forests. The authors found that people began to feel psychologically restored after just 15 minutes of sitting outside in both the park and forest. After a short walk, these feelings increased, although slightly more so in the forest. Only nature worked to improve measures of vitality, although it took forty-five minutes of sitting and strolling. The study participants in the park or forest felt 20% better than those in the urban streetscape; they also reported feeling more creative.

G.2.2.4 Social Benefits

Neighborhood greenspaces and parks can provide opportunities for interactions with neighbors and friends, helping to build what is often referred to as social capital. Studies have shown that individuals with high levels of social capital tend to have better health outcomes and more economic opportunity (NRPA 2016). Wolf and Flora (2010) note that social capital can also decrease the chance of depression and increase self-esteem. Social interaction can be particularly important for the elderly; it is correlated with lower mortality rates, depression, and cognitive impairment.

NRPA (2016) offers several examples of studies that demonstrate the importance of greenspace in building social capital:

- In a study of the relationship between tree cover and social capital in Baltimore, residents of neighborhoods with lots of trees had higher levels of individual social capital than residents of neighborhoods with few trees (Holton et al. 2015).

- In a survey of neighborhood park users in Los Angeles, 73% reported socializing with people they knew at the park (Cohen et al. 2006). In another study, women who used Prospect Park in Brooklyn, New York, reported that they valued the sense of community that comes from unplanned interactions with friends and acquaintances (Krenichyn 2004).
- In Chicago, researchers found that a park on the city's far north side that served as a boundary between racially and ethnically different neighborhoods attracted residents from both neighborhoods, fostering social interactions that may not otherwise occur (Gobster 1998).

Additionally, a series of related studies of public housing residents have found multiple links between greenspace and increased social capital. These studies showed that common areas with trees and grass attracted larger and more diverse groups of residents than hardscaped areas and promoted stronger social ties (Coley et al. 1997, Kuo et al. 1998, Taylor et al. 1998). Elderly public housing residents with better access to green common areas were also found to have stronger relationships and a more positive sense of community (Kweon et al. 1998).

G.2.3 Quantifying and Valuing Recreational Benefits

G.2.3.1 Park Use and Recreational Activity

As noted above, a key step in assessing the recreational benefits of GSI is to establish the number of recreational trips that the planned GSI installations will support. A review of relevant literature indicates that several studies have estimated park visitation to specific sites and for specific park systems; however, few of these studies are easily transferable or generalizable. For example, many of the studies that report visitation data are conducted for specialized sites that experience high levels of use (e.g., national parks or large city parks such as Central Park and Golden Gate Park). However, a few studies do provide insights on visitation to local neighborhood parks and pocket parks (or mini-parks), which provide recreational opportunities more similar to those that would likely be supported by GSI projects.

Research indicates that overall use of park and recreational sites varies significantly depending on sociodemographic characteristics of the local community (including population density/proximity), park size, available facilities, and aesthetics. Parks are generally categorized by size and facilities into different types, including pocket parks or mini-parks, neighborhood parks, community parks, and natural resource areas, such as nature preserves, wetlands, and green belts. Table G-1 provides a brief description of different park types, including typical design standards. Although they may vary a bit, the definitions and standards presented in Table G-1 are relatively well-established and consistent across agencies/municipalities. Within the context of GSI, pocket parks and neighborhood parks are likely most relevant, although wetlands that support recreational activity may be more similar to parks classified as nature preserves.

In 2015, the National Recreation and Parks Association (NRPA) commissioned a national survey to better understand Americans' use and perceptions of local parks, including how frequently they visit parks. Seventy percent of respondents said that they personally used public parks, playgrounds, or open spaces, with 44% using them occasionally and 26% using them frequently. In total, 30% of residents indicated that they did not use local parks at all. In its annual compilation of park metrics for the 100 largest cities in the U.S., The Trust for Public Land reports that approximately 29% of residents within these cities do not live within a 10-minute walk of a local park (The Trust for Public Land 2019). This may be one reason why some individuals report they do not use parks.

Since 2016, NRPA has conducted an annual survey of U.S. residents to better understand their engagement with local parks and recreation facilities. Results of the most recent (2018) survey indicate that Americans visit their local parks and recreation facilities an average of 26.7 times per year (with 10 being the median number of trips). This includes the 11% of respondents who reported that they have not visited a park or recreation facility in over a year and the 1% of respondents who stated they never visit (i.e., the 26.7 estimate is a weighted average). As shown in Figure G-1, the 2018 survey included visits to outdoor park areas (e.g., green spaces, playgrounds, open space areas) as well as recreation facilities (e.g., indoor recreation centers, pools, senior centers). Based on the information provided in Figure G-1, we estimate that up to approximately 60% of the trips taken to local parks may be related to outdoor park areas, although this represents a rough approximation based on the survey data reported and reasonable assumptions.

In addition to park usage data, NRPA also publishes annual information and data on park systems across the country. The *2019 NRPA Agency Performance Review* presents the data and key insights from 1,075 park and recreation agencies throughout the U.S. Findings from NRPA's data collection efforts indicate that the typical park and recreation agency offers one park for every 2,181 residents, with an average of 10.1 acres of parkland per 1,000 residents. Thus, a typical city with a population of 100,000 would have 1,010 acres of parkland. As noted above, NRPA reports that residents visit local parks an average of 26.7 times per year; based on NRPA findings, we estimate that up to approximately 60% of those trips (16 trips per year) are taken to participate in activities similar to the types of recreation that GSI projects might support. Going back to the city of 100,000 people, this would mean typical visitation per acre to local parks (excluding facility visits) would amount to approximately 1,580 visits per year per acre (16 trips per year x 100,000 people / 1,010 acres).

Table G-1. Park Classifications and Associated Standards.

Park Type	Description	Desirable Size (acres)	Acres per 1,000 Residents	Service area (mile radius)
Mini-park or pocket park	Typically ¼ acre or less, located within a residential neighborhood or commercial business district. Usually lack active recreational facilities but may have gardens, benches, gazebos, fountains, or other small gathering facilities. No off-street parking or restrooms.	< 1.5[a]	0.25 to 0.5	1/8 to 1/4
Neighborhood playgrounds	Serve active recreational needs of children; may offer passive recreation opportunities to adults. Typically have one or more playground apparatus, small green space/general purpose fields, and benches. No off-street parking, shelters, or restrooms.	1 - 3	0.5 to 1.5	1/4 to 1/2
Neighborhood parks	Serve active and passive recreation needs; often include playground, shelters, grills, basketball courts, and ball diamonds. Some have off-street parking and restrooms.	2 - 10	1.0 to 2.0	1/2 to 1
Community parks	Serve active and passive recreational needs of several neighborhoods or a medium-sized municipality. In addition to active recreation facilities, often also have wooded areas and walking trails, scenic lookouts, botanical gardens, multiple shelters, grills, and picnic areas. Off-street parking, permanent restroom facilities, shower facilities, and lighting are common.	25+	5 to 8	2 to 5
Nature preserves/Natural resource areas	May be established to conserve forest lands, marshlands, floodplains, prairies, wildlife habitats, and other areas having cultural, scenic, or natural values. Usually include large tracts of land that are undeveloped or have limited development. Improvements may include parking areas, interpretive centers, and restrooms. Recreational uses might include hunting, backpacking, camping, trail use, picnicking, and bird watching. Also includes greenbelts.	*varies*		

a. NRPA states that pocket parks are typically no more than 0.25 acres, and serves 500 to 1000 residents

In the first national-level assessment of neighborhood park visitation, Cohen et al. (2016) conducted observational studies at 174 neighborhood parks in 25 U.S. cities with a population of more than 100,000. Key objectives of the study were to determine how neighborhood park systems support physical activity and to identify factors associated with park use and park activities. Generally consistent with the definition above, this study defined neighborhood parks as being between 2 and 20 acres, having multiple facilities (e.g., playgrounds, picnic tables, green spaces, shade trees, and recreational facilities such as basketball courts), and being designed to serve residents living within a 1-mile radius. The average size of the parks included in the study was 8.8 acres; the average number of people living within a 1-mile radius of each park was 24,200 (which is relatively high). The authors used the observational data they collected to develop models to estimate park use. One of the models developed (the simple model) estimated that on average, one additional acre was associated with a 9% increase in park use, while the addition of 10,000 people living within a one-mile radius of the park was associated with a 13% increase. A 10% increase in the poverty rate for households surrounding the park was associated with a 12% decrease in park use. Overall, the authors estimate that neighborhood park use amounts to 1,533 person-hours per week, on average.

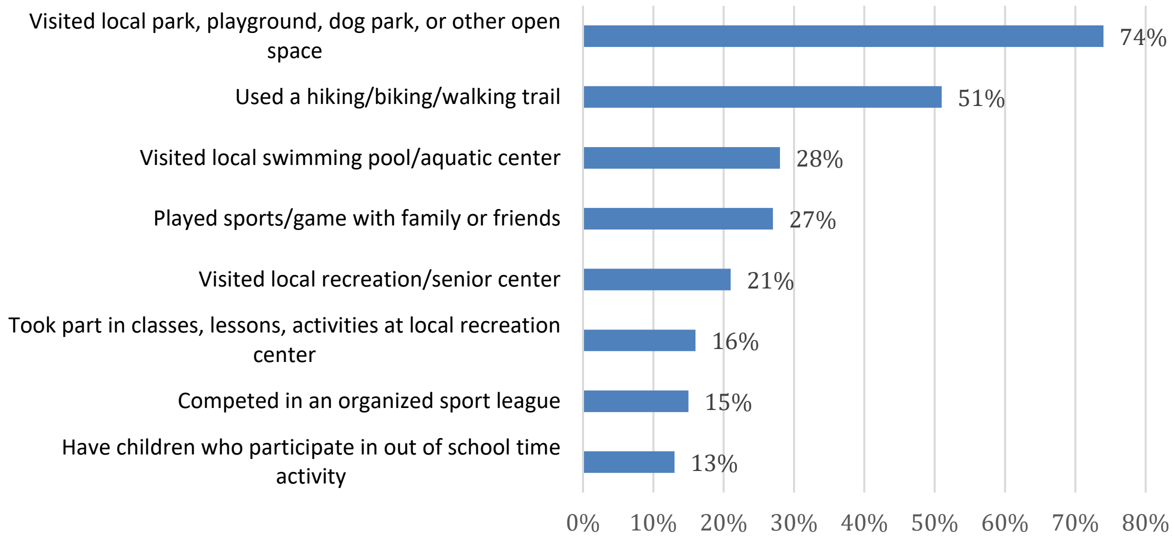

Figure G-1. Survey Responses Related to Favorite Park and Recreation Activities.
Percent of NRPA Survey Respondents Who Personally Have—or Have a Household Member Who Has—Visited a Local Park/Recreation Facility in the Past Year.
Source: NRPA 2018; reprinted with permission from NRPA.

Cohen et al. (2016) did not report the amount of time that users spent at parks. However, assuming an average visit of 1.5 hours, 1,533 person hours per week would translate to 1,022 visits per week, or approximately 500 visits per acre of parkland per month (based on the average parks size of 8.8 acres). Assuming in most places people visit parks 9 out of 12 months per year due to weather, this would equate to approximately 4,500 visits per acre per year to neighborhood parks. This is higher than the estimate calculated above from the NRPA survey data. This may be due in part to the fact that neighborhood parks see a higher level of usage per acre relative to parks that may be much larger but do not offer as many facilities or amenities (e.g., large nature preserves). The cities included in Cohen et al. (2016) are also all relatively large cities with high population densities.

A series of economic studies conducted by The Trust for Public Land over the past decade have estimated park visits in various cities across the country. These studies are based on surveys of residents regarding their visits to city or county parks. Depending on the city, this can include smaller neighborhood parks, recreation centers, large regional parks, and/or natural resource areas with miles of trails. As such, estimates of annual per acre park visitation vary across cities, as it depends on the nature of the parks. For example, one of the most recent economic benefits studies evaluated recreational visits to parks managed by Metroparks Toledo in Lucas County, OH (The Trust for Public Land 2019). The authors estimate that Lucas County residents make close to 4.1 million visits annually to Metroparks, which encompass 12,300 acres across 16 parks. Thus, annual visitation amounts to approximately 333 visits per acre. Based on a population of 431,000, this would mean that Lucas County residents took close to 10 trips to this subset of local parks in 2019, on average.

In The Trust for Public Land's 2008 study of the economic benefits of parks in Philadelphia (The Trust for Public Land 2008), the authors estimate that Philadelphia residents make close to 250 million visits per year to the City's 10,334 acres of parks. This amounts to 24,168 visits per acre per year, or an average of 170 trips per resident (based on the 2009 population for Philadelphia). These estimates include a wide range of activities, including team sports, swimming, visits to public golf courses, arts and crafts fairs, and more. When only general park uses are included, these estimates decrease to 6,350 visits per acre and an average of 45 trips per resident. Note that that visitation estimates from these two studies should not be directly compared for several reasons, including: 1) differences in population per acre of parkland included in the study; 2) the nature and size of the parks included in the study (e.g., the Lucas County study did not include city parks in Toledo, which on its own has 156 parks, while the Philadelphia study included all parks in the city); and 3) the Philadelphia study's total includes activities engaged in, whereas Toledo trips could include multiple activities).

Finally, Cohen et al. (2006) assessed park use for three newly constructed pocket parks in Los Angeles, CA. In addition to observational counts, the authors surveyed households within one-half mile of the three pocket parks before and after park construction, as well as pocket park users. For comparison purposes, they also surveyed residents living within a half mile of other (larger) neighborhood parks and neighborhood park users. At baseline (i.e., prior to construction of the pocket parks), 42% of pocket park neighborhood residents reported having ever visited a park in the Los Angeles area; in the follow-up survey (i.e., after construction) this increased to 58%. After construction of the pocket parks, the percentage of residents within a half mile radius of the parks also reported a 5% decrease in visits to other parks. This suggests that an 11% overall increase in park use in these communities may be attributable to first-time park visitors going to the newly constructed pocket parks. In addition, of those who visited the pocket parks, 92% (on average across the three parks) reported visiting once per week in the follow up survey. Eighty-five percent of neighborhood park users reported visiting once per week.

G.2.3.2 Valuing Recreational Trips

As noted above, recreational experiences associated with GSI are not bought and sold in a market (i.e., there is no fee for participation) and therefore do not have a direct market price. However, economists have developed methods to estimate direct use values for different types of recreational activities. For example:

- Stated preference methods (e.g., contingent valuation, conjoint analysis, or choice experiments) ask individuals how much they are willing to pay to participate in given recreational experience. Stated preference approaches rely on answers to carefully worded survey questions and/or choice experiments that yield WTP estimates.
- Travel cost method (TCM) infers the value of recreation based on the costs and time that people incur during a recreational trip. Travel cost method can underestimate the value of recreational trips because it does not capture the amount that individuals would be willing to pay over and above the amount/time they actually spend (i.e., consumer surplus). In addition, the types of recreational activities that GI projects support are local in nature; individuals typically do not incur significant costs to participate in them.
- In addition, some studies have estimated the avoided healthcare costs associated with recreational activities in parks and urban greenspaces (e.g., The Trust for Public Land park value series, 2007 – 2016); however, these values only apply to individuals who visit parks or use greenspace regularly for physical activity.

An original stated preference or travel cost study typically requires a significant amount of time and financial resources. For this reason, researchers often use the *benefits transfer* approach to estimate non-market values, including direct use values for recreation. Bergstrom and De Civita (1999, p. 79) offer the following definition of benefits transfer:

> *Benefits transfer can be defined practically as the transfer of existing economic values estimated in one context to estimate economic values in a different context …. In the case of natural resource and environmental policies and projects, benefits transfer*

involves transferring value estimates from a "study site" to a "policy site" where sites can vary across geographic space and or time.

Benefits transfer is commonly used in economics, and there is a well-developed literature on how to correctly apply this method (e.g., Rosenberger and Loomis, 2003; U.S. OMB, 2003). As described in more detail below, benefits transfer serves as the basis for the "Unit Day Value" method developed by the Army Corps of Engineers for estimating recreational benefits associated with federal water resource projects. The Unit Day Value method relies on expert or informed opinion and judgment to estimate the average WTP to participate in different types of recreational activities. Specifically, the model assigns points to recreational experiences based on various factors and assigns direct use values based on total points received and the type of recreation activity.

A multitude of studies have estimated direct use values for various recreational activities and locations. Researchers at Oregon State University have compiled data from many of these studies into a comprehensive database of direct use values. The Recreation Use Values Database (RUVD, Rosenberger 2016 update) currently contains 3,192 direct use estimates from 421 valuation studies conducted between 1958 and 2015 in the U.S. and Canada. The estimates are reported in value ($) per person per activity day units for 22 types of activities. With some exceptions, most values included in the RUVD are for more specialized activities (e.g., camping, fishing, motorized boating, biking) and/or locations, and are therefore not necessarily representative of the types of recreation supported by GSI improvements. The RUVD does contain 190 direct use value estimates for "general recreation" activities; these estimates average $61.75 per person per day. Picnicking is also a category included in the database and is also more similar to the type of recreation facilitated by GSI. Across 24 estimates, the average direct use estimate for picnicking is $33.90 per person per day. Only one study in the RUVD includes relevant values for jogging and/or walking (Bergstrom and Cordell 1991); direct use values reported in this national study are $5.32 and $20.28 for jogging and walking, respectively.

The U.S. Army Corps of Engineers updates its Unit Day Values for different types of recreational activities each year. As shown in Table G-2, the direct use values range from $4.14 per person per day or recreational trip for general recreation activities to $49.19 per person for specialized activities, including fishing, hunting, and other unique activities (e.g., backpacking, white water boating).

Table G-2. Army Corps of Engineers Unit Day Values for Recreational Activities, FY 2019.
(2019 USD)

Point values	General recreation values ($)	General fishing and hunting values ($)	Specialized fishing and hunting values ($)	Specialized recreation values other than fishing and hunting ($)
0	4.14	5.95	29.00	16.83
10	4.92	6.73	29.77	17.86
20	5.44	7.25	30.29	19.16
30	6.21	8.03	31.07	20.71
40	7.77	8.80	31.85	22.01
50	8.80	9.58	34.95	24.86
60	9.58	10.62	38.06	27.44
70	10.10	11.13	40.39	33.14
80	11.13	11.91	43.50	38.58
90	11.91	12.17	46.60	44.02
100	12.43	12.43	49.19	49.19

Source: USACOE 2018.

Again, the direct use estimates applied in the Unit Day Value Method depend on the points that individual recreation activities receive (0 – 100). Points are assigned based on five criteria:

- Recreation Experience: the number and type of recreational activities that a site or recreational area supports (0 – 30 points)
- Availability of Opportunity: the availability of similar recreational opportunities located nearby (0 – 18 points)
- Carrying Capacity: the degree to which a site provides adequate services to support recreation (0 - 14 points)
- Accessibility: the degree to which the area is readily accessible (0 – 18 points)
- Environmental Quality: the aesthetic qualities of the area including water and vegetation, air and water quality, scenery, and climate (0 – 20 points)

In its' series of studies on the value of city parks, The Trust for Public Land has used a methodology based on the Unit Day Value method to estimate the recreational benefits associated with park systems. The Trust for Public Land leverages information on private market rates as well as research from the RUVD database to develop estimates for different types of park-based activities (e.g., using playgrounds and picnicking, walking and hiking, and riding a bike), as well as to estimate separate values for children and adults. The Trust for Public Land's economists also calculate individual demand curves and account for the diminishing value that additional visits provide the park user, based on the theory that the first visit to a park in a year is more valuable than subsequent visits. The authors have also incorporated methodologies to account for the over-reporting of park use and individuals who engage in multiple activities on their park visits. Stratus Consulting (2009) used the direct use values that The Trust for Public Land developed for Philadelphia's parks (The Trust for Public Land 2008) to estimate the recreational benefits associated with GSI improvements implemented as part of the City's Green City, Clean Waters Program for reducing combined sewer overflows. Table G-3 shows the direct use values used in the Philadelphia study (updated to 2019 values). Since 2008, The Trust for Public Land has continued to update its' methodology for estimating recreational use values associated with city and county parks across the country.

Table G-3. Direct Use Values for Park-Based Recreation Activities in Philadelphia.
(2019 USD)

Activity	Value per Person (Youth, $)	Value per Person (Adult, $)
Playgrounds or Tot Lots	3.45	3.52
Picnicking or Bench-Sitting	3.06	3.09
Walking on Trails	2.02	1.80
Walking Dog in Park	1.55	1.62
Birdwatching/Nature	2.52	2.39
Fishing	6.09	5.29
Swimming	3.64	3.84
Boating	4.47	5.17
Running on Park Trails	3.98	3.99
Bicycling on Trails	3.62	3.88
Community Gardening	3.91	3.78

Source: The Trust for Public Land 2008.

G.3 Tool Methodology for Quantifying and Monetizing Recreation Benefits

With several potential avenues for creating recreational opportunities through city- or neighborhood-scale GSI installations, the Tool relies on a series of inputs to determine potential recreational benefits.

G.3.1 Characterizing Recreational Sites

First, the Tool asks the user whether the GSI projects they are analyzing will include creation or enhancement of the following types of green space or park areas:

- Small recreation areas or pocket parks
- Stormwater parks
- Wetland areas that support recreation
- General neighborhood greening that supports recreation (e.g., green streets, improvements to pedestrian corridors)

For each type of potential recreation area, the Tool asks the user a series of questions related to the number and size of parks (as relevant), population in local area, number of months per year that residents typically recreate, and other local factors. The Tool provides default values intended to help the user answer each question; however, the user is encouraged to enter information that best reflects local circumstances.

G.3.2 Quantifying Change in Recreational Use

If recreational sites are included in the user's GSI scenario, the tool relies on user input, estimates from the literature, and reasonable assumptions to estimate the level of use that these areas will experience.

First, the Tool estimates usage for small park areas or pocket parks. Using the NRPA design standards for pocket parks, the Tool assumes that these areas average one-quarter acre in size and serve residents within a one-quarter to one-half-mile radius, depending on population density. NRPA recommends that pocket parks should serve 500 to 1,000 residents on average.

Cohen et al. (2006) reports that 22% of residents living within a half mile radius of newly constructed pocket parks in L.A. visited the parks once per week. This is generally consistent with the NRPA (2015) survey, which found that 26% of U.S. residents visit parks, playgrounds, and greenspaces "frequently." The Tool therefore assumes that 22% of nearby residents would use the pocket park once per week. Using data from NRPA (2015), the Tool also assumes that 30% of nearby residents will never use the parks, while the remaining 48% will use them occasionally. For estimation purposes, we assume that occasionally means six times per year, on average. For a population of 1,000 residents, these assumptions would yield a total of 11,460 visits per year, or an average of 11.5 trips per resident per year (on average, including those that never visit). However, these estimates represent usage in areas where parks can be used year-round with no weather constraints. The Tool adjusts these assumptions for areas that experience a significant reduction in usage in the winter months based on user input.

To estimate visitation to stormwater parks or similar recreational sites created by GSI, we rely on the regression model developed by Cohen et al. (2016). Although the nature of the parks included in Cohen et al. (2016) may vary some from the types of recreational sites included in the GSI scenario being analyzed, the model provides a reasonable estimate of average weekly use for parks ranging in size from 2 to 20 acres. Specifically, the Tool starts with an estimate of 1,022 visits per park per week and adjust this number based on inputs from the user related to park size, local poverty rate, and population within a one-mile radius of the park. Similar to the methodology for pocket parks, the Tool adjusts annual park use for areas in which the weather prohibits year-round use. In both cases, the Tool allows users to adjust assumptions regarding visitation in the event that site-specific or local data exists.

To estimate recreational use associated with general neighborhood greening (i.e., non-park improvements), the tool assumes a usage equal to the population density of the area affected by general urban greening and assumes a relatively modest additional number of new recreational trips of four times per year per resident. This is similar to the methodology used by Stratus Consulting (2009) for the TBL study of GSI alternatives in Philadelphia.

G.3.3 Monetizing Additional Recreational Visits

With the exception of wetland-related recreation (see below), to monetize the value of additional recreational trips, we apply the Unit Day Value Method developed by the US ACOE. To estimate direct use values, the Tool walks the user through a similar series of questions for each relevant type of recreation provided (i.e., small pocket parks, stormwater parks, stream-related recreation) and assigns points to the recreational experience based on the answers to the questions. Table G-4 shows the questions asked and points assigned.

To value recreational benefits associated with wetlands, the Tool relies on extensive research that provides a range of values reflecting WTP per acre for various services provided by wetlands, including recreation. These values reflect both use values (WTP by recreators), as well as non-use values (e.g., WTP by members of the public who may not recreate but value the existence or option value that wetlands provide in this context). Based on estimates from the literature, the Tool applies a value of $2,995 to $3,473 per acre of wetland created depending on whether the wetland offers opportunities for recreational fishing. For more background on wetland valuation literature, see Appendix K on ecosystem and biodiversity benefits associated with GSI.

Table G-4. Recreational Value Point Assignment.

Army Corps of Engineers Unit Day Value Method

Category/Questions	Answers	Rating/Available Points
Recreation Experience		0 – 30 pts
Will the project provide capacity for hunting or fishing?	Yes/No	Note, if the project will support hunting, fishing, or specialized activities, the user will need to answer questions related to the percentage of total recreational activities they expect specialized activities to account for.
If yes, does this facility have the capacity for specialized fishing and/or hunting (e.g., big game)? While this answer will likely be no in most cases, some stream restoration activities might support specialized fishing, e.g., fishing for salmon or steelhead.	Yes/No	
Does the facility support other types of specialized recreation? Examples may include white water rafting, community gardening, or other non-general park uses.	Yes/No	
How many general recreation activities of normal quality will be provided by the project? General activities include picnicking, walking, bench-sitting, playground activity, bike riding, and other general activities of normal quality	Low (5) Moderate (15) High (30)	0 - 30 pts
Opportunity availability. What is the availability of similar recreational opportunities located nearby?	None (18) A few (10) Many (5)	0 to 18 points
Carrying Capacity: the degree to which a site provides adequate services to support recreation	Default is 7	0 to 14 points
Accessibility. How accessible is the facility? Accessibility: the degree to which the area is readily accessible	Default is 14	0 to 18 points
Quality. How are the aesthetic qualities of the area including water and vegetation, air and water quality, scenery, and climate? (0 – 20 points)	Low aesthetic quality (2) Average (10) Above average (20)	0 to 20 points

Source: Adapted from USACOE 2018.

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APPENDIX H

Green Jobs

H.1 Introduction

The construction, operations, and maintenance of GSI projects have the potential to create entry-level job opportunities for low income, low-skilled workers (JFF 2017). When paired with workforce development initiatives, GSI programs can provide participants with the technical skills necessary to enter the green workforce, earn a livable wage, and further professional development. In addition, when GSI jobs are targeted to individuals who are currently unemployed or underemployed, this creates a net social welfare gain that should be reflected in benefit-cost analysis.

Economists have developed various approaches for valuing job creation benefits associated with hiring individuals who would otherwise be unemployed. These approaches include the calculation and application of reservation and/or shadow wages (also known as the social opportunity cost of labor), as well as the estimation of avoided social costs that local, state, and federal governments would otherwise incur to support an individual who is not gainfully employed. The Tool incorporates simplified versions of these approaches to assess job creation benefits associated with GSI.

As an important note, the employment effects of GSI (and other policies and programs that create or reduce employment) are often evaluated using economic impact analysis (EIA). EIA focuses on the effects of a project or policy on the amount and type of economic activity in a region, as well as the distribution of that activity. In contrast, benefit cost and triple bottom line (TBL) analyses are used to determine an action's social welfare effects. Benefit-cost and TBL analyses include market and non-market values (consumer surplus) to reflect overall societal well-being, while EIA is restricted to actual cash flows of money (costs and revenues) accrued through market transactions. EIAs trace the flow of spending in an economy to calculate direct, indirect, and induced effects of a policies and programs. Consistent with sound economic methodology for benefit cost analysis, the Tool focuses on direct effects associated with job creation. It does not include or quantify the indirect or induced economic activity that occurs as a result of these direct effects.

The following sections provide an overview of findings from the literature related to the job creation benefits of GSI and the methodologies economists use to value these benefits. We also provide an overview of the assumptions and methodology included in the Tool to quantify and monetize GSI job creation benefits.

H.2 Findings from the Literature

This section provides findings and examples from the literature related to GSI job creation and methods economists have used to incorporate employment effects into benefit cost analysis.

H.2.1 Job Creation Benefits of GSI

Benefit cost analyses of large civil works and infrastructure projects do not always include job creation benefits. This is because: 1) the labor retained in such projects often involves skilled workers who would otherwise be gainfully employed in other ventures (private or public investments), especially when the national or regional economy is running at near full employment; and 2) it is reasoned that if the project was not built, the associated investment would be spent elsewhere in the economy (e.g., on another public project or by households who save money through avoided rate or tax increases). This means that there typically is a transfer of employment across potential activities rather than a real net gain in the number of jobs.

However, there are some exceptions that may apply to jobs associated with GSI construction and maintenance. First, investments in water and other infrastructure are one of the most efficient methods of job creation. According to Green for All (2011), infrastructure investments create 16% more jobs, dollar-for-dollar, than a payroll tax holiday; nearly 40% more jobs than an across-the-board tax cut; and more than five times as many jobs as a temporary business tax cut (Green For All, 2011, based on Moody's Analytics). This suggests that compared to a "no project" alternative, under which households avoid tax or rate increases necessary to support the project, infrastructure investments will result in a net increase in employment.

Second, evidence suggests that compared to gray infrastructure, wide-scale implementation of GSI has the potential to generate greater economic impacts in terms of local employment. Gray civil engineering projects often require specialized skills (e.g., specialized tunneling/boring); firms performing these activities typically have these skill sets with their existing staff or contractor pool. Acquiring additional staff for a new project happens largely by hiring labor from competitors or other markets (Stratus Consulting 2009). In contrast, GSI construction and operations and maintenance (O&M) require fewer highly trained and skilled employees, resulting in a greater number of high-quality entry level opportunities (JFF 2017). If GSI jobs can be targeted to local residents who are unemployed or underemployed, this creates a net gain in local employment and returns money and economic benefits to the local economy. There are also social benefits (e.g., avoided social costs) when jobs can be steered to local citizens who are unemployed or otherwise living in poverty due to a lack of education and training and other social circumstances (Stratus Consulting 2009).

A recent study for D.C. Water (Corona Environmental Consulting 2020) confirmed the potential for greater job creation benefits for GSI projects compared to gray infrastructure alternatives. The authors of this study examined the local economic impacts associated with three alternatives for controlling combined sewer overflows (CSOs) in the District's Rock Creek Watershed:

- Alternative 1 includes gray infrastructure storage capacity of 9.5 million gallons (MG)
- Alternative 2 includes a mix of gray infrastructure and GSI practices. Under this alternative DC Water would install 4 MG of gray infrastructure storage capacity. GSI would manage stormwater runoff from 65 impervious acres; and downspout disconnections would remove approximately 0.1 MG from the combined sewer system. Approximately 70% of the 65 acres managed though GSI would be managed through permeable pavement installations; 30% would be managed through bioretention.
- Alternative 3 is similar to Alternative 2, with that only difference being that 50% of the 65 acres managed though GI would be managed through permeable pavement installations and 50% would be managed through bioretention.

Overall, results indicated that the hybrid infrastructure alternatives (Alternatives 2 and 3) would create a greater economic impact across all economic indicators, including direct employment. As shown in Table H-1, per dollar spent by DC Water, the hybrid green/gray alternatives would result in a 25% to 36% greater local employment impact compared with the gray-only alternative (Alternative 1). This is in part because the GSI components associated with the hybrid alternatives create more jobs that can be filled by local residents.

Additional research supports the potential for GSI-related employment to provide a career pathway for workers with lower levels of training and education. For example, Jobs for the Future (JFF) examined emerging workforce trends associated with increased implementation of GSI in many locations (JFF 2017). This research focused on occupations involved in the direct installation, maintenance, and inspection (IMI) of GSI, with an interest in understanding the potential for GSI to provide employment opportunities for low-income residents and other underserved populations in urban areas. The authors acknowledge that the evolution of the GSI workforce is still in early stages of development and that the ability of GSI projects to spur job creation has not yet reached the level that many advocates had hoped. However, they also note that as the number and scope of GSI projects increase, opportunities for developing distinct GSI jobs will also increase. The authors found that several contractors already specialize in GSI (e.g., installation of pervious pavement or green roofs) and are building niche businesses.

Table H-1. Employment Impacts (Jobs Created) per Million Dollars Spent by DC Water, through 2060.

(2019 USD, includes construction and maintenance)

Impact type	Alternative 1 - Gray	Alternative 2 – Green/Gray Hybrid	Alternative 3 – Green/Gray Hybrid
Total direct employment	1,568	1,542	1,599
Direct local employment (i.e., jobs filled by DC residents)[a]	575	674	729
Direct local employment per $M spent by DC Water[b]	2.7	3.4 (25% > Alt 1)	3.7 (36% > Alt 1)

Source: Adapted from Corona Environmental Consulting 2020.

a. Based on DC Water's green jobs goal for specific sectors/types of jobs

b. To be able to directly compare alternatives, the authors modeled the difference in costs across alternatives as a savings to households under the less expensive alternatives (in this case, the hybrid green and gray infrastructure alternatives are less expensive).

In addition, JFF (2017) reports that one of the defining characteristics of occupations involved in GSI-IMI work is their (typically) low educational requirements. Of the 30 occupation categories the authors identified as being relevant to GSI-IMI work, 28 require high school completion or less, 8 require a high school diploma, and 10 do not require any formal educational credential. Only two—environmental engineering technicians and forest and conservation technicians— require education beyond high school (an associate degree) to compete for an entry-level position. Most of the occupations have no work experience requirement and if workers take part in on-the-job training, it is either short or moderate term. The authors conclude that given the overall entry-level nature of this work, GSI can be an important target for workforce development, especially to increase opportunities for low income, low-skilled workers currently underrepresented in the workforce (JFF 2017).

In a report on the benefits of installing "smart surfaces" (e.g., green roofs, permeable pavement, cool roofs, solar roofs) in Washington DC, Kats and Glassbrook (2013) found that wide scale adoption of these practices could help provide unemployed individuals with relatively well-paid work. The authors also found that expanding smart surface deployment in the District would create job opportunities across a wide range of skill levels. Based on data from the DC Office of Planning, the report states that 37% of green job opportunities in the District would likely require little to no preparation, while 42% would require a moderate level, typically an associate degree or specialized training. The remaining jobs require a bachelor's degree or higher. The authors conclude that the relatively low barriers to entry of many "green jobs" are especially important to city residents having trouble finding work.

A study published by Green for All and American Rivers (2013) found that O&M of GSI projects represents a significant opportunity to create entry-level jobs in the green sector for individuals from disadvantaged communities. Specifically, the authors state that O&M jobs are accessible, provide a decent wage, and can offer career advancement opportunities, especially in the public sector. However, their findings also reveal the potential for this work to take place in "low-road work environments," represented by low wages and poor benefits. The report profiles workforce development programs that have successfully utilized GSI O&M work to provide employment to disadvantaged communities, while training them for higher skilled, higher-earning trades. The authors make three recommendations for stabilizing GSI workforce development programs and delivering related GSI employment benefits:

- Generate opportunities for local GSI workers and businesses by inserting community benefits strategies into GSI installation and maintenance contracts (e.g., requiring that a certain percentage of work be performed by targeted workers).
- Public agencies that outsource O&M responsibilities should prioritize contracting with local workforce development programs.
- Require the hiring of trained and certified contractors to install and maintain publicly funded GSI on private property.

The report also outlines a series of steps and areas of further research to strengthen workforce development programs and to solidify career pathways that lead to high quality work, high quality standards and good jobs. It is important to note that since this report was published, several communities, and local non-profit and national organizations (e.g., the Water Environment Federation) have taken steps towards meeting these goals and further developing the GSI workforce. These programs are key to realizing the potential social benefits that GSI jobs can provide for local communities.

In 2016, the Sustainable Business Network (SBN) of Greater Philadelphia GSI Partners published a report documenting the economic impacts and benefits associated with the first five years of Philadelphia Water's Green City Clean Waters (GCCW) Program (SBN 2016). GCCW is Philadelphia's large-scale CSO control plan that focuses on GSI implementation. SBN reports that the traditional gray infrastructure alternative to meeting Philadelphia's CSO goals would likely include a sewage tunnel under the City costing billions of dollars. The authors maintain that this type of large infrastructure project would likely go to a large, international construction firm. Thus, the employment impact would not necessarily be as localized and the gains from the contract would also circulate largely outside the city. In contrast, GSI projects associated with GCCW have created more, smaller opportunities that have provided contract and employment opportunities for local firms and residents. Additionally, GCCW creates opportunities for intersection with many of the City's current programs focused on youth violence reduction, truancy prevention, and ex-offender re-entry. GCCW is supported by a growing network of advocacy groups, technical assistance providers, and other non-profits promoting GSI education and training (SBN 2016).

H.2.2 GSI Job Creation Estimates

A few studies have quantified the direct construction and maintenance jobs created by GSI programs or projects. These studies mostly rely on ex ante and/or construction bid estimates, rather than on ex post data collection. For example, for the study on the economic impacts of alternative CSO control strategies in Washington DC, Corona Environmental Consulting (2020) used labor hour estimates from construction bid sheets, as well as data from the economic impact model IMPLAN to estimate the direct employment generated by construction and maintenance of permeable pavement and bioretention projects. Kats and Glassbrook (2013) used employment multipliers from the Bureau of Economic Analysis to estimate direct jobs associated with bioretention and rainwater harvesting systems in Washington DC. Table H-2 provides a summary of studies that have published (or for which we were able to determine) direct employment estimates per million dollars spent on GSI construction and/or maintenance. All estimates have been updated to reflect jobs created per $1 million in 2019 USD.

Other studies have reported jobs created based on area of GSI practice installation. For example, based on personal communications with a construction company representative, Kats and Glassbrook (2013) report that green roofs can be installed at a rate of approximately 54 square feet per hour. Assuming one job-year is equivalent to 2,000 hours of work, this translates to 8.8 job-years per million square feet of green roof installed. This number is for extensive green roofs and includes planning, travel, and on-site construction. Based on published data, the authors also estimate an annual maintenance requirement of 4 person hours per 1,000 square feet of green roof per year, assuming three annual site visits. This drops to 2.7 yearly person hours after the establishment period, when only two annual site visits are needed. However, green roofs usually last at least twice as long as conventional roofs. This limits the *net* job creation of green roofs since re-roofing of a conventional roof is labor-intensive.

Table H-2. Summary of GSI Job Creation Estimates per $1 Million in Spending.
(2019 USD)

Capital construction (jobs per $1M)	O&M (jobs per $1M)	Practice type	Location	Source
4.52	11.0	Permeable pavement[a]	Washington DC	Corona Environmental Consulting 2020
5.92	17.8	Bioretention	Washington DC	Corona Environmental Consulting 2020
4.59	4.02	General mix of GI practices	Philadelphia	Stratus Consulting 2009
7.36[b]		Bioretention and rainwater harvesting	Washington DC	Kats and Glassbrook 2013
16.5		Green roofs	Washington D.C.	Louis Berger Group et al. 2008
	9.27	Bioretention ponds	Northeast Ohio	Piazza and Clouse 2013
17.44		Wetlands restoration / construction	Southern Illinois, Cache River Watershed	Caudill 2008 (as cited by Hewes et al. 2008)

a. Estimates are higher than reported in Table H-1 because Table H-1 reflects jobs created by alternative rather than for specific GSI practices. The alternatives in Table H-1 all include large investments in gray infrastructure.
b. The authors estimate that half of these jobs would be filled by local DC residents

The Water Research Foundation's (WRF's) BMP and LID Whole Life Cost Models (WRF 2009) document a range of labor requirements associated with the maintenance of eight different SCMs. As shown in Table H-3, the project team pulled labor requirements (hours per year) from the WRF model spreadsheets. Labor hours are determined based on a specific practice area, drainage area, or storage capacity, depending on the SCM. The models do not report labor requirements associated with the installation of different GSI practices.

Table H-3. O&M Job Estimates by Stormwater Control Measure, WERF Whole Life Cost Model.

		Hours per year			Equivalent FTEs per year		
Practice type	**Size**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
Green roof	10,000 ft^2	35	120	472	0.017	0.060	0.236
Rain gardens	200 ft^2	1	5	57	0.001	0.002	0.029
Permeable pavement	21,780 ft^2	2	4	40	0.001	0.002	0.020
Retention ponds	90,750 ft^3 (capacity)	5	12	736	0.002	0.006	0.368
Swales	34,848 ft^2 (drainage area)	7	17	116	0.003	0.008	0.058
Bioretention (curb contained)	34,848 ft^2 (drainage area)	8	14	90	0.004	0.007	0.045
Cisterns	842 ft^3	20	31	211	0.010	0.016	0.106
Extended detention	18,150 ft^3 (capacity)	5	13	463	0.003	0.006	0.232

Source: Data from WERF 2009.

Houle et al. (2013) studied maintenance demands for seven different types of SCMs for the first two to four years of operations. The systems were located at a field facility designed to normalize watershed characteristics including pollutant loading, sizing, and rainfall. System maintenance demand, including materials, labor, activities, maintenance type, and complexity, were tracked for each system. Table H-4 presents selected results from the study, focusing on personnel requirements per hectare of impervious cover treated. The authors note these results document the most expensive period of maintenance that might be anticipated (i.e., the start-up years). Barring unexpected maintenance issues or severe weather events that could occur beyond this study's time frame, the maintenance activities, approaches, and expenditures examined in this study generally became less intensive and diminished over time as maintenance familiarity increased. As an example, maintenance with respect to vegetated systems was found to require more attention during the first months and years of vegetation establishment.

Table H-4. Maintenance Labor Demands by Stormwater Control Measure, per Hectare of Impervious Cover Treated per Year.

Stormwater control measure	Personnel hours	FTEs
Vegetated swale	23.5	0.0118
Wet pond	69.2	0.0346
Dry pond	59.3	0.0297
Sand filter	70.4	0.0352
Gravel wetland	53.6	0.0268
Bioretention	51.1	0.0256
Porous asphalt	14.8	0.0074

Source: Houle et al. 2013.

In addition to Houle et al. (2013), which is based on field experiments, only one other study that we found examined the employment generated by GSI construction and maintenance ex post. As described above, this study (SBN 2106) examined the economic impacts (including job creation) associated with the first five years of the Philadelphia Water Department's GCCW Program. Results of the study indicate that GCCW has encouraged the development of a local industry cluster of GSI firms that provide best-in-class products, services, solutions, and developments (SBN 2016).

SBN's GSI Partners is working to grow the local GSI industry and advance innovation by ensuring processes and incentives encourage GSI and that public and private investment benefits local firms. Members include locally based architecture, engineering, and landscape architecture firms; landscape design, build, maintenance firms; and material suppliers whose services and products pertain to GSI. GSI Partners is growing in membership, and the partner firms are growing as well. SBN (2016) reports that partner firm revenues totaled more than $146.8 million 2014, an increase of 14% from 2013. This is one indication of the rapid growth in this sector, largely attributable to GCCW.

SBN and its consultant used IMPLAN to estimate the economic impact of partner firms' GSI-related activities within the City of Philadelphia. The results indicate that operations associated with just the Philadelphia-based GSI Partners (n=31) on GSI projects in the City of Philadelphia account for $35 million in total annual revenues. This in turn generates an annual economic impact of $57 million within the City of Philadelphia alone (in terms of direct, indirect, and induced economic output) and supports 430 direct, indirect, and induced jobs annually. This amounts to approximately 7.5 jobs created per $1 million in GSI-related economic output; however, these results reflect economic impacts rather than social benefits. The report did not report direct employment generated by GSI opportunities.

H.2.3 Monetary Benefit Value of GSI Job Creation

Benefit cost analysis does not typically include the employment effects associated with a policy or program; some economists posit that this is because traditional benefit cost analysis adopts the simplifying assumption that labor markets "clear" (Masur and Posner 2012), meaning that the demand for labor is equal to supply and that there is no involuntary unemployment or other market distortions. When labor markets clear, the job creation benefits of a policy or program represent a transfer of benefits rather than a net gain in jobs.

An obvious problem with this assumption is that there is rarely no involuntary unemployment in an economy (particularly in urban areas where a GSI program has the potential to result in substantial job creation benefits). As such, economists have developed various approaches and assumptions for incorporating employment effects into benefit cost analysis, with a focus on benefits gained from employing individuals who are not currently employed (or are underemployed). As described by Bartik (2012), the "textbook approach" to including jobs in benefit-cost analysis assumes that the benefit of reduced unemployment is equal to the market wage associated with the new job minus the unemployed persons reservation wages ($w - r_w$), where:

- w is equal to the market wage for the newly created job
- r_w is equal to the unemployed individual's reservation wage. In labor economics, the reservation wage is the lowest wage rate at which a worker would be willing to accept a specific job.

To obtain an aggregate benefit, the analyst can multiply this difference by the number of unemployed individuals expected to find work through the program being analyzed.

As described in Bartik (2012), the reservation wage of the newly employed depends upon their location on the supply curve. If the newly employed are randomly chosen from the available labor supply (i.e., the pool of unemployed individuals), their reservation wage will be the average reservation wage of the available labor supply. With some assumptions about the labor supply curve, the average reservation wage of available labor supply can be measured. For example, if the labor supply curve is linear and passes through both 1) the current market wage and labor supply and 2) a wage and labor supply of zero (i.e., the origin), the reservation wage will be one-half the market wage, regardless of unemployment (see Figure H-1). Others have reported reservation wages based on varying labor supply curves; Bartik (2012) reports that based on Greenberg (1997), average reservation wages range from 0% to 88% of market wages.

In some cases, jobs may go to labor suppliers with lower reservation wages. If jobs are perfectly assigned to those with the lowest reservation wages, the reservation wages of the newly employed can be estimated, again, if we know the shape of labor supply curve. Suppose the labor supply curve for workers with the lowest reservation wages is linear and passes through zero wages and zero labor supply. In this case, if the involuntary unemployment rate is x%, the reservation wage of the newly employed will be x% below the market wage. If labor supply is less elastic (Figure H-1), which is often the case in relatively lower-skilled jobs because a pool of labor is available to be employed at a fairly constant market wage, reservation wages will vary more with unemployment. In this case, the log of the change in wages ($w - r_w$) is equal to the percentage reduction in labor supply due to involuntary unemployment divided by the labor supply elasticity (with respect to wages). The percentage reduction in labor supply due to involuntary unemployment equals:

-1 * (current unemployment rate - the full unemployment rate) *
(1 + the elasticity of labor force participation with respect to unemployment).

Based on estimates from the literature, Bartik (2012) assumes the following:

- Unemployment in excess of 3% is involuntary unemployment

- The elasticity of labor force participation with respect to the unemployment rate is 0.5
- The elasticity of labor supply with respect to wages is 0.15

Thus, the change in wages of the marginal worker due to high unemployment ln(wages) can be represented as follows:

$$((-1) * (\text{unemployment rate} - 0.03) * (1+0.5)) / 0.15$$

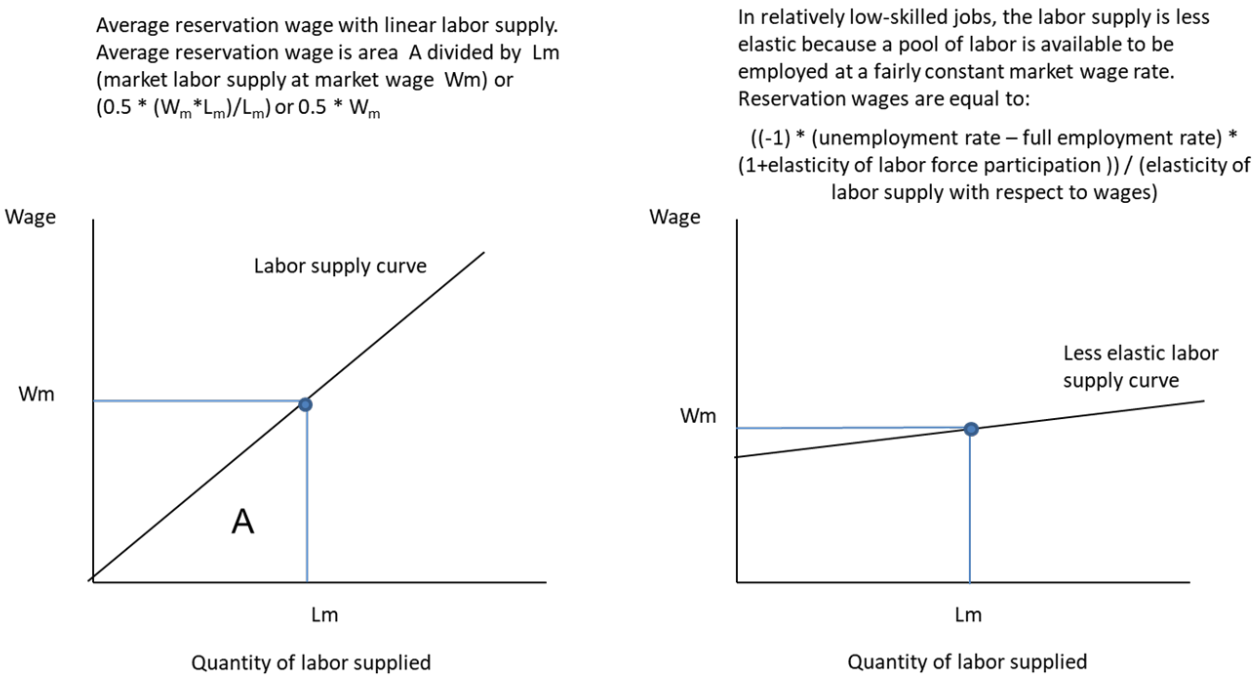

Figure H-1. Reservation Wages and Labor Supply Curves.
Source: Adapted from Bartik 2012.

Raising the resulting number e to that power yields the ratio of the reservation wage of the marginal worker to the market wage. Thus, at an unemployment rate of 3.6% (2019 U.S. average), the reservation wage of the newly employed is 4.2% below the market wage. When unemployment is 9.6% (as it was in 2010), the reservation wage of the newly employed is 48% below the market wage.

In addition to outlining the “textbook approach” for incorporating job creation benefits into benefit cost analysis, Bartik (2012) also provides a review of its limitations (see Figure H-2).

Autocase, a proprietary tool designed to quantify and monetize the benefits of GSI, applies this same general concept, with somewhat different terminology. Specifically, Autocase calculates the social opportunity cost of labor (i.e., the cost of labor in its next best use, also referred to as the shadow wage) and subtracts it from the total wage bill for the project (Autocase 2020). Social opportunity is calculated as follows (from Shaffer 2010):

$$SOCL = p_u * v_u + (1 - p_u) * w, \text{ where:}$$

- SOCL is the social opportunity cost of labor
- p_u is the probability of hiring people who would otherwise be unemployed
- v_u is the value of what the unemployed persons would otherwise be doing (the minimum they

would have to be paid to willingly work at the new job). *Note: this is the same as the reservation wage as defined above.* Autocase applies a default value for v_u equal to 70% of the market wage rate.
- w is the wages that are paid in the new or comparable existing job

The net employment or shadow wage benefit is therefore equal to:

$$(w – SOCL), \text{ which is equal to: } p_u * (w - vu).$$

Figure H-2. Limitations of Traditional "Textbook" Approach for Incorporating Employment Impacts into Benefit Cost Analysis.

Source: Data from Bartik 2012.

- The textbook approach does not include wage gains from occupational upgrading. New jobs create a chain of job opportunities. Ultimately, the chain is broken by the hiring of someone that was not employed in the local labor market. Before that happens, there are wage gains. Based on Persky et al. (2004), the average new job results in 2.5 job vacancies: 1 person moving to employment and 1.5 people moving to a better job. Estimates from the literature indicate that total wage upgrades are typically equal to 15% to 24% of the wages of the new job.
- The individual gain for an unemployed worker who is hired, measured by her actual wage minus her reservation wage, does not reflect overall efficiency gains from that hiring. The unemployed worker's reservation wage reflects her probability of being hired in the future for various jobs and wages (Mortensen 1986, Shimer & Werning 2007). The acceptance of this job offer means that those future job prospects are more available to other workers. This greater availability benefits these other workers. Focusing only on the initial gain for the newly employed understates the market-wide worker benefits.
- The textbook approach does not consider whether occupational upgrading is offset by losses to employers. Assume the worker's productivity at their previous occupation was typical of that occupation. If the worker's productivity at the new occupation is below standard, employers lose. If unemployment is high, employers have a more skilled labor pool to choose from and therefore can likely avoid productivity losses. If unemployment is low, an increase in labor demand may lead to workers being promoted further beyond their previous job experience.

As stated by Autocase (2020), the net benefit associated with an increase in employment generated by a project or policy is based on the assumption that an increase in employment may lead to hiring more people from a pool of unemployed individuals; this creates value because the wages paid in the new jobs (w) is greater than what they would otherwise be doing (vu).

Based on its 2015 documentation (Parker and Meyers 2015), Autocase assumes a value for v_u equal to 70% of w. Thus, the net employment benefit equation can be rearranged as follows:

$$w – SOCL = pu * (w - vu) = pu * (w - 70\% * w) = pu * 30\% * w$$

The Autocase methodology is essentially the same as the calculation detailed above from Bartik (2012), which describes the benefit of reduced unemployment as being equal to the market wage associated with the new job minus the unemployed persons reservation wage (in this case, v_u). Autocase documentation notes that the tool calculates shadow wage benefits from both the construction and operations stages and compares them against the shadow wage benefits from the Reference Case (the status quo or "do nothing" scenario). These values are used to determine the project's net shadow wage benefit.

Another approach that has been utilized by at least two studies that evaluated the benefits of GSI (Stratus Consulting 2009; Kats and Glassbrook 2013) is to value job creation benefits based on the (poverty- and unemployment- related) social costs that the new GSI jobs help to avoid. The rationale behind this methodology is based on the expectation that some portion of new GSI jobs will provide opportunities for unemployed (or under employed) low-skilled workers, helping to create a path out of poverty which would not otherwise exist. This compares to a traditional gray infrastructure approach, which as described above, is much less likely to create jobs that would be filled by unskilled workers who are currently not in the workforce.

As detailed in a study on the triple bottom line (TBL) benefits of GSI-based CSO control strategies for the City of Philadelphia (Stratus Consulting 2009), society spends large amounts every year in its efforts to cope with the effects of poverty. This includes expenditures by local, state, and federal governments related to social services and welfare payments, public housing, education, and crime, as well as costs to individuals in terms of foregone earnings. Stratus Consulting's review of available studies yielded an estimated annual cost of poverty in Philadelphia of between $15,000 to $57,000 (2009 USD) per unemployed individual. One reason for this wide range is that the source studies included (or excluded) different cost categories. For example, several of the Philadelphia-specific studies did not include federal costs associated with poverty.

For the Philadelphia study, Stratus Consulting applied a conservative estimate of $10,000 per unemployed person per year in terms of reduced social costs of coping with poverty. The benefits of GSI-related jobs were estimated by multiplying the $10,000 in avoided costs by the number of newly created positions that would be filled by previously unemployed workers. It was assumed that one-quarter of jobs created would be supervisory positions and therefore less likely to result in the hiring of unskilled and otherwise unemployed people.

Kats and Glassbrook (2013) followed a similar approach, relying on estimates of foregone taxes and avoided welfare costs to estimate the benefit of GSI-related job creation associated with citywide installation of "smart surfaces" in Washington DC. Specifically, the authors developed an average estimate for avoided social costs per unemployed individual based on the following estimates for two age groups:

- An average unemployed 24- to 35-year-old in the District of Columbia costs the combined federal and state governments $15,093. This includes $2,949 in foregone state income tax, $3,221 in foregone Federal Insurance Contributions Act (FICA) taxes, $8,530 in foregone federal taxes, and $293 in welfare payments.
- An average unemployed 18- to 24-year-old in DC costs the government $5,849, which includes $2,655 in foregone federal income tax, $2,012 in foregone FICA taxes, $1,138 in foregone state income taxes, and $44 in welfare payments.

Kats and Glassbrook (2013) assumed that all jobs created through investments in smart surfaces (relative to conventional surfaces) are net jobs, meaning that they go to individuals who would not otherwise be in the workforce, providing a net gain in employment to the economy. This is because infrastructure investment dollars are mainly spent in the construction and landscaping industries, areas of the economy with high excess capacity. The authors further assumed that 50% of jobs created would be filled by DC residents. They estimated total job creation benefits by multiplying the number of new jobs created for local residents by the avoided social costs per unemployed individual (as described above).

The authors state that this approach underestimates total benefits for two reasons. First, the estimates ignore the significant individual and social costs and benefits that go beyond direct government expenditures/foregone revenues. The authors cite several studies demonstrate additional costs of unemployment, for example:

- According to Belfield et al. (2012), each American age 16 to 24 who is not in school or working costs taxpayers $13,900 annually in direct costs that involve lost tax payments, public criminal justice system costs, public health expenditures, welfare, and avoided education spending.
- Using social security data for high-seniority males in Pennsylvania, Sullivan and von Wachter (2009) find that even 20 years after experiencing job loss, mortality is 10-15 years higher for those who lost their jobs, primarily due to reduced ability to invest in good health care and a healthy lifestyle.
- Blanchflower and Oswald (2004), found that to 'compensate' men exactly for lost happiness due to one year of unemployment would take a rise in income approximately $60,000 per year.

Second, the authors note that their estimates are based on an average unemployed individual, whereas green jobs are usually targeted toward hard-to-employ individuals who typically contribute different costs and revenues to the government. For example, green jobs training programs in Washington DC and other cities often recruit low-income, chronically unemployed, and hard-to-employ individuals. As an example, the United Planning Organization in DC only accepts students into its Building Careers Academy who make up to 125% of the federal poverty line. Several students in their programs have experienced homelessness or are currently homeless (Kats and Glassbrook 2013).

H.3 Tool Methodology for Quantifying and Monetizing Green Job Benefits

The Tool employs two approaches for calculating job creation benefits: the representative wage approach (similar to the shadow wage approach employed by Autocase) and the avoided social cost approach.

Under both approaches, the first step to quantifying the employment effects associated with a GSI program or project is to estimate the construction and O&M jobs that will created by the GSI scenario. Ideally, this information would be known by the user and input into the Tool using local data or knowledge. However, the Tool also includes default values:

- For construction jobs, the Tool assumes a default value of 5.5 jobs per $1 million of construction activity across all GSI types. This estimate reflects an approximate average from studies that produced low- to mid-range estimates; it excludes the Louis Berger Group et al. (2008) estimate for green roofs and the Caudill (2008) estimate for wetlands, which were both around 17 jobs per $1 million. In addition, the Tool assumes that Construction spending amounts to 77% of total costs (this assumes a 30% mark up for planning, design, and engineering – i.e., construction costs (percentage-wise) are equal to 100%/(1 + 30%).
- For O&M jobs, the Tool includes default values based on data from the WRF Whole Life Cycle Cost Tool (2009). These estimates are presented in Table H-3 above; the Tool incorporates the mid-range estimates as defaults.
- For maintenance jobs related to street trees, the Tool draws on a study by Davey Tree (2019), conducted for the City of Portland to estimate the maintenance requirements associated with the City's 218,602 street trees. The study does not directly report maintenance jobs per tree or per million dollars; however, the project team reviewed costs and information provided in the report (total maintenance costs, hourly rates, etc.) and applied reasonable assumptions (e.g., percentage of maintenance costs that labor accounts for) to develop a ballpark estimate of 0.00014 FTEs per tree

per year.

The next step is to determine the percent of jobs that will be filled by unemployed individuals. This percentage can be input into the Tool by the user; the Tool assumes a default value of 30%.

For the reservation wage approach, the Tool assumes a market wage of $20 per hour for construction and maintenance workers ($40,000 per year) and a reservation wage that amounts to 55% of the market wage. The 55% assumption is based on the average amount that individuals typically receive in unemployment insurance. This is often used as a starting point for reservation wages in labor economics models. These inputs are used to calculate total job creation benefits.

For the avoided social cost method, the Tool applies a value of $11,900 per unemployed worker (updated from the Stratus Consulting 2009 estimate based on the consumer price index). The net present value calculation for total benefits presents the mid-point of this range, although the user can also select which method they would like to employ.

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APPENDIX I

Water Quality

I.1 Introduction

Stormwater runoff from developed areas delivers pollutants— including pathogens, nutrients, sediment, and heavy metals—to nearby streams, lakes, and beaches. High stormwater flows can also result in streambank erosion, and in cities with combined sewers, can cause overflows that discharge untreated sewage into local waterways. Green stormwater infrastructure (GSI) projects that retain rainfall from small storms, or that treat stormwater runoff prior to discharge, reduce the amount of untreated stormwater runoff entering local water systems. This in turn can result in substantial water quality and related aquatic habitat improvements (U.S. EPA, n.d.). In addition, some GSI projects, including stream restoration and wetlands, can result in physical improvements to rivers and streams that create additional water quality and habitat benefits.

Individuals value clean water (and water quality improvements) for several reasons, including for recreation, economic development, public health, water supply reliability, and other ecosystem services. Because clean water is generally not traded in a market, it can be difficult to quantify the value associated with it. However, economists have developed non-market valuation techniques to monetize the value that individuals place on clean water. These methods yield estimates of household willingness-to-pay (WTP), which serve as a measure of the total economic value associated with clean water, water quality improvements, and the ecosystem services they support.

To estimate the value of water quality improvements associated with GSI investments, the GSI TBL Benefit Cost Framework and Tool (Tool) relies on existing research that synthesizes findings from multiple nonmarket valuation studies that estimate WTP for water quality improvements across a range of locations and water resource types. Specifically, as described in more detail below, the Tool incorporates a WTP function from a meta-analysis of water quality-related stated preference studies. The WTP function allows users to estimate WTP for water quality improvements based on site-specific characteristics, such as household median income, baseline water quality, recreational use of affected water bodies, and more.

As an important note, it is not within the scope of this research to develop estimates of the physical unit improvements in water quality associated with GSI scenarios (e.g., percent pollution load reduction, reduction in combined sewer overflows, CSOs). While the water quality benefits of GSI have been well documented, quantifying water quality improvements typically requires modeling of site-specific circumstances. The methodology described in this appendix assumes that the user can provide a general estimate of the expected changes in water quality based on a 10-point water quality scale.

The following sections provide an overview of findings from the literature related to the water quality benefits of GSI, the methodologies economists use to value these benefits, and findings from multiple studies that have estimated WTP for water quality improvements. We also describe the assumptions and methodology included in the Tool to monetize the water quality benefits associated with GSI.

I.2 Findings from the Literature

I.2.1 GSI Effectiveness in Improving Water Quality

It is important to understand the potential for GSI to substantially improve water quality and aquatic habitat in order to quantify the economic value of these benefits. U.S. EPA (n.d.) describes several sources that have documented the performance and effectiveness of GSI in improving water quality through reductions in stormwater runoff, peak flow, and pollutant load concentrations (Figure I-1).

Figure I-1. EPA Summary of Sources Documenting the Effectiveness of GSI in Improving Water Quality.
Source: U.S. EPA (n.d.)

International Stormwater Best Management Practices (BMP) Database This database summarizes findings of more than 400 BMP studies, including for several different types of GI BMPs. Users can perform custom queries or download technical papers that summarize performance results (Pitt and Maestre 2015).

This technical brief by the Center for Watershed Protection summarizes the results of more than 150 performance studies. It includes statistical and graphical data on removal rates for several types of GI BMPs.

Runoff Reduction Method Technical Memo - BMP Research Summary Tables. This technical memo by the Center for Watershed Protection presents the results of more than 100 papers in tabular form. Water quality and quantity data are presented for GI and conventional controls.

Green Infrastructure for Stormwater Control: Gauging Its Effectiveness with Community Partners. This report summarizes results to date from research conducted by the U.S. EPA's Office of Research and Development (ORD) on the performance of several GI practices. Scientists with ORD's National Exposure Research Laboratory/Water Supply and Water Resources Division worked with communities in eight EPA regions to evaluate water quality changes, hydrologic response, and soil infiltration.

Illinois Green Infrastructure Study. This report summarizes pollutant removal and volume reduction results for GI projects based on of more than 50 peer-reviewed journal articles. It includes reductions in total nitrogen, total suspended solids, runoff volume, and peak flow.

University of New Hampshire Stormwater Center (UNHSC): 2009 Biannual Report. UNHSC operates a field research facility that hosts three classes of stormwater treatment systems: conventional systems, LID systems, and manufactured devices. This report summarizes the results of 4 years of monitoring at the research facility. It provides performance summaries for 17 stormwater treatment practices, as well as detailed cost and performance data for nine stormwater treatment practices.

I.2.2 Methods for Valuing Water Quality Improvements

GSI programs yield different types and levels of water quality-related benefits depending on the scale and nature of projects implemented and other local conditions. For example, in some areas, water quality improvements associated with GSI can improve or create new recreational opportunities by reducing local beach closures; increasing the number of swimmable, fishable, and/or boatable recreation sites; and/or otherwise enhancing the quality of existing sites. Residents who participate in water-based recreation activities value these improvements for obvious reasons. The values individuals derive from local water quality improvements that enhance recreational access or experiences are referred to as "use values."

Water resources provide value beyond the ability to support specific human uses. For example, many individuals who do not participate in water-based recreation activities (or who otherwise do not directly use affected local water resources) are often willing-to-pay for local water quality improvements. These "non-use" values may stem from an inherent value for clean water and the ecosystems it supports. In environmental economics, nonuse values are generally categorized as existence or bequest values (King and Mazzotta, 2005). Existence value is the benefit generated by knowing that a resource exists even if no use of the resource is anticipated. Bequest value reflects the value individuals gain from the preservation of the resource for use by their heirs. Option value is a third type of nonuse value; option value reflects the value individuals place on maintaining an asset or resource even if there is little or no likelihood that they will ever use it. Option value can reflect uncertainty about future supply (the continued existence of the asset) and/or future demand (the possibility that it may someday be used).

Because clean water is generally not directly traded in a market, it can be difficult to quantify the value associated with it. Economists have developed several methods to monetize the value that individuals place on clean water and other non-market goods and services, including both use and nonuse values. These methods yield estimates of WTP for specific improvements in (or avoided degradation of) water quality based on characteristics of the water resource, the nature of the improvements, and other local factors. For example:

- Stated preference methods (e.g., contingent valuation, choice experiments) ask individuals how much they are willing to pay to for a given change in water quality or to avoid water quality degradation. Stated preference approaches rely on answers to carefully worded survey questions and/or choice experiments that yield WTP estimates. Stated preference methods can capture both use and non-use values.
- Hedonic methods use statistical analysis to isolate the effect of local water quality on a property's market value by controlling for all other factors. For example, a house on a lake or river is usually more expensive than a similar one not on an aquatic site. Likewise, a house on a very clean lake or river is usually more expensive than one on a lake or river that has poor water quality. The differences in housing price reflect the amount that individuals are willing to pay for clean water. Hedonic analysis is referred to as a revealed preference method because it infers economic values based on an individual's "revealed" behavior.
- Travel cost method (TCM) infers the value of recreation based on the costs and time that people incur during a recreational trip. TCM can underestimate the value of recreational trips because it does not capture the amount that individuals would be willing to pay over and above the amount/time they actually spend (i.e., consumer surplus). It also does not capture non-use values. TCM is a revealed preference method; it infers economic values based on revealed behaviour associated with recreational visits.

An original stated preference or revealed preference study typically requires a significant amount of time and financial resources to conduct. For this reason, researchers often use the *benefits transfer* approach to estimate non-market values. Bergstrom and De Civita (1999, p. 79) offer the following definition of benefits transfer:

> *Benefits transfer can be defined practically as the transfer of existing economic values estimated in one context to estimate economic values in a different context …. In the case of natural resource and environmental policies and projects, benefits transfer involves transferring value estimates from a "study site" to a "policy site" where sites can vary across geographic space and or time.*

Benefits transfer is commonly used in economics, and there is a well-developed literature on how to correctly apply this method (e.g., Rosenberger and Loomis, 2003; U.S. OMB, 2003, U.S. EPA 2010). There are several different types of benefits transfer, ranging from a simple *unit value transfer*, where a point estimate for a unit change in value from one study is directly applied to a policy case, to a *meta-analysis,* which uses results from multiple valuation studies to develop a transfer function that allows users to estimate values for a policy case based on various influencing variables (U.S. EPA 2010). As described in more detail below, the Tool relies on a meta-analysis to estimate household WTP to pay for water quality improvements associated with a user's GSI scenario.

I.2.3 Willingness-to-Pay for Water Quality Improvements

Multiple studies have estimated household WTP for water quality improvements across a range of water resource types and locations, and for different levels of water quality improvements. Several researchers have synthesized these studies into meta-analyses that yield benefit transfer functions for estimating the economic value of water quality improvements (e.g., Johnston et al. 2005, Van Houtven et al. 2007, Johnston and Thomassin 2010, Ge et al. 2013). For this review, we focus primarily on two of these studies: Van Houtven et al. and Ge et al. 2013. [23]

Van Houtven et al. (2007) incorporated 21 stated preference studies into their meta-analysis and associated benefits transfer function. The incorporated studies yielded 131 annual WTP estimates across various locations, sites, and stated changes in water quality. The authors limited the studies included in the analysis to studies that were conducted in the United States and that describe water quality (and related improvements) in terms that could be converted to a common 10-point scale (e.g., using Vaughn's water quality ladder, 1986). Across the 21 studies and 131 estimates, annual WTP averaged $120 (2018 USD) per household. Estimates ranged from $38 (2018 USD) per year per household from a study conducted in West Bend, Wisconsin (Nowak et al. 1989) to $481 (2018 USD) per year per household for water quality improvements in Upper Narragansett Bay in Rhode Island (Hayes et al. 1992). As described in more detail in the subsequent section, the authors found that WTP varied across studies based on:

- Level of water quality improvement (e.g., individuals are willing to pay more for greater improvements in water quality).
- Characteristics of the study population (e.g., study populations with higher incomes and a high percentage of users of the affected water resources yielded higher WTP estimates)
- Study location (e.g., studies conducted in the Midwest yielded higher estimates than studies located in other areas)
- Study methodological characteristics (e.g., studies in which surveys were conducted in person yielded higher WTP estimates, while studies with higher response rates reported lower estimates)

Ge et al. (2013) included stated preference, travel cost, and hedonic studies in their meta-analysis, totaling 37 studies with 329 individual WTP estimates. Twenty-one of these studies employed stated preference techniques; 14 of the 21 were also included in Van Houtven et al. Across the stated preference studies, average WTP for water quality improvements amounted to $197 (2018 USD) per year ($77 higher than the average reported by Van Houtven et al.). Estimates ranged from approximately $39 for a study related to the Minnesota River in Minnesota (Matthew et al. 1999) to $520 for a study conducted for Lake Mendota in Wisconsin (Stumborg et al. 2001).

The Ge et al. analysis included 11 hedonic studies and six studies that utilized TCM. The authors report that studies employing hedonic and travel cost models yielded higher WTP estimates than those that

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[23]Johnston et al. 2005 is an older study and many of the studies included in it are also included in Van Houtven et al. and/or Ge et al. Further, Johnston and Thomassin is an update to Johnston et al. 2005, with the addition of only two studies.

used stated preference techniques. Based on the study and follow up conversations with a contributing author, one reason the hedonic studies may report higher values is because they were not annualized (i.e., they represent the one-time increase in property values). They therefore cannot be directly compared to annual WTP estimates. In addition, as noted above, the meta-analysis only included six studies that employed TCM. Four of these studies report WTP values that are lower than the weighted average WTP for the stated preference studies.

Table I-1 presents the stated preference studies and associated WTP estimates included in Van Houtven et al. and Ge et al. Table I-2 shows the hedonic and travel cost studies used by Ge et al. The tables exclude four studies from Ge et al. that use more than one methodology to estimate WTP (two studies used both stated preference and travel cost, while two others are reported as using “combined” methods). The subsequent section describes the benefit transfer function developed for each meta-analysis.

Table I-1. Average Annual Household WTP for Water Quality Improvements from Stated Preference Studies, as Reported in Van Houtven et al. (2007) and Ge et al. (2013) Meta-analyses.[a]

Authors	Study area	Number of WTP estimates	Avg. annual household WTP (2018 USD[b])
Azevedo et al. (2001)	Clear Lake, IA	5	$100.37
Binkely and Hanemann (1978)	Boston-Cape Cod area beaches	2	$216.75
Bockstael et al. (1989)	Chesapeake Bay area	2	$110.56
Carson and Mitchell (1993)	Nationwide	3	$244.39
Croke et al. (1986)	Chicago Metro Area	6	$128.01
Cronin (1982)	Potomac River, DC	8	$59.64
Desvousges et al. (1987)	Monongahela River, PA	24	$80.01
Edwards (1984)	RI Salt Ponds	6	$87.28
Farber and Griner (2000)	Loyalhanna Creek, Conemaugh River, PA	10	$90.19
Gramlich (1977)	Charles River, Boston, MA, and nationwide	2	$242.94
Hayes (1987)	Upper Narragansett Bay, RI	16	$90.19
Hayes et al. (1992)	Upper Narragansett Bay, RI	2	$481.51
Johnston et al. (1999)	Wood-Pawcatuck Watershed, RI	2	$180.38
Kaoru (1993)	Martha's Vineyard, MA	1	$264.76
Lant and Roberts (1990)	Rivers in Iowa and Illinois	6	$88.74
Lant and Tobin (1989)	Rivers in Iowa and Illinois	9	$160.02
Lipton (2003)	Chesapeake Bay	5	$112.01
Magat et al. (2000)	National lakes, rivers, and streams	7	$295.50
Moore et al. (2011)	Green Bay, WI	24	$377.11
Nowak et al. (1989)	West Bend, WI	1	$37.82
Nowak et al. (1990)	Milwaukee, WI	14	$126.56
Randall et al. (2001)	Maumee River, OH	3	$73.73
Schuetz et al. (2001)	Maine's great ponds	3	$12.82
Smith et al. (1983)	Monongahela River, PA	2	$30.09
Stumborg et al. (2001)	Lake Mendota, WI	1	$519.74
Walsh et al. (1978)	South Platte River Basin, CO	6	$226.93
Wey (1990)	Great Salt Pond, Block Island RI	1	$46.55

Source**:** Data from Van Houtven et al. 2007 and Ge et al. 2013.

a. Values are as reported by Ge et al. and Van Houtven et al. In several instances, Ge et al. 2013 reported values that varied significantly from the values reported by Houtven et al for the same study. In these instances, we relied on Van Houtven et al. because it is a published, peer reviewed study. Ge et al. is labeled as a working paper and does not seem to have been published in a peer-reviewed journal

b. Values updated to 2018 USD using the Consumer Price Index

While we focus our research on the two meta-analyses, one additional study of note is Cadavid and Ando (2013). This study estimates WTP for water quality improvements and other environmental attributes associated with GSI-based stormwater management strategies. Specifically, the authors used choice experiment (CE), a stated preference methodology, to evaluate people's WTP for different outcomes associated with stormwater management. CE methods allow researchers to estimate the total economic value of an environmental good that is comprised of a set of attributes. In addition to total value, CEs yield estimates of the value of each attribute of the good individually (Holmes and Adamowicz, 2003; Hoyos, 2010). Cadavid and Ando (2013) used CE methods to separately value WTP for various outcomes (or attributes) of stormwater management strategies, including reductions in basement, street, and backyard flooding; improvements in water quality and aquatic habitat; and increased infiltration. The CE was administered through a survey of residents in the Champaign-Urbana, Illinois area.

Table I-2. Average WTP for Water Quality Improvements from Hedonic and Travel Cost Studies, as Reported in Ge et al. (2013) Meta-analysis.

Authors	Study Area	Number of WTP Estimates	Average Household WTP (2018 USD)[a]
Hedonic studies			
Boyle et al. (1999)	Lakes in Maine	6	$ 2,040.43
Boyle and Bouchard (2003)	Selected lakes in VT, NH, ME	22	$449.32
Brashares (1985)	Lakes in southeast MI	7	$92.15
Epp and Al-Ani (1979)	Rivers in Rural Pennsylvania	1	$191.45
Gibbs et al. (2002)	Lakes in NH	4	$489.79
Michael et al. (1996)	Selected Maine lakes	6	$1,017.23
Krysel C. et al. (2003)	Mississippi Headwaters Region, MN	74	$415.93
Leggett and Bockstael (2000)	Chesapeake Bay	1	$454.24
Ralph and Shogren (1989)	Lake Okoboji, IA	2	$1,512.94
Steinnes (1992)	Lakes in northern MN	2	$23.44
Young (1984)	St. Albans Bay on Lake Champaign, VT	2	$638.88
Travel cost method			
Bockstael et al. (1987)	Boston area beaches	1	$63.61
Egan et al. (2009)	Lakes in Iowa	20	$118.19
Huang (1986)	Selected lakes in MN	22	$8.61
Mullen and Menz (1985)	Rivers in Adirondack, NY	1	$90.97

a. Values updated from 2010 USD to 2018 USD using Consumer Price Index

To estimate WTP for water quality, Cadavid and Ando (2013) used a modified ‘‘water quality ladder,’’ which translates technical water quality measures into simple categories. The ladder has four categories (from best to worst quality: drinkable, swimmable, fishable, and boatable) that depend on levels of conventional pollutants. Results indicate that people are willing to pay for improving the environmental quality of streams. Specifically, respondents were willing to pay over $38 per year per household for a discrete improvement in water quality from boatable to fishable and would be willing to pay $40 per year per household to avoid further deterioration of water quality in streams. These estimates represent the lower end of the range reported in the meta-analyses described above.

The authors explain that in the economic model they developed, the coefficients on ‘‘swimmable’’ and ‘‘fishable’’ were positive and the coefficient on ‘‘polluted’’ is negative, as expected. Further, the status quo of ‘‘boatable’’ lies between ‘‘polluted’’ and ‘‘fishable,’’ meaning that people clearly gain utility from improved water quality. However, the coefficients on ‘‘swimmable’’ and ‘‘fishable’’ did not statistically vary from each other. This means that either the survey respondents do not place more value on having water in which they could swim instead of just fish, or they did not carefully distinguish between different levels of improvement when answering the survey questions.

I.2.4 Meta-analysis Models for WTP for Water Quality Improvements

The meta-analyses described above not only provide a comprehensive review of existing literature on WTP for water quality improvements, but also put forth valuation models (or benefit transfer functions) that can be used to derive benefit estimates (i.e., WTP for water quality improvements) in different settings. This section summarizes the methodology used to conduct the meta-analyses and presents the results of the valuation models.

The Van Houtven et al. and Ge et al. valuation models can both represented by a relatively simple WTP function, where the dependent variable is annual WTP per household. The independent variables include the baseline level of water quality (as measured by a water quality index) and the change in water quality described for the policy scenario. In both studies, the models control for different characteristics of the site and study population, as well as for the research methods of the primary studies. A simple representation is as follows:

$$WTP = V (Q_0, Q_1 X, Y, Z)$$

Where WTP is a function of the change in water quality from Q0 to Q1 and control variables related to study population (X), site characteristics (Y), and study research methods (Z).

I.2.4.1 Van Houtven et al. 2007

The Van Houtven et al. (2007) meta-analysis included stated preference studies conducted in the United States that described water quality in terms that could be converted to a common 10-point scale. Once studies that met these criteria were selected, the authors identified common variables across the studies that were likely to influence WTP.

First, the authors converted the baseline water quality and water quality changes evaluated in each study into a common metric. To do this, they constructed a 10-point water quality index (WQI_{10}). This index is based in part on the water quality ladder (WQL) originally developed by Resources for the Future (RFF, also often referred to as Vaughn's WQL) as a way of conveying water quality information to the general public, particularly survey respondents. RFF tied the WQL to specific outcomes and metrics, for example, a water quality index value of 2.5 (out of 10) is defined as "boatable;" 5.1 is "fishable;" and 7.0 is "swimmable." These levels are also tied to specific water quality metrics (e.g., fecal coliform, dissolved oxygen, turbidity). Van Houtven et al.'s WQI_{10} also maps water quality characteristics not specifically related to recreational use (e.g., habitat suitability) to the WQL. Figure I-2 shows a schematic of RFF's original WQL, as cited/used by Mitchell and Carson (1981) in a report developed for the U.S. EPA. Table I-3 shows some specific water quality measures associated with the different use levels identified.

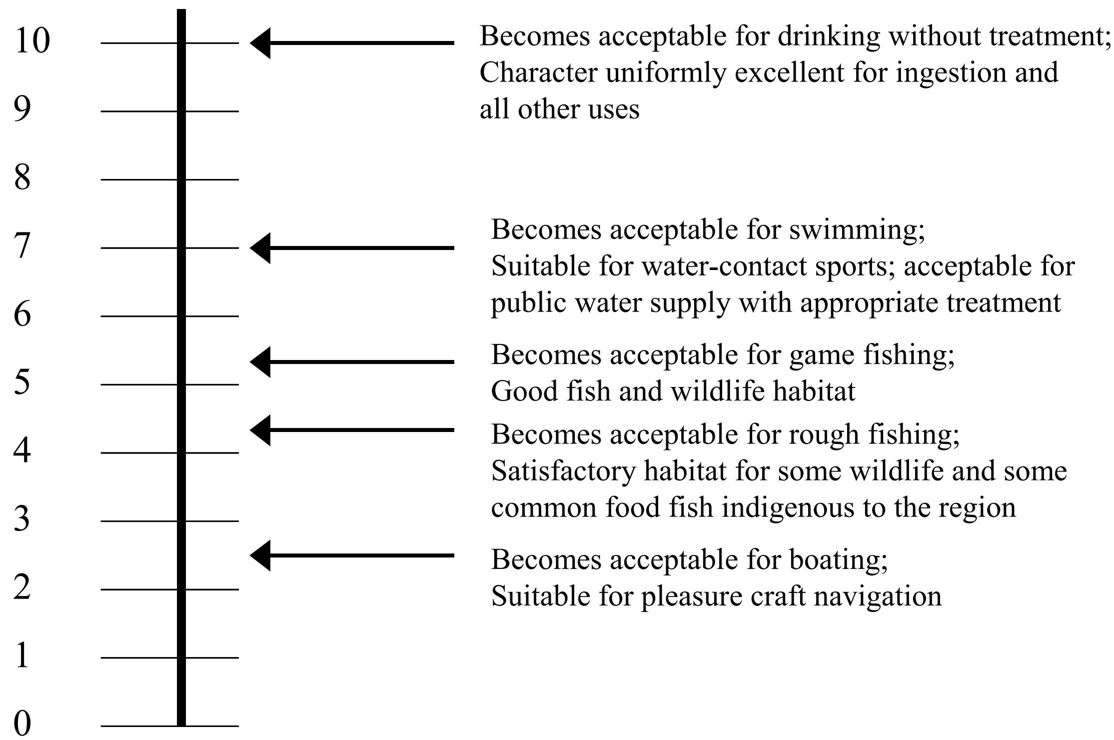

Figure I-2. RFF Water Quality Ladder.
Source: Mitchell and Carson 1981.

Table I-3. Water Quality Characteristics for Five Classes of Water Use.

Water Quality Level	Fecal Coliform (no./100 mL)	Dissolved Oxygen (mg/L)	5-Day BOD (mg/L)	Turbidity (NTU)	pH
Acceptable for drinking without treatment	0	7.0	0	5	7.25
Acceptable for swimming	200	6.5	1.5	10	7.25
Acceptable for game fishing	1,000	5.0	3	50	7.25
Acceptable for rough fishing	1,000	4.0	3	50	7.25
Acceptable for boating	2,000	3.5	4	100	4.25

Source: Mitchell and Carson 1981; Russell et al. 2001.

In addition to defining water quality levels, the authors examined the effect on WTP of variables related to study population (e.g., percentage of "users" of the resource examined, household income), site characteristics (e.g., study region, whether the study was restricted to freshwater in the local area), valuation method (e.g., type of value elicitation format used) and other study characteristics (e.g., survey response rate, publication outlet.). Table I-4 describes the specific variables used to estimate the authors' final WTP model.

Table I-4. Variables Included in Van Houtven et al. Meta-regression Analysis.

Variable	Description
WTP2000	Annual WTP for water quality change (in 2000 dollars)
$WQI_{10}CHANGE$	Water quality change (based on 10-point WQI)
WQ_REC_USE	= 1 if the water quality change described in the study includes a reference to recreational use support (e.g., suitable for recreational fishing)
$WQI_{10}BASE$	Baseline level of water quality from which water quality improves
ESTUARY	= 1 if the water quality change occurs in an estuary
LOCAL_FWATER	= 1 if the water quality change is restricted to freshwater in the local area (i.e., within a single waterbody, county, or metro area)
MIDWEST	= 1 if the affected waterbodies are in the Midwest region of the United States
SOUTH	= 1 if the affected waterbodies are in the Southern region of the United States
INCOME2000	Median household income (in thousands of 2000 dollars)
INCOME_APPROX	= 1 if average household income was approximated based on local Census data
PERCENT_USER	Percent of the sample population that are users of the affected water resource
PUBLISHED	= 1 if the study is published in a peer-reviewed book or journal
OPEN_ENDED	= 1 if the value was estimated from an open-ended valuation question
RESPONSE_RATE	Response rate for the survey used in the study
IN_PERSON	= 1 if the survey used in the study was administered with an in-person interview
STUDY_YR73	= Year SP survey was fielded (minus 1973)

Source: Van Houtven et al. 2007.

Van Houtven et al. estimated three models using different functional forms – linear, semi-log, and log-linear. For each functional form, the authors developed two model specifications. The first is a full model that included all of the main explanatory variables shown in Table I-4 (above). The second is a restricted model, which excludes most of the variables that were not found to be statistically significant at 0.10 or less (based on t-statistics). The restricted models retain the water quality variables from Table I-4 (regardless of their statistical significance) because of their conceptual and economic importance in estimating WTP.

Table I-5 shows the results of log-linear (full and restricted) models estimated by Van Houtven et al. The authors report that while all three of the model forms are reasonable for approximating the relationship between WTP and the other variables, the log-linear approach has at least two advantages. First, the log form implies that, as changes in water quality approach zero, WTP also approaches zero. Second, it implies that the *marginal* effect of a water quality change on WTP depends on income. The semi-log model shares this second advantage; however, it also implies that if WTP increases with larger improvements in water quality, then it does so at an increasing rate. Although the numbers presented below are not inherently intuitive (because they are in logged form), the magnitude and sign of the coefficients provide a relative idea of how the different variables influence WTP.

Table I-5. Van Houtven et al. (2007) Meta-analysis Regression Results (Log-linear model).

Variables	Variable inputs based on mean value across studies	Model coefficient (full model)	Model coefficient (restricted model)
Ln(WQI10CHANGE)	1.22	0.343	0.358
Ln(WQI$_{10}$CHANGE)xWQ_REC_USE	0.83	0.414*	0.465**
WQI$_{10}$BASE	2.80	0.091	0.08
ESTUARY	0.27	0.025	
LOCAL_FWATER	0.43	-0.11	
MIDWEST	0.32	0.329	
SOUTH	0.12	-0.052	
Ln(INCOME2000)	3.92	0.964*	0.897*
Ln(INCOME2000) x INCOME_APPROX	1.02	-0.008	
PERCENT_USER	62.74	0.011**	0.011**
PUBLISHED	0.51	0.960**	0.898**
OPEN_ENDED	0.60	0.051	
RESPONSE_RATE	58.02	-0.014	-0.013*
IN_PERSON	0.31	0.315	0.43
STUDY_YR73	11.63	-0.041**	-0.029**
CONSTANT		-0.399	-0.227
R2		0.64	00.59

Note: ** and * respectively denote statistical significance at the 5% (p = 0.05) and 10% level (p = 0.10).

Source: Van Houtven et al. 2007.

As shown above, most variables included in the model have a positive influence on WTP. Results indicate that the WTP estimates are sensitive to scope when water quality changes are characterized using recreational use descriptions. The analysis also finds that WTP for water quality improvements is not strongly associated with baseline water quality levels. The coefficient for WQI10BASE is estimated to be positive but is not statistically significant. The WTP estimates also show limited sensitivity to the spatial scope of the change in water quality. The coefficient for LOCAL_FWATER is consistently negative but not statistically significant.

The negative effect of STUDY_YR73 indicates that, after controlling for income and price effects, estimates of average real (inflation-adjusted) WTP for water quality improvements has declined over time. The authors reason that this decline may reflect changes in preferences over time, but that it may also be the result of other factors, such as possible changes in publication selection processes or in estimation methods, that tend to favor lower WTP estimates. The effect of RESPONSE_RATE is also negative. The authors report that although there are no strong priors for how response rates should affect the magnitude of WTP estimates, these results suggest that surveys with lower response rates might exclude individuals with lower average WTP for water quality improvements.

To apply the WTP function for benefit transfer purposes, the model coefficients are multiplied by their respective input variable (shown as the mean across studies in Table I-5). So, for example, based on the restricted model results shown in Table I-5, the WTP functions is as follows:

Ln(WTP2000) = -0.227 **+** (0.358 × Ln[WQI10CHANGE]) **+** (0.465 × Ln(WQI$_{10}$CHANGE) × WQ_REC_USE) + (0.08 × WQI$_{10}$BASE) + (0.897 × Ln(INCOME2000)) + (0.011 × PERCENT_USER) + (0.898 × PUBLISHED) + (0.013 × RESPONSE_RATE) + (0.43 × IN_PERSON) + (-0.029 × STUDY_YR73)

Using the mean values for the model inputs reported in Table I-5, the above equation would yield an estimated WTP of approximately $88 in 2000 USD. Updated to 2018 values, this represents a WTP of $128 per year per household.

I.2.4.2 Ge et al. 2013

Ge et al. (2013) follows a methodology similar to Van Houtven et al. to develop a WTP function. However, the studies differ in three primary ways. First, Ge et al. includes site size (i.e., the size of the affected water bodies in square miles) and region size (the size of the sampling region in square miles) as independent variables in the meta-regression. Second, while Van Houtven et al. limited their analysis to stated preference studies, Ge et al. included stated preference studies, as well as studies that used hedonic and travel cost approaches. Third, Van Houtven et al. also limited their analysis to studies that used the WQL or similar indices that could easily be converted to a 10-point water quality scale to define water quality improvements on a consistent basis. Although the WQL (or similar index) was used in many of the studies included in Ge et al., the authors also included studies that used other indicators, such as Secchi depth or water quality attributes (e.g., specific changes in pH, phosphorus, oxygen, or nitrogen levels). The authors developed a model to convert the studies to a common unit of water quality change, using a 100-point water quality index.

One benefit of including the additional studies is a larger sample size: Ge et al. obtained 332 WTP estimates from 38 unique studies, compared with 131 observations from 21 studies in the Van Houtven et al. paper. Like Van Houtven et al., the authors examined the effect of changes in water quality on WTP, as well as the effect of different variables related to study population, site characteristics, valuation method, and other study characteristics. Table I-6 describes the specific variables used to estimate the authors' final WTP models.

Table I-6. Variables Included in Ge et al. Meta-regression Analysis.

Variable	Mean value across studies	Description
WTP2010	$312.14	Annual WTP for water quality change (dependent variable, in 2010 dollars)
NE	0.41	= 1 if the affected water bodies are in the Northeast region of the U.S.
Lake_Estuary	0.63	=1 if the affected water bodies are lakes and estuaries
PubDate	19.64	publication year, 0=year 1977
InPerson	0.22	=1 if the survey used in the study was administered with an in-person interview
Income	$51,582	Median household income in 2010 dollars
TotalValue	0.29	=1 if the original study estimates total value
Improvement	0.75	=1 if the change in water quality is an improvement
Ladder	0.41	=1 if the water quality indicator used in the original study is an index
StartingWQI	61.2	Starting water quality index of affected water bodies
DeltaWQI	16.3	Change in water quality index of affected water bodies
CV	0.44	=1 if the original paper uses contingent valutation method
Hedonic	0.38	=1 if the original paper uses hedonic method
Open ended	0.13	=1 if elicitation method is open-ended
Bidding	0.1	=1 if elicitation method is iterative bidding
ElitmtdOther	0.12	=1 if elicitation method is not open-ended, bidding, or dichotomous choice (default)
Site_size	7908.13	The size of the affected water bodies in square miles
Region_size	119851.6	The size of the sampling region in square miles

Source: Ge et al. 2013.

Ge et al. developed a linear model to estimate the WTP function. Most of the studies included in Ge et al. contain more than one WTP estimate; as a result, the data is naturally clustered. To account for the clustered nature of the data, the authors used a clustered robust regression model where each study is a cluster. Table I-7 shows the clustered robust regression results. The column labeled Pooled 1 shows the results (i.e., model coefficients) using the full data, with all explanatory variables and including all studies; the column labeled Pooled 2 shows the regression results from the pooled data, with all explanatory variables except site size and region size. The column labeled stated preference shows the regression results from only the stated preference studies included in the meta-analysis. As shown, the R^2 value for both the pooled models is relatively low, while the stated preference model performs much better in this sense.[24]

Table I-7. Ge et al. 2013 Meta-Analysis Regression Results.

Variables	Pooled 1	Pooled 2	Stated preference only
StartingWQI	-2.667*	-1.89	-0.37
DeltaWQI	4.48*	4.62*	1.67**
NE	27.94	-2.76	-72.62**
Lake_Estuary	287.23**	274.01**	268.11**
PubDate	4.69	3.75	-2.95
InPerson	284.09**	283.37**	133.32**
Income	-0.01142	-0.01134	0.003
TotalValue	78.96	92.8	104.49**
Improvement	-212.5*	-193.56*	12.91
Ladder	-208.04*	-142.73	-141.76*
CV	-277.2*6	-123.59	
Hedonic	217.88*	349.16**	
Openended	9.95	-65.99	40.11
Bidding	-121.12	-175.972	84.67
D_elitmtdOther	99.52	69.69	144.48
Site size	0.06**		0.003
Region size	-0.004**		-0.0002
Constant	909.49	745.16	-126.55
R2	0.1322	0.1242	0.4555

Note: ** and * respectively denote statistical significance at the 5% (p = 0.05) and 10% level (p = 0.10).
Source: Ge et al. 2013.

Because the model is linear, the coefficients shown in Table I-7 represent unit value changes in WTP. For example, results of all models show that WTP depends on the absolute level of change in the water quality index. Specifically, the Pooled 1 model shows that for a 1-point change (out of 100) in the water quality index, an average household is willing to pay $4.48 per year (or $44.80 for a 10-point change), all else equal. Results of the regressions also show that WTP for given water quality improvement is higher for lakes and estuaries than for rivers. It is also higher when the survey is administered in person, or when water quality is indicated by secchi depth in the original study (the default), compared to a water quality ladder. The pooled models indicate that individuals are willing to pay more to avoid water quality degradation rather than to make an improvement, although this is not true for the stated preference only model. Notably, as with Van Houtven et al., the starting level of water quality is not statistically significant; however, results from Ge et al. show a negative relationship between WTP and starting water quality. This means that WTP increases when the starting water quality level is lower.

In the pooled regression models, the hedonic dummy variable is positive and significant, while the stated preference dummy variable is negative and significant. This means that the hedonic approach tends to produce larger valuations, followed by the travel cost approach (the default), followed by the stated preference approach. However, as noted previously, based on conversations with contributing authors, it does not appear that the hedonic values were annualized in any way meaning they cannot necessarily be compared to annual WTP estimates from stated preference studies. In addition, there are very few travel cost studies included in the meta-analysis.

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[24] R-Squared (R^2 or the coefficient of determination) is a statistical measure in a regression model that determines the proportion of variance in the dependent variable that can be explained by the independent variable. In other words, r-squared tells how well the data fit the regression model (the goodness of fit).

Region and site size have significant impacts on the willingness to pay for water quality improvement in the Pooled 1 model but are not statistically significant in the stated preference only model. In the Pooled 1 model, site size (i.e., the size of the affected water bodies) has a positive effect on WTP. Specifically, results show that WTP for a given water quality improvement will be $0.60 higher if the site size increases by 10 square miles. Region size (i.e., the size of the sampling region) has a negative effect; the model estimates that on average, WTP will be $4 lower if the sampling region increases by 1,000 square miles. The authors reason that is likely because the further away a household lives from the site, the less important the quality of the site is to the household.

As described above for Van Houtven et al., WTP can be estimated for a policy site (i.e., benefit transfer site) by multiplying the model coefficients by their respective input variable (shown as the mean across studies in Table I-6). Using the stated preference only model from Ge et al., the WTP function is:

WTP 2010 = -126.55 **+** (-0.37 × Starting_WQI) **+** (1.67 × Delta_WQI) + (-72.62 × NE)
+ (268.11 × Lake_Estuary) + (-2.95 x PubDate) + (133.32 × In_Person) + (0.003 × INCOME)
+ (104.49 × TOTAL_VALUE) + (12.91 × IMPROVEMENT) + (-141.76 × LADDER) + ((40.11 X OpenEnded) + (84.67 x Bidding) + (144.48 x ElitMethOther) + (.003 * SITE_SIZE) + (-0.0002 x Region_Size)

Using the mean values for the model inputs reported in Table I-6, the above equation yields an estimated WTP of approximately $156 in 2010 USD. Updated to 2018 values, this represents a WTP of $179 per year per household.

I.3 Tool Methodology for Quantifying and Monetizing Water Quality Benefits

To estimate WTP for water quality improvements associated with city-, neighborhood-, or watershed-scale GSI installations, the Tool relies on the meta-analysis performed by Van Houtven et al. (2007). While the Ge et al. (2013) meta-analysis is more recent, it includes only an additional six studies that are not included in Van Houtven et al., all of which were conducted in 2001 or before. Ge et al. (2013) also excludes seven state preference studies that are included in Van Houtven et al. Finally, the models developed by Van Houtven et al. also perform better (statistically) compared to the models developed by Ge et al.; and Van Houtven et al. is published in a peer-reviewed journal, while Ge et al. is labeled as a "working paper" and currently being updated by researchers at Iowa State University.

The WTP function for the restricted log-linear model from Van Houtven et al., and associated calculations, are incorporated into the background of the Tool, as follows:

Ln(WTP2000) = -0.227 **+** (0.358 × Ln[WQI10CHANGE]) **+** (0.465 × Ln(WQI_{10}CHANGE) × WQ_REC_USE) + (0.08 × WQI_{10}BASE) + (0.897 × Ln(INCOME2000)) + (0.011 × PERCENT_USER) + (0.898 × PUBLISHED)
+ (-0.013 × RESPONSE_RATE) + (0.43 × IN_PERSON) + (-0.029 × STUDY_YR73)

The user will need to input the following information into the Tool:

- Estimated baseline level of water quality (using the 10-point water quality scale)
- Estimated change in water quality (increase the baseline) associated with GSI scenario (using the 10-point water quality scale)
- Whether or not the water quality change occurs in an estuary; if the user's GSI scenario will benefit an estuary, the user will need to estimate the percentage of affected waterbodies (e.g., by surface

area) that the estuary accounts for.

- Median household income in the local area in 2010 USD (from the 2010 Census). The Tool automatically deflates this value to 2000 USD, which is the value used in the Van Houtven et al. model.
- Whether the GSI scenario will result in water quality improvements in local waterways that support water-based recreation activities. If this is the case, the user will need to enter the estimated percentage of affected waterbodies (e.g., by surface area) that support recreation.

For the remaining model variables, the Tool uses the mean values from studies included in the Van Houtven et al. meta-analysis or, as relevant, includes default values for relevant dummy variables.

Based on user inputs and the standard (mean) values, the Tool calculates WTP per household per year for improvements in water quality. The user must enter the number of affected households (e.g., households within the GSI management area) to calculate total annual value. The Tool automatically updates WTP estimates to today's dollar values using the Consumer Price Index.

The two most difficult inputs for users to determine likely include the baseline level of water quality, as well as the change in water quality that will occur in affected water bodies under the GSI scenario. It is important to note that it is outside the scope of this research to estimate physical water quality improvements for affected water bodies under various GSI scenarios. The guidance accompanying the Tool provides some advice on determining these inputs. In addition, the user can enter a range of values to better understand how changes in these assumptions affect WTP results.

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APPENDIX J

Carbon Reduction Benefits

J.1 Introduction

Carbon dioxide (CO_2) is widely recognized as a significant greenhouse gas (GHG) that contributes to rising atmospheric temperatures and associated climate change. According to the National Oceanic and Atmospheric Administration (NOAA), CO_2 is the most important of Earth's greenhouse gases. While it absorbs less heat per molecule than other greenhouse gases (e.g., methane), it is more abundant and stays in the atmosphere much longer (NOAA 2018).

Vegetation removes CO_2 from the atmosphere when it photosynthesizes and acts as a sink by storing carbon in the form of biomass (Nowak et al., 2013). Thus, most GSI practices that involve vegetation remove CO_2 from the air. In addition, as described in Appendix C, GSI practices can save energy by providing shade and insulation to buildings and reducing pumping and treatment requirements. This in turn reduces energy-related CO_2 emissions.

Economists typically value the benefits of CO_2 reductions using the "social cost of carbon" (SCC), which represents the aggregate net economic value of damages from climate change across the globe (IPCC, 2007). In 2016, the U.S. Government's Interagency Working Group (IWG) on Social Cost of Carbon issued updated guidance on recommended SCC values (per ton of CO_2) for regulatory benefit-cost analysis. The Working Group's mean SCC estimate reflects the worldwide net benefit of reducing one ton of atmospheric CO_2.

This appendix describes the carbon sequestration benefits associated with stormwater trees, as well as the availability of sequestration estimates for other GSI practices such as green roofs, bioswales, and rain gardens. It also provides an overview of CO_2 emissions reductions due to GSI-related energy savings and describes how carbon reduction benefits are quantified and monetized in the GSI TBL Benefit Cost Framework and Tool (Tool).

J.2 Findings from the Literature

This section provides an overview of findings from the literature related to carbon sequestration and storage from trees, green roofs, and other GSI practices, as well as the reduction in CO_2 emissions associated with GSI-related energy savings.

It is important to note that when quantifying carbon sequestration benefits, the pounds of carbon stored in plants do not equal the pounds of CO_2 that are removed from the atmosphere (because an atom of carbon has a smaller atomic mass than a CO_2 molecule). For every pound of carbon stored or sequestered, 3.67 pounds of CO_2 are removed from the atmosphere.

J.2.1 Carbon Sequestration and Storage: Trees

Trees in urban and semi-urban settings can play a significant role in mitigating the impacts of climate change by storing vast amounts of carbon (Erickson 2018). While they are growing, trees take in more CO_2 from the air through photosynthesis than they release through respiration, resulting in a net reduction of CO_2 in the atmosphere. Most of the carbon sequestered becomes fixed and is stored as woody biomass in the tree. Nowak et al. (2013) estimates that as of 2005, total tree carbon storage in urban areas of the U.S. amounted to 643 million metric tons, with annual carbon sequestration estimated at 25.6 million metric tons.

Carbon sequestration and storage benefits of trees vary based on several factors. For example:

- Newly planted trees have the highest rate of carbon uptake. After several decades, the annual amount of carbon sequestered by trees begins to decline.
- Larger trees (e.g., 30+ inches in size, measured as diameter breast height, dbh), sequester more carbon than smaller trees (Nowak, 1994). Similarly, species with a higher leaf area index (LAI) sequester more carbon (Koss et al. 2007).
- Healthy trees absorb more carbon than diseased or drought stressed trees.
- Sequestration from trees varies by season because deciduous vegetation goes dormant in winter months. Thus, carbon sequestration is greatest from early spring through September in the growing season.

Overall, rural forests sequester about twice as much carbon than do urban forests because of higher tree densities in rural forests (I.e., more biomass). However, urban trees tend to grow faster than rural trees because they are typically more spread out and therefore have less competition for access to sunlight and nutrients. Urban trees therefore sequester more carbon per tree compared to rural trees. In addition, urban trees are typically located in areas with higher concentration of CO_2 (e.g., street trees are located next to areas with higher levels of vehicle emissions). Koss et al. (2007) report that elevated atmospheric CO_2 levels allow more carbon to be available for plants to uptake.

The U.S. Forest Service (USFS) has conducted extensive research on carbon sequestration and storage of trees[25] based on extensive field data and numerical models. For example, Nowak et al. (2013) used field sample data for 28 cities and 6 states (statewide estimates) to estimate average carbon density per unit of tree cover in urban/semi-urban areas. Results showed that carbon storage varied by sampled city and state, ranging from 3.14 (South Dakota) to 14.1 (Omaha, NE) kg of C per square meter (m^2) of tree cover, with an average of 7.69 kg of C per m^2. The authors attribute this wide range in part, to differences in forest structure (e.g., tree size, spacing, canopy density and other factors).

In addition to storage, Nowak et al. (2013) found that annual gross carbon sequestration averaged 0.277 kg C per m^2 per year across sampled areas, while net sequestration amounted to 0.205 kg C per m^2 per year (74% of the gross sequestration rate). For this study, the net carbon sequestration rate for tree cover was calculated by reducing the amount of carbon sequestered due to tree growth (gross sequestration) by the estimated amount of carbon lost each year due to tree mortality and decay. Using the field data and model analysis from the sample data mentioned above, the authors employed photo interpretation of tree cover to estimate statewide urban forest carbon sequestration rates for each U.S. state. Results indicate that net sequestration rates vary widely by state, from 0.168 (Alaska) to 0.581 (Hawaii) kg C per m^2 of tree cover per year.

In its' Community Tree Guides, which estimate the costs and benefits of trees for 16 regions of the U.S., the USFS warns that it is important to report net sequestration rates to present a complete picture of atmospheric CO_2 reductions from tree plantings. For example, it is important to consider CO_2 released into the atmosphere through tree planting and care activities, as well as decomposition of wood from pruned or dead trees (as described above).

USFS researchers have also developed models and methods to estimate carbon storage and

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[25] Much of this work has been led by Dr. David Nowak and J. McPherson, USFS researchers Nowak and McPherson are commonly the lead authors on research related to the benefits of trees, including carbon storage and sequestration.

sequestration rates for various tree species at different stages of growth. McPherson et al. (2016) presents urban tree growth and volumetric equations to calculate stored carbon based on different variables. Specifically, the authors developed volumetric equations for different tree species to estimate aboveground fresh-wood volume (dependent variable, in cubic meters) based on dbh and tree height (independent variables). Fresh-wood volume is then multiplied by the species' dry weight density factor to obtain aboveground dry weight biomass. To estimate total carbon storage (and stored CO_2 equivalents), dry weight biomass is first multiplied by 1.28 to incorporate belowground biomass, then multiplied by the constant 0.5 to convert to total carbon stored, and finally, multiplied by the constant 3.67 (molecular weight of CO_2) to convert carbon to total CO_2 stored.[26] Annual rates of sequestration can be calculated using the same formulas and applying average growth rates for different tree species (e.g., annual increases in DBH, Nowak et al. 1994).

J.2.2 Carbon Sequestration and Storage: Green Roofs

Green roofs can also reduce CO_2 and other greenhouse gases through carbon sequestration. Green roofs store carbon in above ground biomass, below ground biomass (e.g., roots), and in the soil which makes up the growing medium.

Green roofs are generally classified as extensive or intensive. Extensive green roofs tend to be simpler, lighter weight roofs with hardier plants and a growing medium of 2 to 6 inches in depth, whereas intensive green roofs tend to be more complex and can be more like a conventional park or garden. Intensive green roofs have greater soil depth, often 6 to 15 inches or more. Intensive green roofs generally sequester more carbon than extensive green roofs.

There are a limited number of studies on the carbon storage and sequestration potential of green roofs; however, these studies indicate that sequestration varies based on plant type/species, soil depth, climate, and potentially other factors. In addition, these studies generally represent the amount of carbon stored over a certain period at a given point in time. Green roofs do not continue to sequester the same amount year after year. Any system will eventually reach an equilibrium where carbon sequestered equals decomposition and thus carbon release. In a shallow green roof this occurs relatively fast, as compared to a newly planted forest, where annual carbon uptake may not start to decline until after 30-years or more.

Getter et al. (2009) presents results from two experiments on carbon storage from green roofs. The first analyzed eight green roofs in Michigan and four green roofs in Maryland. The roofs analyzed were extensive green roofs that ranged between 1 to 6 years in age and were composed primarily of *Sedum* plant species. The depth of substrate varied from 2.5 to 12.7 cm (1 to 5 inches). The analysis found that the green roofs stored an average of 0.594 kg $CO_{2\,eq}/m^2$[27] in their above ground biomass. The second study, from East Lansing, Michigan analyzed 20 plots with a substrate depth of 6 cm (~2.5 inches). Results showed that after two years, aboveground biomass storage ranged from 0.235 kg $CO_{2\,eq}/m^2$ to 0.876 kg $CO_{2\,eq}/m^2$, depending on the species, with an average of 0.616 kg $CO_{2\,eq}/m^2$. Belowground biomass ranged from 0.136 kg $CO_{2\,eq}/m^2$ to 0.678 kg $CO_{2\,eq}/m^2$ and averaged 0.392 kg $CO_{2\,eq}/m^2$. In addition, the authors estimated that the substrate sequestered 0.367 kg $CO_{2\,eq}/m^2$. In total, the extensive green roof system sequestered 1.38 kg $CO_{2\,eq}/m^2$ in above- and belowground biomass and substrate organic matter over the two-year study period.

A study by Whittinghill et al. (2014), also conducted in East Lansing, Michigan, compared carbon storage of nine in-ground landscape systems and three green roofs of varying complexity over three years.

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[26] The constants employed in this model are based on estimates from published literature and do not vary by region.
[27] Carbon storage/sequestration has been converted to CO2 equivalent reductions by applying the 3.67 conversion factor.

Across all landscaping types, green roofs had a lower carbon content than their in-ground system counterparts at the end of the study period, although the amount reported for herbaceous perennials and grasses was similar. Landscape systems containing more woody plants, such as shrubs, and herbaceous perennials and grasses had higher carbon content than other landscape systems.

As shown in Table J-1, the estimates from Whittinghill et al. (2014) are much higher than reported by Getter et al. (which are all less than 1.0 kg/CO2 equivalent), with differences in above ground biomass particularly significant. Whittinghill et al. suggests that for prairie and ornamental green roofs this is not surprising, as the species represented in their study have much greater above-ground biomass and more woody structures than the *Sedum* examined by Getter et al. The authors also suggest that the differences may be because the green roofs they examined had a deeper substrate and/or were irrigated while Getter et al.'s may not have been. In addition, for the native prairie mix green roof, the authors did not account for any carbon released when they system died back during winter; they also did not account for the carbon associated with removal of plant material during maintenance for the other green roof types. The authors state that the net carbon sequestration could therefore be lower than the study suggests. Indeed, Whittinghill et al.'s estimate for herbaceous perennials and grasses is at the top end of the range of carbon storage estimate seen in the literature.

Table J-1. Green Roof Carbon Storage, Over 3-Year Study Period, Whittinghill et al. (2014).

Green Roof Vegetation Types	Above-Ground Carbon (kg $CO_{2\ eq}/m^2$)	Below-Ground Carbon (kg $CO_{2\ eq}/m^2$)	Total Carbon (kg $CO_{2\ eq}/m^2$)
Herbaceous perennials and grasses	236.42	0.66	236.46
Native prairie mix	15.27	2.64	18.19
Succulent rock garden (Sedum)	12.81	1.72	14.33
Vegetable and herb garden	0.18	2.90	4.48

Source: Whittinghill et al. 2014.

Note: pers. comm. with Dr. Rowe, MSU, March 15, 2019, indicate that total carbon reported in the study results did not account for the initial carbon content of the soil. Results for total CO2 eq/m2 have been adjusted to account for this initial amount. Carbon content of soil at end of study period was not directly reported in the study. Study results also converted to CO2 equivalents from total C stored.

More recently, several international studies have reported values higher than Getter et al (2009). For example, Kuronuma et al. (2018) conducted a one-year field test to estimate carbon sequestration of extensive green roofs in Japan with three grass species and irrigation treatment. The authors report that annual sequestration by the three grass species averaged approximately 2.5 kg $CO_{2\ eq}/m^2$; this compared to 1.68 kg $CO_{2\ eq}/m^2$ for a green roof planted in *Sedum* and with irrigation. However, the authors also report that annual emissions associated with the maintenance of the green roof system amounted to 0.33 kg CO_2/m^2 per year.

Chen et al. (2018) examined the carbon storage potential of green roofs in China that had soils amended with sludge and biochar (25 cm substrate depth, or about 10 in). Results showed that compared to the control soil, the carbon content of biochar-amended soils was 15 to 51% greater after one-year; for sludge-amended soils the increase ranged from 5 to 23%. The carbon storage potential of a biochar green roof (34.1 kg $CO_{2\ eq}/m^2$) was higher than that of a sludge green roof (29.0 kg $CO_{2\ eq}/m^2$). According to the authors, biochar increased the carbon content of the green roof by improving the physical properties of the roof soil and promoting plant growth, whereas sludge increased the carbon content of the green roof by improving the chemical properties of the roof soil. It is not clear from the study whether the carbon storage estimates account for the initial carbon content of the soil.

Kavehi et al. (2018) list other international estimates of carbon sequestration in green roofs. When examining the range of studies other than Whittinghill et al. (2014), the carbon storage estimates vary from 0.91 kg (compost, silica, sand soil) $CO_{2\ eq}$ per m^2 per year for a 10 cm deep roof in Spain (Ondoño et al. 2016), to between 22.3 (native soil) and 25.2 (mixed-sewage sludge soil) kg $CO_{2\ eq}$ per m^2 per year for a roof with 20 to 30 cm deep soil in China (Luo et al., 2015).

L.2.3 Carbon Sequestration and Storage: Other GSI Practices and Vegetation

GSI such as rain gardens, bioswales and other practices that involve herbaceous plants, shrubs, and trees also sequester carbon from the air and store carbon in the soil/biomass. Estimates of carbon sequestration from rain gardens, bioswales, and similar GSI practices to date have generally come from studies of carbon sequestration by vegetation type (e.g., grasses, wetlands, herbaceous plants) that do not specifically consider the use of that vegetation for stormwater control.

Kavehi et al. (2018) identified two estimates for carbon sequestration by vegetated swales in the United States. Those estimates are 0.36 kg $CO_{2\ eq}/m^2$ for a swale that is mostly grass (Bouchard et al., 2013) and 0.62 kg $CO_{2\ eq}/m^2$ for a swale that is composed of grasses, woody vegetation, and shrubs (FHWA, 2010). The latter value is from the Federal Highway Administration (FHWA). It is based on the range of sequestration rates published by the Chicago Climate Exchange for grasslands (range of 0.4 to 1.0 metric tons of carbon per acre per year, depending on location).

Flynn and Traver (2013) provided a carbon sequestration estimate for a rain garden. After identifying the land cover and tree species in the garden, they applied the Forest Service i-Tree model to calculate air pollutant removal and carbon sequestration. The carbon sequestration results were for tree species only. They calculated that the 405 m^2 rain garden sequestered 146.8 kg of CO_2 equivalent annually, equal to a sequestration rate of 0.36 kg $CO_{2\ eq}/m^2$.

Jo and McPherson (1995) estimated the carbon storage and sequestration capacity for trees and shrubs, soil, and mowed lawns on two urban residential blocks in Chicago with different amounts of green area/cover. The process used for trees and shrubs was similar to that used in other USFS studies related to trees, but the process for grass, because it was mowed, involved the additional step of calculating biomass loss from mowing. Table J-2 shows the results of this study.

Table J-1. Carbon Storage in Different Urban Vegetated Spaces in Chicago.

	% Vegetative Cover		Carbon Stored (kg $CO_{2\ eq}/m^2$)		Annual Carbon Uptake (kg $CO_{2\ eq}/m^2$)	
	Block 1	Block 2	Block 1	Block 2	Block 1	Block 2
Trees and Shrubs	41.6	13.1	12.6	3.78	0.81	0.26
Soil to 60cm depth: Organic (**Inorganic**)	15.1	5.2	67.8 (**15.2**)	51.6 (**16.3**)	2.6	2.4
Grass	37.7	26.9	0.68	0.91	0.33	0.32
Herbaceous Plants[a]	6.8	5.6	0.66	0.66		

Source: Jo and McPherson 1995.

a. Herbaceous plants included in study were perennials; annual carbon uptake not reported but carbon stored likely represents one year of growth. After one-year, carbon from plant can be incorporated into soil.

While Jo and McPherson were not looking at specific GSI practices, NYC DEP (n.d.) notes several important observations from this study. First, carbon storage in soil is much higher than in biomass, indicating its importance in carbon sequestration. Second, the authors found that landscape management practices, such as pruning and mowing, counterbalance annual uptake by grass and shrubs. The third observation is that the total carbon stored long term in herbaceous plants is nearly zero. This is because most of the herbaceous plants seasonally decayed after flowering and were pulled out at the end of the growing season for ornamental reasons. If dead or decayed plant matter is removed from the site, then it will not contribute to soil carbon storage.

In 2019, the City of Calgary evaluated several alternatives for integrating GSI into its' stormwater management plan for a specific area of the City. The study applied a triple bottom line approach to assess the benefits and costs of a variety of stormwater management strategies, including the lifecycle costs and environmental benefits of bioretention systems. The report cited an Australian study that reported carbon sequestration rates for various landscape types, ranging from 0.07 for lilies to 3.67 kg CO2 eq/m2 for shrubs. To estimate carbon reduction benefits for bioretention, the city applied a sequestration rate of 1.48 Kg of CO2 eq/m2 per year.

Whittinghill et al. (2014) reported values for in-ground landscapes that are likely similar to some rain gardens and some other GI practices. Results are shown in Table J-3.

Table J-3. Ground-Level Landscape Carbon Storage, Over 3-Year Study Period, Whittinghill et al. 2014.

Vegetation Type	Above-Ground Carbon (kg $CO_{2\,eq}/m^2$)	Below-Ground Carbon (kg $CO_{2\,eq}/m^2$)	Total Carbon (kg $CO_{2\,eq}/m^2$)
Broad leaf evergreen shrubs	239.54	0.37	239.8
Deciduous shrubs	194.11	0.51	193.6
Herbaceous perennials and grasses	204.02	2.13	207.4
Kentucky blue grass lawn	9.87	11.93	20.96
Native prairie mix	58.57	1.17	57.36
Needle leaf evergreen shrubs	244.17	2.02	185.3
Succulent rock garden	14.35	1.61	7.41
Vegetable and herb garden	0.18	5.21	39.31
Woody ground covers	6.35	1.17	6.39

Source: Whittinghill et al. 2014.

Note: pers. comm. with Dr. Rowe, MSU, March 15, 2019, indicate that total carbon reported in the study results did not account for the initial carbon content of the soil. Results for total CO2 eq/m2 have been adjusted to account for this initial amount. Carbon content of soil at end of study period was not directly reported in the study. Study results also converted to CO2 equivalents from total C stored.

Finally, several studies examined the promising benefits of carbon storage and sequestration in wetlands (Pant et al. 2003, Tan et al. 2015, Mazurczyk and Brooks, 2018). Wetlands have the highest carbon density among terrestrial ecosystems and greater capacities to sequester additional CO_2 through high rates of organic matter inputs and reduced rates of decomposition (Pant et al. 2003). The U.S. EPA estimates wetlands to store an average plant biomass of 250.9 grams of carbon per square foot (Kloss et al. 2015). An extensive study by Mazurczyk and Brooks (2018) provided a holistic accounting of total carbon values for 193 wetland sites in Pennsylvania to assess different carbon pools. They found total carbon storage ranged from 8.87 kg C/m^2 (Lacustrine, human impounded) to 26.96 kg C/m2 (perennial seasonal depression), with an average across sites of 17.5 kg C/m^2 across wetland types. A study of Federal lands across the U.S. estimated carbon storage and sequestration potential of various ecosystems from 2006-2050 (Tan et al. 2015). The authors projected an average annual carbon sequestration rate for wetlands of 0.41 kg CO2 eq/m2, nearly double the rate of other types of federally managed ecosystems.

J.2.3 Energy-Related CO_2 Emissions Reductions

As described in Appendix C, GSI practices, such as green roofs and trees, can reduce energy needed for heating and cooling in buildings by providing shade and evaporative cooling. In some systems, GSI practices reduce stormwater treatment and pumping requirements and/or result in potable water supply savings. These energy savings result in avoided CO2 emissions associated with electricity production. According to the U.S. EPA, electricity production currently accounts for 25% percent of greenhouse gas emissions (U.S. EPA 2021).

Emission rates associated with power generation depend on several factors, including fuel resource mix (i.e., percentage of energy generated from coal, natural gas, wind energy, etc.), quality of the fuel, combustion technology, the efficiency of the electric generating unit, and the availability of pollution controls (Massetti et al. 2017). Most energy-related emissions come from the combustion of fossil fuels, including coal, natural gas, and petroleum products, although small amounts are also emitted from biomass and other energy sources (Massetti et al. 2017).

The U.S. EPA and Energy Information Administration (EIA) track emission rates for different pollutants (i.e., lbs of CO_2 emitted per MWh or MBtu) for almost all power generation in the United States (i.e., by plant/power company); these agencies publish emission rates for various grid regions and at other geographic scales. As described below, the Tool applies this data to estimate total emission reductions associated with GSI-related energy savings.

J.2.4 Social Cost of Carbon: Valuing CO_2 Reductions

Several approaches have been developed to estimate the value of reducing CO_2 levels. The standard (or most widely accepted) estimate is known as the "social cost of carbon" (SCC), which was developed by the IWG based on models that estimate the global impacts from climate change. These agencies developed this estimate of damages over a series of memoranda starting in 2010, the most recent of which is an August 2016 revision to a memorandum initially developed in May 2013. The SCC estimates present and future monetary damages associated with an incremental increase in carbon emissions emitted now. These damages "include but are not limited to the impact on agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change" (IWG, 2010).

The IWG used three integrated assessment models (IAMs) to develop the SCC estimates. IAMs are mathematical models that include both physical and social science models that consider demographic, political, and economic variables that affect greenhouse gas emission scenarios in addition to the physical climate system. These models have been published and peer reviewed in the literature and updated to include recent advances.

The interagency method developed four SCC estimates. The first three estimates are based on the average SCC from the IAMs at discount rates of 2.5, 3, and 5%. The fourth estimate represents the 95th percentile SCC estimate across all three IAMs at a 3% discount rate; this represents higher-than-expected impacts from temperature change further out in the tails of the SCC distribution (IWG, 2010).

Table J-4 shows the four SCC estimates at different discount rates, in five-year increments from 2010 to 2050. The SCC values were calculated in 2007 dollars and have been updated to 2018 dollars using the Consumer Price Index (CPI). The IWG's estimate of the SCC increases over time because there is a greater accumulation of CO_2 in the atmosphere over time, and higher future levels of population, global output, and emissions. This leads to a higher total willingness to pay to avoid climate change damages. This rate of increase should be considered a "real" escalation rate, which shows increases in values above the general rate of inflation.

Table J-4. SCC Estimates, Updated to 2018 USD.

($/MT CO_2)

Year	Average SCC ($), 5% discount rate	Average SCC ($) 3% discount rate	Average SCC ($), 2.5% discount rate	95th Percentile SCC ($), 3% discount rate
2010	12	38	61	104
2015	13	44	68	127
2020	15	51	75	167
2025	17	56	82	160
2030	19	61	88	184
2035	22	67	94	203
2040	25	73	102	222
2045	28	78	108	239
2050	31	84	115	257

Source: IWG 2016.

Updated from 2007 to 2018 dollars using the CPI.

The IWG recommends using the mean of the 3% discount rate (e.g., $51 per MT for 2020) as the central tendency value for the social cost of carbon. The recommended mean estimate reflects the worldwide net benefits of reducing CO_2 emissions. Estimates of the portion of the net benefits occurring in the United States range from 7% to 23% of the worldwide social cost of carbon.

As shown in the IWG SCC estimate, the estimate is very dependent on the choice of discount rate. Another estimate called The Stern Review was based on a version of the PAGE model (one of the IAMs used to calculate the SCC). Stern used parameters that resulted in a discount rate assumption of 1.4%, with a resulting SCC estimate of $85. The rationale for using a low discount rate is that it gives higher weight to the well-being of future generations compared to that of the current generation. However, critics point out that this unusually low discount rate conflicts with current observed behavior and preferences for consumption now compared to saving for the future.

In 2018, Ricke et al. estimated the SCC to be much higher than the range of IWG estimates or the Stern Review. Ricke's estimate was $417 per metric ton of CO_2, with a 66% confidence interval of $177 to $805 per metric ton. Ricke et al. estimates that approximately $50 per metric ton of the worldwide total reflects damages caused by the United States.

J.3 Tool Methodology for Quantifying Carbon Reduction Benefits

This section describes the methodology the project team integrated into the Tool for calculating and valuing reductions in CO_2 associated with GSI, including carbon sequestration and avoided carbon emissions benefits.

J.3.1 The Value of Carbon Sequestration from Trees

The USFS has developed a suite of software packages, known as i-Tree, that allow practitioners to inventory and assess the benefits and costs of trees in various settings. The i-Tree Streets package uses tree growth and benefit models for predominant urban tree species in 16 climate zones to estimate the monetary value of the ecosystem services that street trees provide, including energy savings and reduced CO_2 emissions. Based on extensive field sampling and simulation modeling, i-Tree Streets (and other i-Tree packages) represents the most comprehensive and peer-reviewed source of information and data on the benefits of urban trees.

In 2009, Casey Trees and Davey Tree partnered with the USFS to integrate i-Tree Streets data into an easily accessible online tool that allows users to estimate the per-tree benefits of street trees based on diameter at breast height (a common size measurement for trees), species, region, and adjacent structures (e.g., residential, commercial, industrial). This tool is known as the National Tree Benefit Calculator (NTBC). We have integrated data from the NTBC into the Tool to estimate the carbon sequestration benefits of street trees.

First, we relied on the Urban Tree Database (McPherson et a. 2016) to identify the 15 to 20 most common street tree species in each of 16 U.S. climate zones (see Figure J-1).[28] Next, we used the tree growth equations developed by McPherson et al. (2016) to estimate dbh for the common street tree species in each region based on age of tree (independent variable in the equation), in 5-year increments. We then entered the estimated dbh at 30 years, for each tree in each region, into the NTBC to obtain carbon sequestration benefits (see Table J-5). The Tool scales annual sequestration over time (to account for tree growth) based on dbh at different ages.

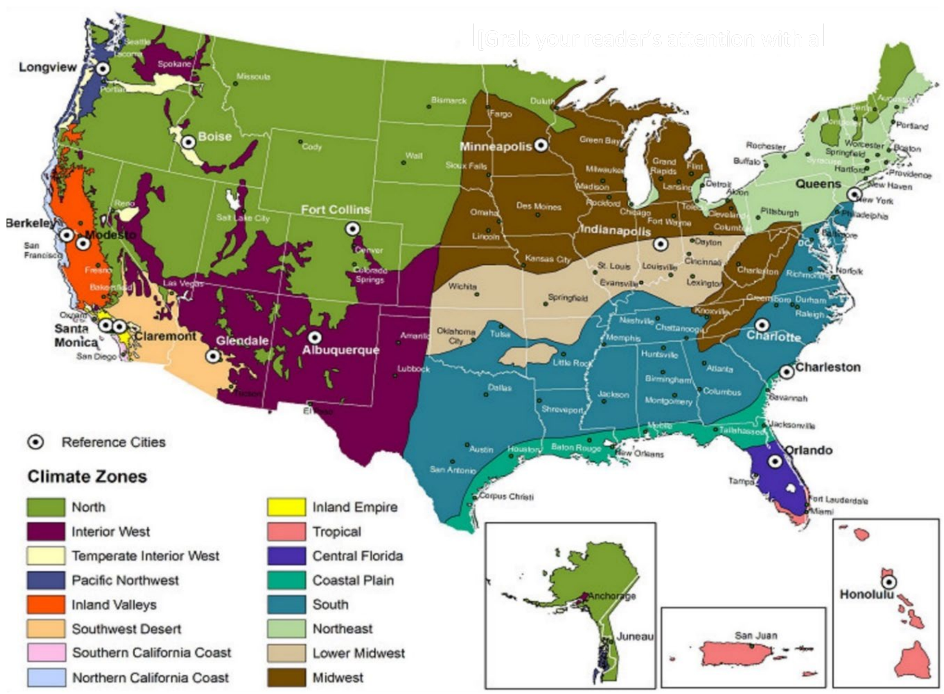

Figure J-1. i-Tree Climate Zones.
Source: U.S. Forest Service, n.d.

As shown in Table J-5, the amount of carbon sequestered per year for a 30-year old street tree varies according to climate zone; CO_2 removal ranges from an average of 108 lbs per year in the Inland Valleys region to 627 lbs per year in the Midwest region. Using a Coastal Plain region tree as an example, with an average annual sequestration rate of 280 lbs per year, the Tool applies the IWG SCC central estimate for 2020 of $51 per metric ton. This results in a benefit of $6.48 per year in 2018 dollars (I.e., 280 lbs per year divided by 2,204.6 lbs per metric ton multiplied by $51 per metric ton is equal to $6.48 per year). This is the value in year 30 at the assumed maximum dbh. The avoided CO_2 value in years prior to this will be less than this value, as the amount of CO2 avoided and sequestered is assumed ramp up in a linear fashion from initial years to year 30. To estimate carbon sequestration over time, we apply the urban tree growth models (McPherson et al. 2016) to estimate dbh in different years and scale benefits

[28] Rather than having the user input specific tree species, the Tool incorporates a mix of the most common street tree species in each region. While some tree species have much higher stormwater capture benefits (the primary benefit of interest for stormwater managers), site constraints can prevent planting of certain species (e.g., larger trees). However, we excluded species if they had particularly low stormwater capture benefits (also calculated through the NTBC).

accordingly.

As an important note, the NTBC has not been updated with more recent research that the USFS has conducted related to the carbon sequestration of trees. However, the project team compared the estimates from the NTBC to more recent studies on carbon sequestration rates in different states and regions (e.g., as published in Nowak et al. 2013) and did not find significant differences.

J.3.2 Carbon Sequestration from Green Roofs and Other GSI Practices

Table J-6 provides a summary of the carbon storage and sequestration values for green roofs, as described in the review of studies above.

Table J-5. Average Annual Carbon Sequestered (CO_2 reduction) for Common Street Tree Species at Year 30, by Climate Zone, Calculated using NTBC.

Tree Climate Zones	Number of tree species	Average dbh at 30 years (inches)[a]	Carbon sequestration benefit (lbs of CO_2 removed)
Central Florida	15	23.7	570
Coastal Plain	17	17.9	280
Inland Empire	21	16.1	145
Inland Valleys	22	15.4	108
Interior West	20	15.7	113
Lower Midwest	20	15.9	187
Midwest	17	21.3	627
North	20	16.1	213
Northern California Coast	21	14.6	200
Northeast	21	13.4	186
Pacific Northwest	22	19.3	341
South	21	22.4	536
Southern California Coast	18	14.1	113
Southwest Desert	18	16.1	164
Temperate Interior West	20	16.0	188
Tropical	19	14.5	140

a. Average dbh calculated using equations from McPherson et al. 2016

Table J-6. Summary of Green Roof Carbon Storage and Sequestration Estimates from the Literature.

Study	Carbon uptake/ storage (kg C/m^2)	Equivalent CO2 reduction (kg $CO_{2\ eq}/m^2$)	Study period (years)[c]	Substrate depth (cm)	Study location
Getter et al. 2009 (Sedum)	0.38	1.39	2	6	Michigan
Whittinghill et al. 2014 (Sedum)[a]	3.90	14.33	3	NA, extensive	Michigan
Whittinghill et al. 2014 (Native prairie)	4.96	18.19	3	NA, extensive	Michigan
Kuronuma et al (2018), (Three grass species)	0.68	2.50	1	5	Japan
Kuronuma et al (2018), (Sedum)	0.46	1.68	1	5	Japan
Chen et al. (2018), (Biochar substrate)	9.30	34.13	1	25	China
Chen et al. (2018), (Sludge substrate)	7.90	28.99	1	25	China
Ondoño et al 2016 (Compost-silica-sand substrate)	0.25	0 .91	1	10	Spain
Ondoño et al 2016 (compost-soil-bricks substrate)	1.20	4.40	1	5 to 10	Spain
Luo et al. 2015[b]	6.47	23.74	1	20 to 30	China

a. Whittinghill et al. (2014) estimate for herbaceous plant green roof is excluded from table because of its very high value relative to all other existing studies.

b. Luo et al. (2015) estimate represents average sequestration across soil types and depths included in study; average total carbon storage reported was 18.28 kg C/m2

c. For studies with a study period of more than 1-year, carbon reduction can be divided by study period to obtain average annual sequestration rate.

As shown, carbon sequestration estimates for green roofs vary significantly. The Tool applies a default value of 2.04 kg CO_{2eq} per m2 as a relatively conservative value. This estimate represents the average annual sequestration rate from Getter et al., Kuronuma et al., and Ondoño et al. It excludes Whittinghill et al.'s estimates, as well as estimates from the two studies conducted in China due (Chen et al. and Luo et al.) because of their extremely high values compared to other sequestration estimates found in the literature for different types of vegetation. In addition, based on Whittinghill et al. (2014), we know that roofs continue to sequester carbon for at least three years. We did not find any studies that estimate at which point green roof systems reach equilibrium in terms of maximum net carbon storage. The Tool currently applies an assumption that green roof systems will reach equilibrium after four years. No carbon sequestration benefits are counted after this time.

For bioretention, rain gardens, and wetlands, the Tool incorporates average sequestration rates based on the range of estimates reported in the literature, as follows:

- Wetlands: 0.41 kg CO_{2eq}/m^2 based on Tan et al. (2015)
- Bioretention, rain gardens, and bioswales: 1.01 kg CO2 eq/m2 based on an average from Kavehei et al. (2018), Flynn and Traver (2013), Jo and McPherson (1995), and City of Calgary (2019).

To monetize CO2 sequestration benefits, the Tool multiplies CO_2 reductions by the SCC (2020 average estimate, 3% discount rate) over time.

J.3.3 Avoided GHG Emissions from Reduced Energy Use

The Tool calculates avoided CO_{2e} emissions associated with avoided energy use based on emissions rates published in the 2018 eGrid database (U.S. EPA 2020). Table J-7 shows the GHG emission rates and transmission loss by eGrid subregion.

To estimate avoided emissions, the Tool multiplies the avoided energy use calculated in a previous step (see Appendix B) by the relevant non-baseload emissions rate for their eGrid subregion, accounting for grid transmission losses. For example, an energy savings of 5 MWh per year in the WECC Northeast (NWPP) would be multiplied by the corresponding avoided emission rate of 1,533.8 lbs/MWh, and again by the transmission loss rate of 4.23%. This yields an estimate of 7,993 lbs of CO2e emission avoided per year (5 MWh * 1,533.8 lbs/MWh * 1.0423 = 7,993 lbs CO2e). When multiplied by the SCC for 2020 of $51/MT, the result is $184.92 (7,993.4 lbs /2,204.6 lbs per metric ton * $51 $/metric ton = $184.92).

Table J-7. eGrid GHG Emission Rates and Transmission Loss Percentage, by eGrid Subregion.

eGRID subregion acronym	eGRID subregion name	Non-baseload output emission rates, electricity (lb/MWh)				Grid Gross Loss (%)
		CO_2	CH_4	N_2O	CO_2e	
AKGD	ASCC Alaska Grid	1,262.5	0.110	0.015	1,269.6	5.12%
AKMS	ASCC Miscellaneous	1,528.3	0.068	0.012	1,533.6	5.12%
AZNM	WECC Southwest	1,435.3	0.097	0.014	1,441.8	4.80%
CAMX	WECC California	929.5	0.047	0.006	932.5	4.80%
ERCT	ERCOT All	1,261.0	0.083	0.012	1,266.5	4.87%
FRCC	FRCC All	1,123.9	0.068	0.009	1,128.3	4.88%
HIMS	HICC Miscellaneous	1,535.7	0.139	0.022	1,545.8	5.14%
HIOA	HICC Oahu	1,682.1	0.159	0.025	1,693.6	5.14%
MROE	MRO East	1,634.3	0.149	0.022	1,644.5	4.88%
MROW	MRO West	1,764.3	0.192	0.027	1,777.0	4.88%
NEWE	NPCC New England	931.0	0.086	0.011	936.5	4.88%
NWPP	WECC Northwest	1,575.1	0.148	0.021	1,585.2	4.80%
NYCW	NPCC NYC/Westchester	1,067.6	0.022	0.002	1,068.9	4.88%
NYLI	NPCC Long Island	1,320.3	0.040	0.005	1,322.8	4.88%
NYUP	NPCC Upstate NY	931.5	0.043	0.005	934.0	4.88%
RFCE	RFC East	1,242.6	0.091	0.013	1,248.6	4.88%
RFCM	RFC Michigan	1,748.9	0.171	0.024	1,760.3	4.88%
RFCW	RFC West	1,828.3	0.179	0.026	1,840.5	4.88%
RMPA	WECC Rockies	1,542.6	0.120	0.017	1,550.7	4.80%
SPNO	SPP North	1,945.5	0.201	0.029	1,959.2	4.88%
SPSO	SPP South	1,603.5	0.118	0.017	1,611.5	4.88%
SRMV	SERC Mississippi Valley	1,137.6	0.069	0.010	1,142.2	4.88%
SRMW	SERC Midwest	1,907.0	0.204	0.030	1,920.9	4.88%
SRSO	SERC South	1,413.7	0.107	0.015	1,420.9	4.88%
SRTV	SERC Tennessee Valley	1,644.3	0.149	0.021	1,654.4	4.88%
SRVC	SERC Virginia/Carolina	1,422.6	0.128	0.018	1,430.9	4.88%
U.S.		**1,432.3**	**0.117**	**0.017**	**1,440.1**	**4.87%**

Source: U.S. EPA 2020.

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APPENDIX K

Ecosystem and Biodiversity Benefits

K.1 Introduction

Urban and suburban areas generally consist of a network of green spaces – including parks, yards, street plantings, greenways, urban streams, commercial landscaping, and vacant lots - that provide important ecosystem and biodiversity benefits. These areas:

- Provide food and refuge for birds, amphibians, bees, butterflies, and other species (Melles et al. 2003, Muller et al. 2010).
- Promote functional groups of insects that enhance pollination and bird communities, which in turn enhance seed dispersal (Andersson et al. 2007).
- Provide landscape connectivity and encouraging the movement of mobile organisms between habitat patches (Elmqvist et al. 2008).

Many green stormwater infrastructure (GSI) practices, including rain gardens, bioretention facilities, trees, retention ponds, and wetlands, can contribute to the network of green spaces that support terrestrial ecosystems and biodiversity in urban and suburban settings. This is particularly true in areas where development and impervious cover have degraded habitat for native species and/or where green spaces are isolated within the built environment. However, urban and suburban ecosystems are complex; the extent to which GSI benefits terrestrial ecosystems depends on several factors, including proximity to other natural areas, design and management of the surrounding built environment, local environmental conditions, and the characteristics of individual GSI projects (e.g., type and diversity of vegetation). Additional research is needed to better understand how GSI practices can be designed and managed to maximize terrestrial ecosystem and biodiversity benefits in different settings.

The ecosystem and biodiversity benefits associated with terrestrial habitat are environmental goods that are not directly traded in the marketplace. Economists have used non-market valuation techniques, including revealed and stated preference methods, to better understand how individuals value this habitat. The GSI TBL Benefit Cost Framework and Tool (Tool) relies on stated preference studies that estimate willingness-to-pay (WTP) for terrestrial habitat of specified quality. The Tool incorporates a range of WTP estimates to determine the monetary value of this benefit across relevant GSI practices.

The following sections provide an overview of findings from the literature related to the terrestrial ecosystem and biodiversity benefits of relevant (i.e., vegetated) GSI practices. Following this review, we provide an overview of the assumptions and methodology that we have incorporated into the Tool for quantifying and monetizing these benefits.

As an important note, in addition to supporting terrestrial ecosystems, GSI provides important benefits for aquatic ecosystems by improving water quality, reducing peak flows (which can reduce flashiness in streams and rivers); and/or recharging groundwater aquifers (which can increase baseflow in local waterways). Flow and the dimensions of flow (magnitude, frequency, duration, timing, and rate of change) directly and indirectly affect biodiversity in aquatic systems. Flow directly affects biodiversity because individual aquatic organisms depend on flow for feeding, reproduction, and movement at least at some point during their life. Flow indirectly affects biodiversity because it influences water quality, food supply, physical habitat, and biological interactions; all of these affect the species that can occupy streams and rivers (MMSD 2018). The benefits of GSI for aquatic ecosystems and biodiversity are included in the valuation methodology for water quality benefits (see Appendix I); they are therefore not addressed here.

K.2 Findings from the Literature

This section provides findings and examples from the literature on the ecosystem and biodiversity benefits associated with vegetated GSI projects, as well as the methods economists have used to value these benefits.

K.2.1 Ecosystem and Biodiversity Benefits of GSI

Relative to many of the other benefits included in the Tool, the terrestrial ecosystem and biodiversity benefits of GSI have been less thoroughly studied. However, research suggests that vegetated GSI practices, such as bioretention, rain gardens, green roofs, and wetlands, can enhance urban ecosystems by creating new habitat and/or improving the quality of existing habitat. The following provides a review of existing research linking GSI practices to urban ecosystem and biodiversity improvements, as well as the design parameters and other factors that affect the provision of these services.

In 2018, the Milwaukee Metropolitan Sewerage District (MMSD) evaluated the potential for its' GSI program to support regional biodiversity efforts. As part of this evaluation, MMSD reviewed available literature to better understand the ability of various GSI strategies to provide direct biodiversity benefits, as well as to identify approaches for better realizing these benefits through strategic GSI application. Table K-1 provides a summary of the author's findings from the literature for the GSI practices that they identified as having a "high" or "medium" potential to provide direct biodiversity benefits, including bioretention, native landscaping, rain gardens, stormwater trees (all rated as having a "high" biodiversity potential), and green roofs (rated as having "medium" biodiversity potential).

MMSD (2018) reports that the extent to which GSI practices provide biodiversity benefits depends on several factors, including basic ecologic principles and the design and management of nearby built areas. For example, the authors cite local environmental conditions (e.g., sun exposure, moisture, priority species) and species interactions (e.g., predation and competition for resources) and mass-effect processes (emigration and immigration) as key factors affecting the ability of GSI practices to provide desired benefits. The authors explain that mass effect processes affect community composition to varying degrees based on species-level behavioral constraints, such as distances travelled for routine movements (e.g., feeding and reproduction) and distances travelled for dispersal. Therefore, given the appropriate environmental conditions, "projects placed closer to natural source populations or primary environmental corridors are, in theory, more likely to become colonized with regional species that use such habitats, provided they are within the routine movement or dispersal distance of the desired species" (MMSD 2018).

Overall, MMSD (2018) notes that there is a small body of literature investigating the ecosystem and biodiversity benefits of green roofs, but there is relatively little information regarding rain gardens, bioswales, native landscaping, and stormwater trees. While research is limited, some studies have documented biodiversity potential of various GSI practices, including the factors affecting the realization of these benefits. For example, Kazemi et al. (2009a) evaluated the biodiversity benefits of bioretention swales, comparing nine swales and nine corresponding "typical" green spaces in Melbourne, Australia. The authors found that number of species, and species richness and diversity were higher in bioretention swales compared to both garden areas and lawn-type green spaces. In addition, larger bioretention basins with more leaf litter, vegetation structure, and number of flowering plants support more insect diversity than other basins (Kazemi et al. 2009b).

Table K-1. MMSD (2018) Summary of Findings for Biodiversity Potential of GSI Strategies.

GSI Practice	Design Parameters Affecting Biodiversity Benefits	Supporting Literature
Bioretention	Type and diversity of vegetation	Kazemi et al. (2009a) found a greater number of invertebrate species in bioretention basins compared to garden bed and lawn-type greenspaces, likely because bioretention basins provide better quality foraging and sheltering habitat. The greater leaf/plant litter depth and larger number of plant taxa were significant contributors to biodiversity (Kazemi et al. 2009b). The bioretention basins also had lower levels of human disturbance than the lawn-type greenspaces that were subject to more human traffic and intensive maintenance regimes such as mowing.
Native landscaping (tallgrass prairie plants)	Type of vegetation	Native plant communities provide important habitat and food for native animals and insects (Tallamy 2009). Because native plants are adapted to the local soils and climate, they may have fewer disease or insect problems. Several studies have found that native plant species support higher biodiversity than non-natives. For example, in the mid-Atlantic region of the U.S., Burghardt et al. (2009) found that native plants supported significantly more caterpillars and significantly higher bird abundance and diversity (likely because most birds feed insects to their young).
Rain Gardens	Type and diversity of vegetation	No empirical studies were found in the peer-reviewed literature documenting the biodiversity value of rain gardens, but MMSD posits that results would likely be similar to those for bioretention basins, which have been shown to have higher invertebrate biodiversity than garden bed and lawn-type greenspaces (Kazemi et al. 2009a). Rain gardens can provide food (fruits, seeds, and nectar) and shelter for birds and other species. Their biodiversity value can be enhanced through careful plant selection (Penn State Extension 2016).
Stormwater trees	Tree size and species	Urban trees serve many different purposes for many different species. They provide habitat, refugia, food, shelter, nesting materials, breeding sites, and locations for perching and roosting (Dunster 1998). Kubista and Bruckner (2015) reported that urban trees provided 50% of the roost sites for several species of bats. Trees also serve as hosts for flora, such as epiphytes (plants that grow harmlessly upon other plants), which can provide rich and diverse habitats for other organisms. Urban trees further benefit wildlife by reducing urban heat island effects and providing nutrients to various levels of the food chain through leaf litter and decaying materials.
Green roofs	Roof height, substrate depth, substrate source/composition, vegetation type, structural diversity	Studies in Europe and America have documented that green roofs can enhance biodiversity in urban settings by providing feeding, breeding, and resting grounds for local and migratory birds (Baumann 2006, Grant 2006, Eakin et al. 2015), habitat for invertebrate species like spiders, beetles, wasps, and bees (Brenneisen 2003, Kadas 2006, MacIvor and Lundholm 2011), and food for pollinators (Colla et al. 2009, Tonietto et al. 2011, Benvenuti 2014). Green roofs can also help facilitate dispersal of wildlife by connecting fragmented habitats (Currie and Bass 2010). The habitat created by green roofs typically does not provide the same quality of food, habitat, or shelter found in nearby (ground-level) natural areas.

Source: MMSD 2018.

Note: Table K-1, column 3 (supporting literature) was taken directly from the Table 3 in MMSD 2018, with some minor modifications.

Several studies have cited the role that trees play in increasing urban biodiversity by providing food, habitat, protection, and landscape connectivity for urban fauna, including small animals, birds, and insects (Lerman et al. 2013, Livesly et al. 2016). In its review of literature on the biodiversity benefits of GSI, MMSD (2018) found that the type and size of trees influence the level of benefits realized. For example, several studies have shown that native tree species support higher diversities and/or abundance of insect and bird species than non-natives (Tallamy 2009, Helden et al. 2012, Ikin et al. 2012, Shackleton 2016). Stagoll et al. (2012) and Shackleton (2016) also found a higher diversity of birds in large versus small urban trees. Both studies emphasized the importance of a diversity of tree sizes to support biodiversity (MMSD 2018).

Others have examined the ecosystem and biodiversity benefits of wetlands and retention ponds. Hsu et al. (2011) evaluated the biodiversity of two constructed wetlands in Taiwan by analyzing the water quality, habitat characteristics, and biotic communities of algae, macrophytes, birds, fish, and aquatic macroinvertebrates. Results indicated that the two integrated wetlands achieved the intended water quality objectives for wastewater treatment. In addition, the authors recorded 58 bird species, 7 fish species, and 34 aquatic macroinvertebrate taxa at the site. Study results showed that wetland area, cover of aquatic macrophytes, and water quality were the most important factors governing the species richness, abundance, and diversity in the wetlands and that factors influencing community structures vary among different taxonomic groups. As described in more detail below, several valuation meta-analyses have also documented the ecosystem/habitat benefits of wetlands (Borosiva-Kidder 2006, Woodward and Wui 2001, Ghermandi et al. 2010).

Studies of biodiversity in retention ponds have also found that key indicators vary based on habitat characteristics or specific attributes. Hamer et al. (2011) tracked the use of retention ponds by frogs in a rapidly-urbanizing region of south-eastern Australia to determine the habitat attributes associated with individual species. The authors detected nine species of frogs at 30 retention pond sites. Again, results highlight the contrasting differences in habitat associations (e.g., site area, waterbody shore depth, time since construction or dredging, aquatic connectivity) among species. Le Viol et al. (2009) compared aquatic macroinvertebrate communities in highway stormwater ponds with ponds in the wider landscape. Highway ponds were found to differ in abiotic conditions from surrounding ponds due to their pollutant removal function; however, they were also found to support aquatic macroinvertebrate communities at least as rich and diverse at the family level as surrounding ponds. In addition, they exhibited similar variability in family community composition and structure. The authors conclude that the similar community compositions and structures suggest that highway ponds contribute to the biodiversity of the pond network at a regional scale.

Oertli and Parris (2019) reviewed 279 studies on the biodiversity of urban ponds, including ponds designed for stormwater management, as well as ponds developed for aesthetic value and/or leisure. The objective of this review was to 1) identify factors that can impair or enhance pond biodiversity; and 2) develop recommendations for managing urban ponds in ways that promote biodiversity benefits while avoiding ecosystem disservices or the creation of ecological traps. The authors found that that the biodiversity of urban ponds, measured by species richness, is generally lower than in rural ponds but that urban ponds often support threatened species. Another key finding is that well-managed urban ponds have the potential to support a much greater biodiversity than they currently do. Local factors that affect biodiversity include design parameters (surface area, pond depth, banks and margins, shade, shoreline irregularity), water quality (conductivity, nutrients, heavy metals), and hydroperiod and biotic characteristics (stands of vegetation, fish, invasive species). Important regional factors include several indicators of urbanization (roads, buildings, density of population, impervious surfaces, car traffic), as well as the presence of other wetlands or green spaces in the surrounding landscape. At the city scale, the biodiversity of a pond-scape benefits from a high diversity of pond types, differing in their environmental characteristics and management.

The above studies describe potential ecosystem and biodiversity benefits associated with ground-level GSI practices. While only a relatively small number of studies have looked specifically at GSI practices within this context, many studies have documented the benefits that other types of green space provide in terms of habitat connectivity (Elmqvist et al. 2008). Elmqvist et al. (2008) notes that increased habitat connectivity prevents local extinction, facilitates re-colonization, and is important for maintaining vital biological interactions (e.g., plant-pollinator interactions and plant-seed dispersal). This suggests that strategically located ground-level GSI holds significant potential to enhance local ecosystems. However, Lepczyk et al. (2017) writes that more information is needed on required patch size, and the extent and heterogeneity of overall green networks, in order to fully realize ecosystem and biodiversity benefits.

As noted above, there is a small but developing body of literature on the ecosystem and biodiversity benefits associated with green roofs. In general, research suggests that green roofs have greater species diversity than conventional roofs and can provide habitat for both generalist and (some) rare species (Williams et al. 2014). For example:

- MacIvor and Lundholm (2011) compared insect richness, abundance, and diversity indices on five pairs of intensive green roofs and adjacent ground-level habitat patches in Halifax, Nova Scotia. The authors detected no significant differences in any of the indices between the two groups; however, richness and abundance tended to be greater at ground level for all orders (except for Heteroptera, often referred to as true bugs) and diversity was higher sites located further from the downtown core. Insect composition differed slightly between green roof and ground level sites; however, a wide variety of insects, including many uncommon species, were collected from the green roofs.
- In a study of 115 green roof sites in northern France, Madre et al. (2013) found that green roofs with more complex vegetation supported significantly higher species richness and abundance of arthropods (beetles and spiders) and hymenopteran (ants, wasps, and bees) taxa.
- Based on analysis of the same 115 sites, Madre et al. (2014) found substrate depth was the most important factor in increasing wild plant diversity on green roofs designed to accept colonizing species. In addition to substrate depth, the taxonomic and functional compositions of the colonizing plant communities varied based on green roof age, surface area, and height and maintenance intensity at the building scale.
- Tonietto et al. (2011) assessed the potential value of green roofs for native pollinator conservation in the Chicago region, comparing them with reference habitats of tallgrass prairie natural areas and traditional city-park green spaces. The authors found that native bees are present on green roofs, though at lower abundance and diversity than in reference habitats. Overall, bee abundance and species richness increased with greater proportions of green space in the surrounding landscape. However, this relationship disappeared in cases where green space was dominated by turf grass. At the site scale, bees benefited from greater diversity of blooming plants.
- Braaker et al. (2014) studied the effectiveness of extensive green roofs facilitate connectivity of arthropod communities within the urban environment. The study revealed that community composition of high-mobility arthropod groups (bees and weevils) on green roofs were mainly shaped by habitat connectivity, while low-mobility arthropod groups (carabids and spiders) were more influenced by local environmental conditions. The authors conclude that the high importance of habitat connectivity in shaping the community composition of high-mobility species indicates a frequent exchange of individuals among surrounding green roofs. However, low-mobility species communities on green roofs are more likely connected to ground sites than to other green roofs.

While evidence suggests a potential role of green roofs in enhancing urban ecosystems and promoting biodiversity, Williams et al. (2014) notes that very few ecological studies with adequate replication and controls, or of sufficient duration, have assessed this. Specifically, the authors state that the ability of green roofs "to support similar biodiversity to ground-level habitats, replicate ground-level ecological communities, or facilitate the movement of organisms through urban landscapes is still unclear." For example, the authors note that the only study to directly address connectivity between green roofs (Braaker et al. 2014, described above) concluded only that higher proximity facilitated a greater exchange of individuals between green roofs. The study also found that many species identified only occurred on green roofs, and not in adjacent urban green areas, suggesting that high-mobility (flying) species originate in habitats outside of the city. The extent to which green roofs provide a connectivity benefits depends on the species' typical flight distances (Williams et al. 2014).

Maynard and Clergeau (2018) report similar findings, cautioning that the role of green roofs in urban wildlife corridors remains questionable because of limited patch size, distinct habitat quality at the building scale, and limited redundancy of the patch quality within the landscape. Potential habitat and biodiversity benefits also seem to depend on building height. Madre et al. (2013) found that spider diversity is inversely related to green roof height. Other researchers have reported declines in solitary bee and wasp numbers nesting in artificial nests (MacIvor 2013) and in overhead bat activity (Pearce and Walters 2012) with increasing green roof height.

K.2.2 Valuing Urban Ecosystem and Biodiversity Benefits

With the exception of wetlands, we did not identify any studies that separately value the terrestrial ecosystem and biodiversity benefits associated with specific GSI practices. However, we identified a few studies that provide or estimate these values in similar contexts. These studies provide insights into the monetary values associated with potential ecosystem benefits.

For example, Liu and Swallow (2016) conducted a series of choice experiments[29] to elicit values that individuals place on the co-benefits associated with water quality projects that are sold in the form of credits (represented by pounds of nutrient reduction per year) in the Ohio River Basin water quality trading market. The choice experiment method enabled the authors to estimate individual values for co-benefits relative to the public-good value for water quality improvement, based on the descriptions of real projects that were sold in the market.

To conduct this analysis, the authors surveyed 117 undergraduate students, using three different survey methods to help ensure robustness of the elicitation method relative to response incentives and consequentiality.[30] The study was conducted from the perspective of a conservation buyer of credits (rather than from buyers seeking compliance offsets). Results indicated that WTP is affected not only by the quantity of water quality credits but also by the associated co-benefit profile, including habitat enhancement and pollinator habitat, which were defined in the survey as follows:

[29] Choice experiments fall within the class of stated preference valuation; this method allows researchers to understand how individuals value selected attributes of a program or service by asking them to state their choice over different hypothetical alternatives.

[30] The three elicitation methods included: 1) Hypothetical referendum, where individuals are told their decisions will be used for policy analyses only; 2) Real referendum lacking incentive compatibility, where individuals are told their decisions will influence real purchase decisions, and that the influence will be through aggregated decisions of their group. 3) Real choice with incentive compatibility, which includes a random lottery decision rule where respondents were told that the authors would implement the actual choices made by a randomly chosen individual. According to authors, the first two treatments present opportunities for individuals to misrepresent their true preferences in a strategic effort to generate outcomes they prefer without fully accounting for personal cost. The third procedure makes the choices real, not simply stated.

- **Habitat Enhancement:** Add more diversity and select species of vegetation that benefit wildlife by providing food and cover.
- **Pollinator Habitat:** Provide food, habitat and cover to pollinators including honeybees, solitary bees, and other pollinators (e.g., bats).

Table K-2 shows the results of the analysis across the three survey elicitation methods (Models 1 through 3), as well for a model that pools all responses together (i.e., estimates WTP across all three elicitation methods). Values shown represent WTP per water quality credit, equivalent to one pound of nutrient reduction, overall, as well as for individual co-benefits. As shown, WTP varies from $0.22 to $0.51 per credit, accounting for 9% to 10% of total credit value across all models. While water quality projects may be somewhat different than the GSI practices included in the Tool (e.g., many of them are implemented on agricultural land), they do often share similar characteristics. Results from Liu and Swallow indicate a WTP for habitat enhancement and pollinator habitat, which are attributes that can be incorporated into many vegetated GSI projects.

Table K-2. Willingness-to-Pay for Water Quality Credits and Associated Co-Benefits, across Liu and Swallow (2016) Four Economic Models.

(2019 USD[a])

Credit Benefit Categories	Pooled	Model 1	Model 2	Model 3
Water quality credit only	$2.08	$2.82	$2.44	$1.38
Nitrogen[b]	$0.04	$0.06	$0.05	$0.03
Agricultural viability	$0.05	$0.08	$0.05	$0.03
Carbon sequestration and soil health	$0.46	$0.72	$0.50	$0.29
Habitat enhancement and pollinator habitat	$0.37	$0.55	$0.39	$0.24
Runoff reduction	$0.41	$0.64	$0.44	$0.26
Reduced animal stress and mortality	$0.46	$0.72	$0.51	$0.30
Co-benefits total	$1.78	$2.71	$1.89	$1.12
Water quality credit and co-benefits	$3.84	$5.52	$4.33	$2.50

a. Updated from 2015 USD using CPI

b. Represents additional WTP for nitrogen credits vs. phosphorous credits

Source: Liu and Swallow 2016.

To put the price of a credit in the context of WTP per acre of habitat, we used U.S. EPA's Region 5 Model for Estimating Pollutant Load Reductions to translate credits into standardized areas for two stormwater control measures (SCMs): infiltration basins and Low Impact Development (LID) bioretention (as defined by the U.S. EPA Model). We calculated total annual nitrogen reduction (lbs) resulting from implementation of the respective SCMs for managing runoff from approximately 120 impervious acres across a range of land uses.[31] On average, the SCMs would reduce 172 pounds of nitrogen per year per acre of SCM; this equates to 172 credits per year per acre. Thus, using the average WTP estimates for habitat enhancement and pollinator habitat from Table K-2 ($0.39 per credit average across the four models), the average annual benefit per acre would amount to $66.33 (2019 USD). This represents the marginal WTP for one-acre habitat by so-called "conservation buyers." Thus, it reflects a market price, rather than a total value across individuals who value this service.

Several studies have attempted to value the ecosystem/habitat values associated with wetlands through meta-analyses (e.g., Woodward and Wui 2001, Borosiva-Kidder 2006, Ghermandi et al. 2010). These analyses aggregate and statistically analyze wetland valuation studies to better understand the factors that determine wetland value. For example, Woodward and Wui (2001) examined 39 wetland valuation

[31] Analysis assumes management of a 200-acre watershed that is 55% impervious (117 total impervious acres). Percent imperviousness was determined using standard impervious area cover estimates from the NLC database.

studies that produced 65 observations of wetlands located worldwide. A key objective of this analysis was to understand how different wetland services, including habitat provision, influence wetland value.

To conduct this analysis, the authors developed a regression model to analyze the 65 wetland value observations. The dependent variable in the model is the natural log of the value per acre of wetland (1990 USD). The 23 independent variables included wetland size and type (i.e., coastal v. non-coastal), ten binary variables representative of the services provided by the wetlands (including habitat provision), five variables related to study methodology (e.g., whether the value was an estimate of producer's surplus, used stated or revealed preference techniques), three variables related to study quality, variables describing study publication year and location, and a constant term.

Results of the model indicate the extent to which the presence of various wetland services changes the value per acre. The authors used these results to estimate the value of single-service wetlands for each of the ten wetland services included in the model. Table K-3 shows the results, including the estimated value of a wetland that only provides habitat value compared to the value of wetlands that provide other (single) services. As shown, the authors estimate that habitat value for wetlands amounts to $599 per acre per year (2019 USD). In this case, habitat provision was defined as nonuse appreciation of aquatic, terrestrial, and avian species associated with wetlands.

Table K-3. Woodward and Wui (2001) Annual per Acre Values for Single-Service Wetlands.
(2019 USD)

Wetland Service	Mean Value[a,b]
Flood risk reduction	$769
Water Quality	$816
Water Quantity	$248
Recreational fishing	$698
Commercial fishing	$1,522
Bird hunting	$137
Bird watching	$2,371
Amenity value	$6
Habitat provision	**$599**
Erosion reduction	$464

Source: Adapted from Woodward and Wui 2001.

a. Predicted values are obtained at the means of year and acre variables from meta-regression model. Values do not represent marginal values and cannot be summed to obtain the value of multiple function wetlands.
b. Updated from 1990 to 2019 values using CPI

Ghermandi et al. (2010) used meta-analysis to analyze the value of both natural and human-made wetlands, relying on 418 value observations derived from 170 valuation studies and 186 wetland sites worldwide. A key objective of this study was to explore the variation in wetland values associated with different wetland types (e.g., human-made, riverine, estuarine) and ecosystem services, including biological diversity enhancement, among others. The dependent variable in the meta-regression model is the natural log of wetland value per hectare per year (in 2003 USD). Dependent variables include variables related to study characteristics, wetland characteristics, characteristics of the study area and population, and ecosystem services provided by the wetland (Table K-4). The authors note that the study expands on previous meta-regression models by including explanatory variables related to the presence of substitute sites and the anthropogenic pressure exercised on the wetlands.

Table K-4. Variables Included in Ghermandi et al. (2010) Meta-Regression Model of Wetland Values.

Variable Category	Variables in Meta-Regression Model
Study characteristics	*Valuation method:* Contingent valuation method; hedonic pricing; travel cost method; replacement cost; net factor income; production function; market prices; opportunity cost; choice experiment. *Value estimate:* average price; marginal price *Year of publication* (from year of first valuation, 1974)
Wetland type / characteristics	*Wetland type:* Estuarine; marine; riverine; palustrine; lacustrine; human-made Wetland size *Anthropogenic pressure:* Low; medium-low; medium-high; high
Ecosystem services	Flood control and storm buffering Surface and groundwater supply Water quality improvement Commercial fishing and hunting Recreational hunting Recreational fishing Harvesting of natural materials Fuel wood Non-consumptive (passive) recreation Amenity and aesthetics **Natural habitat and biodiversity**
Study area context	GDP per capita (2003 USD) Population density Wetland abundance

Source: Adapted from Ghermandi et al. 2010.

Results of the model indicate that wetland type appears to significantly affect the value; human-made and marine wetlands are the most highly valued wetland types. The authors note that a possible explanation for the high value of human-made wetlands is that they are usually constructed with the specific purpose of providing services for human use and thus their value is more easily realized and recognized by the local population. In addition, the coefficient on natural habitat and biodiversity is highly significant and positive, indicating that individuals place a value on the ecosystem benefits that wetlands provide. The coefficient on wetland size is negative, indicating decreasing returns to scale, and studies that estimated marginal values yielded higher values than those that estimated average values (likely because of the context within which these studies were conducted).

The authors looked at the cross-effects of different wetland types and ecosystem services. A somewhat surprising result to the authors was that the coefficient of provision of natural habitat and biodiversity in human-made wetlands is positive and highly statistically significant, despite the fact that such service is generally not a primary goal in the creation of such ecosystems. The large size of the coefficient, compared to other cross effects, suggests that the ecosystem benefits provided by wetlands represent an important component of their total economic value (Ghermandi et al. 2010).

We used the meta-regression model developed by Ghermandi et al. to estimate the marginal value per acre associated with wetlands under a range of assumptions. We started with the author’s baseline model, using the sample means for most variable values (i.e., the average values across studies) but comparing the effect of changing the value for natural habitat and biodiversity from 0 to 1. This allows us to isolate the effect of natural habitat and biodiversity on overall wetland value. We also examined the effects of changing additional variable values to better fit the context of constructed/restored wetlands (i.e., human-made) within urban and suburban settings. Table K-5 shows the results of this analysis, indicating a range of per acre values for wetland habitat and biodiversity of between $670 and

$4,264. Each row in Table K-5 builds on the previous row such that previous variable changes are kept in each calculation.

Table K-5. Ghermandi et al. (2010) Meta-Regression Model Results, Assuming Different Variable Values. (2019 USD)[a]

Variable Values/Changes	Natural Habitat and Biodiversity Benefit (Per Acre Per Year)
Value of wetland habitat and biodiversity using study sample means and setting wetland type to "human-made" (i.e., net change in value of constructed wetlands when natural habitat and biodiversity is set to 0 and 1, all other variables are equal)	$670
Marginal value variable set to 1 (habitat and biodiversity value represents marginal benefit)	$1,253
Ecosystem services of fuel wood provision, commercial hunting and fishing, and recreational hunting set to 0 (assumes these ecosystem services are not typically provided by wetlands constructed for stormwater purposes)	$1,060
Anthropogenic pressure set to "medium to high human pressure"	$2,060
Population density variable change to reflect current average population density for metropolitan statistical areas (MSAs, which include suburbs) within the U.S. (283 persons per sq. mile)[b]	$2,917
GDP per capita variable changed to reflect average 2017 values for average across MSAs[c]	$4,264

Source: Values calculated based on meta-analysis model developed by Ghermandi et al. 2010.

a. Updated to 2019 USD using CPI
b. University of Michigan, Center for Sustainable Systems, 2018
c. Deflated to 2003 USD to fit within model parameters; represents real 2017 values (most recent available information)

Borosiva-Kidder (2006) also conducted a meta-analysis of wetland values, similar to those previously described, as part of a Master's thesis. This meta-analysis incorporated 72 separate observations of wetland value from 33 studies conducted in the U.S. However, in the model developed by the author, habitat was not found to be a statistically significant factor in the determination of wetland value. Note that this does not necessarily mean that the there is no value associated with the habitat services that wetlands provide, but that the value of wetlands that provide this service are very close to the average value for all wetlands (Woodward and Wui 2001).

As part of the same research effort, Borosiva-Kidder also conducted a meta-analysis of studies conducted in the U.S. that attempt to value terrestrial habitat through non-market valuation. The authors were only able to identify 11 (with 23 observations) to include in the analysis. Results indicated an overall WTP for terrestrial habitat of $180 per acre per year (on average); however, many of the studies included in the analysis were performed within the context of large conservation areas (e.g., wildlife refuges, ranches) – the average size of the environmental amenity being valued was close to 30,000 acres. Thus, this estimate is not directly applicable to the value of terrestrial habitat in developed areas, where habitat is typically scarcer and provides different types of services.

K.3 Tool Methodology for Quantifying and Monetizing Ecosystem Benefits

As documented above, evidence suggests that vegetated GSI practices, including rain gardens, bioretention areas, wet ponds, trees, wetlands, and green roofs, have the potential to provide direct ecosystem and biodiversity benefits. However, additional research is needed before the value of these benefits can be fully understood and definitively estimated. Economists have conducted studies to value biodiversity and ecosystem benefits associated with a range of urban habitat types. The Tool relies on these studies to help users develop a ballpark estimate of the potential biodiversity and ecosystem benefits associated with GSI.

Ecological studies have identified the various factors and design parameters that influence the ability of different GSI practices to provide habitat/support ecosystem functions. These factors include GSI design parameters, ecological conditions, and overall landscape characteristics. To realize ecosystem and biodiversity benefits, GSI practices must be designed with these factors in mind. However, it is likely that site-specific conditions and/or competing objectives may not allow for the full realization of these benefits.

As a starting point, the tool calculates the total area of GSI practices that have the potential to provide habitat value using design parameters assumed in the GSI scenario (for trees, the tool uses crown area). The Tool then allows the user to apply an adjustment factor to account for the percentage of GSI area that will likely provide habitat value, by practice type (e.g., the percentage that might be specifically designed for this purpose). The Tool includes a default adjustment factor of 80%; however, this can be easily changed by the user. These inputs provide the user with an estimate of total habitat area by practice type. Again, this methodology is intended to provide a ballpark estimate of potential ecosystem and biodiversity benefits.

Based on the research reviewed for this study, it is evident that not all GSI practices are considered equal in terms of ecosystem and biodiversity value. For example, wetlands seem to have greater richness and abundance of flora and fauna compared to many other GSI practices. Green roofs generally provide fewer benefits compared to ground-level practices, while some practices can be designed to support specific species of interest (e.g., to enhance pollination). The monetary value of ecosystem and biodiversity benefits should vary accordingly.

To account for these differences, the project team searched for quantitative studies that would allow us to develop a relative ranking (e.g., through the use of biodiversity indicators) of different GSI practices or types of green space in developed areas. However, we were not able to develop such a methodology within the scope of this research. As a proxy, we have assigned a relative ranking to the suite of GSI practices that provide ecosystem and biodiversity benefits (based on qualitative research) using a 5-point scale.

The Tool applies monetary estimates from the literature for wetlands and scales the value to different GSI practices according to the relative ranking. Starting with wetlands, the Tool assigns a value of $4,264 per acre per year of wetland habitat. This represents the value from Ghermandi et al. (2010, updated to 2019 USD) for the marginal habitat and biodiversity benefit of constructed wetlands that provide multiple services (not including fuel wood provision commercial fishing or hunting, or recreational hunting), faces medium to high anthropogenic pressure, and is adjusted to the average population density and GDP per capita for all U.S. metropolitan statistical areas.

The Tool scales this value to the other practices based on their relative ecosystem/biodiversity ranking. Table K-6 shows the relative rankings and associated ecosystem/biodiversity values of relevant GSI practices.

Table K-6. Relative Ecosystem/Biodiversity Rankings and Values for Relevant GSI Practices Incorporated into Tool.
(2019 USD)

GSI Practice	Relative Ecosystem / Biodiversity Ranking	Monetary Value ($ Per Acre Per Year)
Wetlands	5	$ 4,264
Wet ponds and trees	3	$ 2,558
Rain gardens and bioretention areas	2	$ 1,706
Green roofs	0.5 to 1.5 (extensive/intensive)	$ 853 (average)

K.4 References

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APPENDIX L

Flood Risk Reduction Benefits

L.1 Background

Green stormwater infrastructure (GSI) can reduce the risk of localized flooding in urban and semi-urban settings. This in turn reduces flood damages to buildings and their contents, streets and other public infrastructure, stream channels and other environmental amenities. GSI can be especially effective at reducing peak flood flows, rather than preventing flooding altogether, and is particularly effective at reducing flood risk associated with smaller storm events– i.e., for the 2-year storm event rather than the 100-year storm event (Medina et al. 2011).

Municipalities experience several different types of flooding. Large-scale riverine flooding is a caused by rivers overflowing their banks. These floods can be influenced by conditions upstream of the municipality by many miles, and the degree and timing of flood flows are usually beyond the control of municipalities. Coastal flooding can combine rain events with storm surge (which can be influence by sea level rise) to present flooding risk. The third major type of flooding is urban flooding, which often involves localized flooding that can be separate from, or in addition to, riverine or coastal influences.

Localized flooding occurs when rain overwhelms drainage systems and waterways. Often the design and the capacity of local storm sewers help determine the extent of flooding associated with local rain events. Localized flooding also can occur as a result of local infrastructure limitations or temporary infrastructure repair needs. For instance, if local pump station capacities are overloaded by runoff from rain events, then localized flooding can occur. As documented by CNT (2014), the impacts of localized flooding can be significant, resulting in street flooding, sewage pipe backup into buildings, seepage of water through building walls and floors, and the accumulation of stormwater on property and in public rights-of-way.

The following sections describe different methods that researchers and public agencies have used to quantify and monetize the impact of flooding (and the benefits of flood risk reduction projects). As an important note, the impacts of GSI on urban flooding can be very site-specific, depending on rainfall amounts, soil types and infiltration rates, impervious surfaces, slopes, and hydrology. As noted above, distributed GSI is likely most effective in reducing the impact of localized flooding from smaller storm events; however, it can also help ameliorate riverine flooding (especially in downstream locations in the watershed) and coastal flooding (e.g., when employed as a buffer against tidal surges).

L.2 Findings from the Literature

L.2.1 Flood Damage Estimation

The benefits of flood protection have been studied for many years; standard methods have been developed by the U.S. Army Corps of Engineers, the Federal Emergency Management Agency (FEMA), and other U.S. agencies (e.g., USACE 1996) for valuing avoided flood damages. This approach values flood damage using the replacement value of the buildings and their contents that are flooded. It usually involves evaluating the return period for different storm events (e.g., 10-, 20-, 50-, and 100-year event) and translating the rainfall associated with these storm events is into runoff. Hydrologic modeling is then used to determine the depth of flooding associated with the different storm event return periods. Depth to damage functions are used to translate the depth of flooding into building damages given the existing stock of buildings and their general classification (e.g., residential, commercial, industrial) or specific industry classification codes. The range of storm event return periods and their expected damage amounts can then be used to calculate an equal annual expected amount of damage across all storm event types. Avoided flood damage as a result of a flood protection measure can then be computed as the difference in expected damage between the with- and without-project conditions.

Medina et al. (2011) took this approach to develop a model and case study application to estimate flood damage reduction benefits of GSI. The authors found significant avoided flood damage potential for GSI, especially when applied at the watershed scale and in watersheds with pervious soils.

L.2.2 Use of Property Values to Estimate Change in Flood Risk

Several studies use hedonic pricing methods to measure the value of reduced flood risk for properties. The hedonic pricing method uses regression analysis to attribute home price to each of the attributes that affect its value. In this case, one of the attributes identified is the housing price discount associated with locating a building inside of the 100-year floodplain compared to a similar building located outside of the floodplain. These hedonic price studies have generally found that homes within the 100-year floodplain are discounted by 2% to 12% compared with equivalent homes outside the floodplain (Braden and Johnston, 2004; Bin and Polasky 2004; CNT and American Rivers, 2010). A hedonic study that specifically accounted for the influence of coastal flood risk reduction projects on housing prices estimated the effect of property location within the floodplain to be 7.8% (Bin, Kruse, and Landry 2008). A range of 2 to 5% from Braden and Johnston (2004) might be used as a conservative estimate of this range.

To use the property value estimates in a specific location, hydrologic modeling is needed to estimate the impact of a GSI project or program on the extent of flooding, and to identify the area where annual flood risk can be reduced from greater than one percent to less than one percent due to a GSI approach. The difference in estimated housing value inside the floodplain compared to outside of the floodplain can then be used to value the impact of the flood risk reduction. Specifically, that value is calculated as the number and value of the homes that are affected by the change in floodplain boundary, multiplied by the range of percent change in housing value.

Johnston, Braden, and Price (2006) estimated the benefits of residential conservation development on flooding using two methods – 1) applying the 2-5% range for change in property value due to location in the floodplain and 2) avoided flood damage estimation. The authors found similar values from each approach.

L.2.3 AutoCASE/Envision BCE Evaluator

Envision's stormwater management business case evaluator (BCE) and the related Autocase, a proprietary software tool signed to conduct TBL-based benefit cost analysis, includes a methodology intended to evaluate the reduction in flood damage from installation of GSI at the site level (Parker and Meyers 2015). Based on existing documentation, Autocase calculates the value of avoided flood damage as follows:

Total Value of Flood Risk Mitigated = Total Value of Property at Risk in the City * (Reduction in flood volume due to project/Total city wide flood volume).

To calculate the total property value at risk in the city, the BCE Evaluator/Autocase determines the total property value in the city using median house value and the number of houses in the city. It then assumes that the percent of residential property value at risk in any storm event (e.g., the 5-, 10-, 25-, 50- and 100-year storm events) is equal to the ratio of the respective state's flood damage (for each year from 1955 to 2003) to the total property value for each state in each year. This step is used in lieu of hydrologic modeling and property inventories in HAZUS that would show what properties would be flooded in the city with different storm return periods, and would provide the associated property values.

To calculate the total city-wide flood volume during storms, the BCE evaluator calculates the representative depth of stormwater associated with the various storm events, subtracts the amount of that stormwater depth that will be infiltrated into the ground assuming predominant land cover and soil types, using the "Curve Number" method[32] created by the Natural Resources Conservation Service (USDA, 1986), and then subtracts the average stormwater drainage capacity of the municipal sewer system for the city using a user-defined "strongest storm event that does not cause flooding".

Next, the BCE Evaluator calculates the reduction in flood volume due to the project. For the without-project runoff volume, it calculates the runoff depth from the project site using the expected precipitation depth (in inches) from the standard flood events (5-, 10-, 25-, 50- and 100-year storm events) multiplied by the site surface area to get the runoff volume. It subtracts the current amount of runoff that is infiltrated using the *current* curve number (with GI), and subtracts any current drainage capacity from the site.

For the with-project runoff volume, it takes the total runoff depth from the standard flood events and subtracts the amount infiltrated with the project using the *expected* curve number (with the project) from the total runoff depth, and subtracts any expected drainage from the site.

To determine the reduction in flood volume, the with-project flood volume is subtracted from the without project flood volume.

L.2.4 Flood Damage Functions

U.S. EPA (2015) conducted a national study using 20 watersheds in the United States to examine the effect of GSI on avoiding flood damages as applied to new development or redevelopment (not retrofits of properties). The study estimated flood depths with and without GSI and determined the value of avoided flood damages using the building inventory approach. The study examined avoided flood damage benefits from 2020 to 2040; benefits increase over time as more development and redevelopment is implemented.

The study points out that GSI has a greater relative effect on avoiding damage from small flood events (e.g., 2-, 5-, or 10-year flood events) than on larger events (e.g., 100-year flood events). Specifically, the study states that GSI flood depth reductions typically range from 0.5 to 1.5 inches. In most locations, this represents a much greater share of the flood depth from 2-year flood events than the depth from 100-year events.

The study modeled three retention scenarios – the 85th, 90th and 95th percentile storm, but concentrated on the 'medium' scenario of retaining the 90th percentile storm. The analysis was applied at the HUC8 watershed level in each location, and GSI was applied to the urban development areas in that HUC8.

Across the modeled locations, the estimated reduction in floodplain area was up to 8% for the 2-year event, whereas the maximum floodplain reduction was 2.5% for the 100-year event.

The study used the FEMA's HAZUS model to estimate the property damage with and without GSI controls. HAZUS assumes that assets are evenly distributed geographically across each Census tract,

[32] The Curve Number approach estimates the depth of runoff in inches, given the amount of rainfall and the predominant local land cover type and hydrologic soil group classification.

whereas in reality structures are not usually located in the most flood-prone portions of the floodplain. As a result, the study adjusts these estimates to assign zero damages to structures in 3 different scenarios -that no assets exist in the 2-, 5- or 10-year flood plains, assuming that structures will not be located so close to flood-prone areas.

The study estimated damage functions to extrapolate the study's findings to other watersheds that were not modeled. Damage equations were estimated for the 2-, 5-, and 10-year zero damage thresholds – in order to capture damages above those thresholds. The study used these damage functions to estimate that national annual avoided flood damage in the year 2040 from installation of GI totals from $63 to $136 million (2011 dollars). Averaged over the 20 years from 2020 to 2040, the benefits range from $30 million to $65 million per year. The present value benefits over that time period range from $0.4 to $1 billion.

L.2.5 Other Literature/Approaches

Other approaches to estimating flood damages related to stormwater have been used in the literature. These estimates are partial approaches to valuing flood risk reduction (e.g., from wetlands or trees) or represent household willingness to pay specific to particular locations.

- Wildish and Schmidt (2019) estimated flood risk reduction for a hypothetical wetland using a value of $0.146 per square foot (in 2019 dollars) of wetland from the literature (McPherson et al., 2005). This value was applied to the total square footage of the wetland and the drainage area flowing to the wetland.
- Woodward and Wui (2001) summarized the value of flood risk reduction from wetlands from a meta-analysis of the literature. The mean value from single-service wetlands for flood risk reduction was $567 per acre (2019 dollars; $0.013 per square foot).
- Wildish and Schmidt (2019) also calculated the flood risk reduction benefit of trees using a value of stormwater capture for trees from the literature of $7.63 per tree (McPherson and Pepper, 2012; in 2019 dollars). The authors adjusted for tree age by applying an adjustment factor based on average tree height by age.
- Brent et al. (2017) found that Australians in Sydney and Melbourne valued prevention of flash flooding via distributed GSI at A$104 (US$80 in 2017 USD using 2017 AU/US exchange rate, or $83 in 2019 dollars) per household per year. The value for flood risk reduction is less than the annual values per household for valuing improvements in local stream health (A$297) and exemption from water restrictions (A$244), but more than the value of decreased urban peak temperatures (A$65).
- Cadavid and Ando (2013) found that Champaign-Urbana Illinois residents who have basements and have experienced basement flooding, would be willing to pay around $35/year ($38 in 2019 dollars) to make basement flooding 50% less frequent. The authors found that residents valued reduced basement flooding more than reductions in yard or street flooding, but WTP for basement flood reduction in the area only exists if individuals are currently experiencing significant flooding themselves.

L.3 Potential Flood Risk Reduction Valuation Methodologies

There are several possible methods for valuing flood risk reduction benefits within a future update of the Tool. Selection of the method to use may depend on available data and resources, as well as the relative level of confidence of the user in each method.

One potential method is to use the avoided flood damage equations from U.S. EPA (2015). The equation for the 10-year zero-damage threshold is shown as Figure L-1. Damage functions for the 2- and 5-year zero-damage thresholds have a similar composition.

$$\frac{AALA_{2006}}{E_{2006}} = \exp\left(-0.7496 + 2.0992\left[\frac{A_N + A_R}{A}\right]^{0.5} + 0.2339\,HS - 0.0184\,R\right) - 1$$

Figure L-1. 10-Year Zero-Damage Threshold Function for Avoided Flood Losses.
Source: U.S. EPA 2015.

Where:

$AALA_{2006}$ is the avoided flood losses in 2006 in millions of dollars (2006 dollars)
E_{2006} is the total exposure in 2006 in millions of dollars (2006 dollars)
AN is the area of new development in 2040 (mi^2)
AR is the area of redevelopment in 2040 (mi^2)
A is the watershed area (mi^2)
HS is the rainfall depth of the 100-year storm (in)
R is the average annual rainfall (in)

In addition to more common data such as watershed area, or average annual rainfall, this method requires the user to estimate some inputs that are not normally estimated or collected. In particular, those variables are E_{2006}, AN and AR. E_{2006} is the equivalent to the value of the total building stock in 2006. This can be complied from data in FEMA's HAZUS model.

Utilities will need to estimate AN and AR with assistance from City departments such as Planning or Economic Development. AN is a projection of the cumulative square miles of area under new development in 2040. AR is a projection of the area of redevelopment in 2040. This approach assumes that there is a requirement to install GSI in new development and redevelopment to control the 90^{th} percentile storm (usually the first one inch of rainfall). However, as a proxy, users could treat the area retrofitted with GSI (e.g., acres managed) as the redevelopment area.

Another method is to apply the values from the literature on the effects of flood risk reduction on classification of properties as being in the 100-year floodplain, and its effect on property values. A conservative range of estimates from the literature is that the value of properties located within the 100-year floodplain are discounted by 2 to 5% compared to properties not located in the floodplain. Application of GSI at the city/regional scale may reduce the boundary of the 100-year floodplain. The increase in value of buildings because they are no longer classified as being within the 100-year floodplain can be counted as a measure of the value of installing GI for flood protection.

Application of this method requires hydrologic modeling to estimate the impact of GSI on the 100-year floodplain boundary. This method also requires a count of homes where annual flood risk can be reduced from greater than one percent to less than one percent due to a green infrastructure approach, and an estimate of the value of those homes. Following Johnston, Braden, and Schwartz (2006), data from the US Census Bureau can be used to obtain property value estimates. Local county assessor's office, the Multiple Listing Service (MLS), or property value websites such as Zillow may be alternate sources of property value data.

Utilities will need several sets of resources into order to pursue the standard method for valuing avoided flood damages. To calculate the depth of flooding, utilities will need a rainfall-runoff model or to use a method such as NRCS's curve number. A hydrologic model will be needed to understand the spatial pattern of runoff. FEMA's HAZUS model, HEC-FIA, or a similar resource will be needed to get an inventory of buildings in the municipality by property type and number of stories in the building, and property value estimates. The HAZUS model, HEC-FIA, or USACE's depth to damage functions can be used to estimate amount of property damage given the depth of flooding. The HAZUS model can also be used to calculate the equal annual expected damage with and without GI across a range of potential storm event return periods.

The AutoCASE/Envision BCE evaluator approach could also be used to estimate damages. This approach would require several sets of data, all of which could be built into the Tool. In this manner, utilities would not need to bring outside resources to use of the tool. Required data or approaches would include:

- Acres of land by land type in the municipality (analysis area) – e.g., open space, impervious area, residential, commercial, or industrial
- Average curve number for the municipality according to the NRCS curve number method
- Weather data with maximum 24-hour precipitation depths and daily weather data across the county
- Data on damage from flood events for each state (available from the Flood Reanalysis Database-Pielke et al. 2002), and total property value in the state from HAZUS or another source

L.3.1 Limitations/Gaps/Uncertainties

Each approach has its own limitations. The following bullets list the main limitations for each method:

- A straightforward flood damage study requires access to various models (rainfall to runoff, hydrologic, and damage estimation models) and technical expertise to run them.
- The property value approach to reduction in flood risk relies on the classification of the 100-year floodplain, which is at odds with the fact that the agreed effect of GI is not on the 100-year storms but instead on the 2-, 5-, and 10-year storms.
- The AutoCase approach provides only an approximate sense of the avoided flood damage. For instance, use of state-level flood damage estimates as a percentage of total state property value is a rough approach for determining the property value at risk in a municipality.
- The damage functions from U.S. EPA 2015 were based on a small number of watersheds (20), and there were not enough watersheds to also independently assess the accuracy of the functions on watersheds not already used to estimate the functions. Applying these damage estimates to additional watersheds that have an independent estimate of the value of GSI on flood damage avoidance would help assess the accuracy of those functions.

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