FEMA Economic Benefit Values for Green Infrastructure

July 2022

FEMA

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1. Background and Purpose of this Report

1.1. Background

Natural disasters are increasing in frequency and severity in the United States (U.S.) and around the globe. Climate change and other factors—including land use planning decisions that have allowed people to live in hazard-prone areas—are behind the increase. Since 1980, the U.S. has experienced 308 weather and climate disasters that accrued $1 billion in damages (as of October 2021), with the total cost exceeding $2.08 trillion.[1] The impacts of these natural disasters are compounded by the effects of the coronavirus disease pandemic and tend to disproportionately impact low-income communities and communities of color, further exacerbating inequality.

The Federal Emergency Management Agency (FEMA) provides billions of dollars each year to communities through its Hazard Mitigation Assistance (HMA) programs to reduce or eliminate risk from natural disasters. FEMA defines hazard mitigation as "Any sustained action taken to reduce or eliminate long-term risk to people and property from natural hazards and their effects."[2] HMA programs include the Hazard Mitigation Grant Program, Building Resilient Infrastructure and Communities, and Flood Mitigation Assistance. FEMA also provides hazard mitigation funding through the Public Assistance program, sometimes referred to as 406 Hazard Mitigation.

FEMA requires that hazard mitigation projects be cost-effective to the federal government; therefore, a project must complete a benefit-cost analysis (BCA) that compares the net present value of future benefits and costs. A benefit-cost ratio (BCR) of 1.0 or greater indicates that the risk reduction benefits of a project outweigh the costs; such a project is "cost-effective" and a worthwhile and eligible investment for the federal government. A BCA is required for most FEMA-funded hazard mitigation activities, with few exceptions (e.g., 5% Initiative projects). For this reason, FEMA developed the BCA Toolkit to assist applicants and subapplicants in conducting BCAs for a range of mitigation actions.

In recent years, FEMA began to recognize and emphasize the value of investing in NBS for mitigating the impacts of floods, wildfires, droughts and other natural hazards. FEMA defines NBS as "Sustainable planning, design, environmental management, and engineering practices that weave natural features or processes into the built environment to build more resilient communities."[3] NBS can include the use of natural features such as wetlands, open space and urban green infrastructure to help buffer communities from damages caused by natural hazards, thereby reducing costs to taxpayers and harm to vulnerable communities. For example, coastal wetlands can reduce coastal storm damage, riverfront trail systems can capture and store water during floods, forested areas managed for vegetation can serve as wildfire buffers, and urban trees can mitigate the impacts of dangerous heatwaves. Economic studies have shown that NBS, sometimes in combination with traditional infrastructure, can be a cost-effective approach for hazard mitigation.[4,5] When their additional social and environmental benefits are factored into a BCA, the economic case for NBS becomes even stronger. Ecosystem services are an important benefit of hazard mitigation projects that incorporate NBS, and they also contribute to hazard mitigation approaches that are not considered NBS (e.g., acquisition and relocation can improve floodplain health in the footprint of the removed structures).

FEMA's new emphasis on NBS has been reflected through several important policy advances and updates to the BCA Toolkit that have made it easier for subapplicants to calculate the benefits of NBS in a BCA. A key foundation for these advances has been the inclusion of monetary values for ecosystem services into the BCA Toolkit. Ecosystem services are defined by FEMA as "direct or indirect contributions that ecosystems make to the environment and human populations."[6] Ecosystem service values are embedded into FEMA's BCA Toolkit, calculated as dollars per acre per year ($/acre/year) values according to land cover type, creating a relatively simple framework for subapplicants who would like to value the ecosystem services associated with their mitigation project.

FEMA's notable policy updates related to ecosystem services have included: [i]

- **2013: Creation of first ecosystem services policy.** FEMA issued its first ecosystem services policy in 2013, incorporating dollar values for ecosystem services into the BCA Toolkit for the riparian and green open space land cover categories.[7] Earth Economics developed the framework and values for these land cover categories and associated ecosystem services, under subcontract to Ideation, Inc. This policy has now been superseded by the 2016 and 2020 policies discussed below.
- **2016: Update and expansion of ecosystem services policy.** FEMA issued another ecosystem services policy in 2016, which introduced ecosystem service values for new land cover categories (wetlands, forest, and marine and estuary).[8] The policy also introduced new eligible activities, including floodplain and stream restoration, green infrastructure, post-wildfire mitigation and aquifer storage and recovery.[ii] Earth Economics developed the values for these new land cover categories, and updated values for existing land cover categories, under

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[i] Ecosystem services were referred to as environmental benefits in both the 2013 and 2016 policies but will be referred to in this report only as ecosystem services to avoid confusion.

[ii] In the supporting materials for FEMA's 2016 environmental benefits policies, the agency had not yet adopted the term NBS. Instead, it used the term green infrastructure (green infrastructure), which it defined as "A sustainable approach to natural landscape preservation and storm water management that can be used for hazard mitigation activities as well as provide additional ecosystem benefits." In the 2016 policy and supporting materials, FEMA also used the term climate resilient mitigation activities, which was not formally defined, but according to the policy language, seemed to refer to activities that included green infrastructure and other nature-based approaches that support flood, drought, and wildfire mitigation, and stormwater management. However, since then it appears FEMA has moved toward the term NBS to refer to a similar set of concepts, as seen in the definition above. In the 2020 guide *Building Community Resilience with Nature-Based Solutions*, FEMA notes that the term NBS is largely interchangeable with terms used by other agencies and organizations, such as green infrastructure, natural infrastructure, or Engineering with Nature (a U.S. Army Corps of Engineers program). For consistency with FEMA's approach, this report uses the term NBS to encompass all of these related terms, though it is recognized that other agencies and experts use the terms in different ways (e.g., EPA uses green infrastructure to refer to specific kinds of stormwater practices).

subcontract to—and with significant input and guidance from—CDM Federal Programs Corporation (CDM Smith), which were summarized for FEMA in a 2015 report, *Update to FEMA Ecosystem Services Values*.[9]

- **2020: Removal of limitations on use of ecosystem services in BCA.** One limitation of the 2013 and 2016 policies was that projects were required to achieve a BCR of 0.75 using standard risk reduction benefits, such as reduced damage to structures, before ecosystem service values could be included in a BCA. However, in September 2020, FEMA released a significant policy update, building directly on the 2013 and 2016 policies. FEMA Policy FP-108-024-02, Ecosystem Service Benefits in Benefit-Cost Analysis for FEMA's Mitigation Programs Policy, recognized that the natural environment is an important component of a community's resilience strategy, and removed the 0.75 BCR threshold requirement.[10] In other words, nature-based hazard mitigation projects could now be considered cost-effective based on the value of their ecosystem services alone. The policy is still relatively new at the time of this report, but it seems likely that this policy will reduce the technical and monetary burden on subapplicants that would like to advance NBS. By eliminating the need for complex modeling in many cases, and welcoming ecosystem services benefits without precondition, FEMA's hazard mitigation funding programs may be opened to a larger pool of novel nature-based project types and subapplicants.

- **2022: Update to 2016 Ecosystem Service Values.** Under subcontract to—and with significant input and guidance from—CDM Smith, Earth Economics provided updates to FEMA's 2016 ecosystem service values in the *FEMA Ecosystem Service Value Updates*. Released in 2022, the report included additional land cover categories (coral reefs, shellfish reefs, and beaches and dunes), and changes to existing land cover types (the green open space category was split into urban green open space and rural green open space; the wetlands category was split into inland wetlands and coastal wetlands; and the marine and estuary category was combined with coastal wetlands). Approximately 50 new source studies were added to support the total ecosystem service benefits per land cover category, and overall, 22 new individual ecosystem service values were added across all land cover types to FEMA's BCA Toolkit. All values were adjusted for inflation to 2021 U.S. dollars (USD).

While FEMA's ecosystem service values provide an important basis for conducting BCAs that involve many common NBS project types, one area not covered by these values is the subcategory of NBS referred to as green infrastructure.

Green infrastructure, also referred to as green stormwater infrastructure (GSI) or urban green infrastructure, is defined in the Water Infrastructure Improvement Act of 2019 as "… the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters."[11]

In a stormwater context, green infrastructure is often contrasted with gray infrastructure, which tends to refer to more conventional, centralized systems of water conveyance, storage and treatment such as pipes, pumps and storage tanks/tunnels. In practice, however, the most effective approach is often a combination of green and gray infrastructure.

Green infrastructure is increasingly used in urban areas to support stormwater management and hazard mitigation goals while providing other community benefits, and can include features such as raingardens/bioretention, grassed/vegetated swales, vegetated filter strips, permeable pavements, green roofs, stormwater tree pits/trenches, downspout disconnection and rainwater harvesting. In contrast with other NBS like restoration of wetlands and riparian areas, green infrastructure features tend to be relatively smaller in terms of their direct footprint but are often highly engineered and distributed across the landscape to maximize stormwater management and other benefits they provide. Ultimately, it is flexible: green infrastructure can be planned, designed, installed and evaluated at a range of scales, from a single raingarden to a portfolio of green infrastructure across a city.

1.2. Purpose

The purpose of this report is to supplement FEMA's 2022 update to ecosystem service values (which have been integrated into the BCA Toolkit as standard values) with a set of proposed values that are specific to green infrastructure features and their associated benefits. If adopted by FEMA, standard values for the benefits of green infrastructure could be expected to facilitate BCA of hazard mitigation projects that incorporate green infrastructure, thereby reducing the burden on subapplicants and ensuring that such projects are being evaluated in the BCA using a consistent set of values and assumptions.

While green infrastructure can be considered a subcategory of NBS, and many of the benefits provided by green infrastructure are considered ecosystem services, green infrastructure is distinct enough that the values and supporting materials assembled here merit a stand-alone report. Green infrastructure requires unique considerations related to the scale of implementation (i.e., usually smaller than other NBS), feasibility and effectiveness criteria, and valuation methods and associated data sources—considerations that are addressed here.

This report is structured as follows:

- **Defining and Classifying Green Infrastructure and Associated Benefits.** This section describes the framework used for classifying different categories of green infrastructure and their associated benefits.

- **Methods for Valuing the Benefits of Green Infrastructure.** This section summarizes the typical valuation methods used for determining the benefits of green infrastructure.

- **Proposed Values for Green Infrastructure.** This section summarizes the proposed values for the benefits of different green infrastructure categories.

- **Using Values for Green Infrastructure in the FEMA BCA Toolkit:** This section provides guidance on how to interpret and apply the values for green infrastructure in the context of a BCA for a mitigation project, including conceptual and real examples.

- **Appendices A–D:** Each appendix contains detailed background information on the values for each of the green infrastructure categories (bioretention, urban trees, permeable pavement, green roofs), including a description of the source study/studies that were used to develop the value, and the methods for deriving the value.

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2. Defining and Classifying Green Infrastructure and Associated Benefits

This section provides background on the concept of green infrastructure, a framework for defining and classifying green infrastructure in the context of a FEMA BCA, and a summary of benefits that were considered for valuation in this analysis.

2.1. What is Green Infrastructure?

While there is no single authoritative definition of green infrastructure, two representative definitions are provided here:

- The Water Infrastructure Improvement Act, enacted by Congress in 2019, defines green infrastructure as "The range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters."[12]
- The New Jersey Department of Environmental Protection (NJDEP) (2018) defines green infrastructure as "a broad term that generally refers to engineered systems that manage runoff close to where it is generated by incorporating natural features into the design of the system … green infrastructure allows stormwater to infiltrate into the ground, be treated by vegetation or soils and slowly released into the sewer system, or be stored for reuse."[13]

The concept of green infrastructure is closely related to the concepts of NBS, low impact development (LID) and (stormwater) best management practices (BMPs), all of which can encompass practices that utilize vegetation and other natural features to manage stormwater and generate other community benefits.

Green infrastructure can support hazard mitigation outcomes while generating a range of other environmental and social benefits, sometimes referred to as co-benefits, including stormwater management, air quality, habitat and aesthetic value. Many of these co-benefits are the same as or similar to the ecosystem service benefits that FEMA values in its BCA Toolkit for forests, wetlands, green open space and other land cover types. Because green infrastructure is typically highly engineered and deployed in developed urban settings (relative to NBS), this report refers not to ecosystem services but instead to the economic benefits of green infrastructure solutions to hazard mitigation and stormwater management.

Green infrastructure is increasingly being adopted by local governments and communities as a component of infrastructure planning. And while communities have only begun to invest in green infrastructure on a meaningful scale in the past few decades, scientific, engineering and economic knowledge related to green infrastructure has grown rapidly in that time.

Green infrastructure is often contrasted with gray infrastructure, which tends to refer to more conventional, centralized systems of water conveyance, storage and treatment such as pipes, pumps and storage tanks/tunnels. Gray infrastructure tends to be designed to perform specific volume reduction and/or water quality services but does not provide the broader environmental and social benefits associated with green infrastructure.

Gray infrastructure also tends to rely on large, centralized systems, which can create risk in the context of climate change and other trends beyond the control of a subapplicant such as a municipality. Even when based on the best available data and modeling, uncertainty remains, and such centralized investments represent “big bets” on how the future will look, and once in place they can be costly and difficult to modify to adapt to changing conditions (e.g., upsize/upgrade, or even downsize). Given the uncertainty of future climate impacts and future infrastructure needs, one advantage of including green infrastructure in a hazard mitigation strategy is that it can be built out in an incremental or modular fashion, which is less risky than relying solely on centralized infrastructure. In this way, investments in green infrastructure can yield immediate and incremental benefits compared to waiting for large gray infrastructure systems to come online. Figure 1 provides a rough visual depiction of this concept.

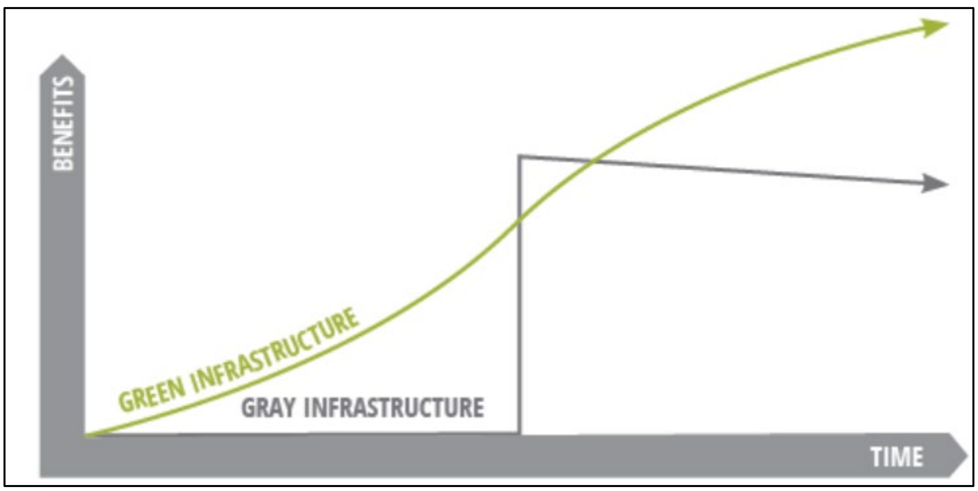

Figure 1. Benefits Realized Over Time: Green versus Gray Infrastructure

At the individual project scale, sometimes an all gray or all green approach is most appropriate and cost-effective, but at the neighborhood or watershed scale, choosing between green and gray options is rarely an either/or decision; some combination of green infrastructure and gray infrastructure typically will best optimize hazard mitigation outcomes and deliver the highest return on investment. This hybrid approach recognizes that there are some functions that gray infrastructure simply cannot perform, such as capturing, slowing and treating rainfall and stormwater at the source to reduce strain on centralized systems. Likewise, there are some functions that green infrastructure cannot perform, like mitigation of large-scale flood events. The optimal green-gray mix for maximum hazard mitigation and return on investment depends on a range of contextual factors, such as the geographic scale of the service area, hazards and other issues to be addressed, community goals and physical factors like climate, topography and soil types.

2.2. Proposed Green Infrastructure Categories

For the purposes of the FEMA BCA Toolkit, four categories of green infrastructure are proposed: bioretention, permeable pavements, green roofs and urban trees. Each proposed category is described in more detail below.

- **Bioretention** practices are described by the U.S. Environmental Protection Agency (EPA) as "… landscaped depressions that treat on-site stormwater discharge from impervious surfaces such as roofs, driveways, sidewalks, parking lots and compacted lawns. They are used to collect stormwater and filter it through a mixture of soil, sand and/or gravel. The designs of bioretention practices mimic volume reduction and pollutant removal mechanisms that work in natural systems. The filtered stormwater soaks into the ground, provides water to plants and can help recharge the local groundwater supply. Through these processes, bioretention practices reduce peak flows within downstream sewer systems and allow pollutant removal through filtration and plant uptake."[14]

  The bioretention category includes rain gardens and stormwater planters, and for the purposes of this analysis, also includes biofiltration systems such as grassed swales, vegetated swales, bioswales and vegetated filter strips.

- **Permeable pavements**. EPA describes permeable pavements as "… a stormwater control that allows stormwater to infiltrate through the surface of the pavement to the ground below—a green infrastructure alternative to traditional impervious surfaces. Types of permeable pavements include porous asphalt, pervious concrete and permeable interlocking concrete pavement." [15]

- **Green roofs.** In a 2021 report prepared for the Water Research Foundation (WRF) by Corona Environmental Consulting and Kennedy Jenks, a green roof is defined as "… 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." [16]

- **Urban trees.** As the term suggests, urban trees are trees within urban areas. The above-referenced WRF report notes that 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."[17]

  It should be emphasized that to qualify for the urban tree category, trees must meet the feasibility and effectiveness criteria found in Section 5, which includes considerations related to site design, planting and maintenance.

2.3. Green Infrastructure Categories Not Considered

While the four proposed green infrastructure categories discussed above capture the most common types of green infrastructure projects, a number of practices commonly referred to as green infrastructure were not included in this initial report. These include practices such as downspout disconnection, rainwater harvesting (e.g., rain barrels), land conservation, green streets or alleys, constructed wetlands, or wet ponds or retention basins, among others.[18] These categories were excluded for one or more of the following reasons:

1. The green infrastructure type can be captured within existing categories (e.g., green streets are often listed as a green infrastructure type but are actually a combination of permeable pavements, bioretention, and other green infrastructure types captured in the existing list).
2. The green infrastructure type could be captured with the ecosystem service values for land cover types already included in the FEMA BCA Toolkit (e.g., land conservation would be captured by FEMA's Acquisition and Demolition/Relocation mitigation action, and the resulting natural land cover could be quantified using the riparian or green open space land cover categories).
3. It is unlikely that subapplicants would bring those types of projects to FEMA, or there would be very few projects of that nature.
4. It is a project type or mitigation action that FEMA is unlikely to fund.
5. Valuation of the green infrastructure category is challenging because of limited data availability.

2.4. Green Infrastructure Benefit Categories

Table 1 provides definitions for the different categories of benefits provided by green infrastructure and valuated in this report. Note that not all categories of green infrastructure provide all categories of benefits.

Table 1. Categories of Green Infrastructure Benefits

Benefit	Definition
Avoided carbon emissions	Energy savings provided by green infrastructure reduces carbon emissions produced by equivalent gray infrastructure
Building energy cost savings	Reduction in energy use for heating and cooling by insulating buildings from large changes in temperature
Carbon sequestration	Process of removing and storing carbon dioxide (CO_2) from the atmosphere
Drought risk reduction	Mitigating drought risk by increasing water supply through groundwater infiltration
Habitat	Providing shelter and refugia to maintain biological diversity

Benefit	Definition
Heat risk reduction	Reducing the risk of human heat-related illness by reducing local temperatures through shade and evapotranspiration
Property value improvement	Increase in home sales price because of proximity to green infrastructure
Removal of air pollutants	Removing air pollutants, such as particulate matter or ozone, from the atmosphere
Stormwater volume and quality	Reducing the quantity of stormwater runoff and pollutant loading through increased infiltration

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3. Methods for Valuing the Benefits of Green Infrastructure

Most planning and infrastructure decisions are considered in economic terms and examined using tools such as BCAs. While green infrastructure provides many market benefits traditionally recognized in such analyses, it also provides tremendous economic values through nonmarket benefits as well. When the nonmarket benefits generated by NBS are not valuated in monetary terms, they are left out from the decisional balance and effectively given a benefit value of zero. This puts NBS at a disadvantage against traditional, engineered approaches. Examining the full suite of benefits offered by green infrastructure provides a comprehensive approach for including green infrastructure economic value in decision-making.

Over the past several decades, the field of environmental and natural resource economics has developed and refined several methods for estimating the economic value of both market and nonmarket benefits that characterize green infrastructure. These valuation methods fall into three broad categories: (1) direct market valuation, (2) revealed preferences and (3) stated preference. Table 2 describes the most commonly used methods to derive values for economic benefits for green infrastructure.

Table 2. Economic Benefit Valuation Methods

Method	Description	Example
Direct Market Valuation		
Market price	Valuations are directly obtained from the prices paid for the good or service in markets	Price of energy sold on open markets
Replacement cost	Cost of replacing a given benefit provided by functioning green infrastructure with a built solution	Cost of replacing a raingarden's natural filtration capacity with a water filtration plant
Avoided cost	Economic losses that would be incurred if a particular form of green infrastructure were removed or its function significantly impaired	Costs related to flooding (e.g., life losses, building and road damages, missed workdays) that would be mitigated by green infrastructure that reduces flood extents
Revealed Preference Approaches		
Travel cost	Costs incurred in the traveling required to consume or enjoy a benefit provided by green infrastructure	People who travel to visit an urban park must value that experience at least as much as the cost of traveling there
Hedonic pricing	Benefits (or costs) of green infrastructure manifested through the	Property values near lakes and parks tend to exceed similar

Method	Description	Example
	impact of different factors on observed market prices	properties without such nearby amenities, all else being equal
Stated Preference Approaches		
Contingent valuation	Value elicited from survey instruments that pose hypothetical valuation scenarios	What people are willing to pay to protect water quality

The approaches described above are primary methods, meaning they rely on new data generated by the authors of the study. There are also approaches to benefit valuation that are secondary methods, meaning they rely on values, data and/or models that already exist from previously conducted primary studies. This approach is often referred to as benefit transfer or value transfer, which can be broadly defined as the process of estimating the value of an economic benefit (or cost) at the site of interest by using existing valuation estimates that have been developed at another site. Benefit transfer is often used to estimate the value of nonmarket benefits (and costs) provided by NBS and green infrastructure, as this method can generate defensible estimates quickly and at a fraction of the cost of conducting site-specific primary studies.

The United Nations Environmental Program, in its *Guidance Manual on Value Transfer Methods for Ecosystem Services*, defines three main types of value transfer (direct quote):[19]

- **Unit value transfer** uses values for ecosystem services at a study site, expressed as a value per unit, combined with information on the quantity of units at the policy site to estimate policy site values. Unit values can be adjusted to reflect differences between the study and policy sites (e.g., income and price levels).
- **Value function transfer** uses a value function estimated for an individual study site in conjunction with information on policy site characteristics to calculate the unit value of an ecosystem service at the policy site. A value function is an equation that relates the value of an ecosystem service to the characteristics of the ecosystem and the beneficiaries of the ecosystem service.
- **Meta-analytic function transfer (or simply "meta-analysis")** uses a value function estimated from the results of multiple primary studies representing multiple study sites in conjunction with information on policy site characteristics to calculate the unit value of an ecosystem service at the policy site. Since the value function is estimated from the results of multiple studies it can represent and control for greater variation in the characteristics of ecosystems, beneficiaries and other contextual characteristics.

4. Proposed Values for Green Infrastructure

Table 3 summarizes the full proposed values for the benefits of green infrastructure. All values presented are in 2021 USD.

Table 3. Summary of Proposed Green Infrastructure Categories and Benefits

Benefit	Green Roofs ($/ft²/year)	Permeable Pavement ($/ft²/year)	Bioretention ($/ft²/year)	Urban Trees ($/tree/year)
Building energy cost savings	$0.05			$17.05
Carbon sequestration and avoided emissions	$0.01	$0.003	$0.02	$6.33
Drought risk reduction		$0.13	$0.52	$5.53
Habitat	$0.05		$0.11	$40.18
Heat risk reduction				$910.28
Property value improvement	$0.19		$0.40	$53.15
Removal of air pollutants	$0.001		$0.004	$2.50
Stormwater volume and quality	$0.09	$0.51	$1.80	$20.17
Total ($/ft²/year)	**$0.40**	**$0.64**	**$2.84**	**$1,055.19**
Total ($/acre/year)	$17,616.66	$27,949.13	$123,598.82	*

$/ft²/year = dollars per square foot per year

*values could not be converted to $/acre/year

Not every green infrastructure/benefit combination could be valuated because of lack of appropriate literature, data or methodology to create a broadly applicable nationwide estimate. That a specific combination of green infrastructure and benefit value has not been included here does not necessarily mean such infrastructure does not produce a given benefit or that the benefit is not valuable, but rather reflects a lack of appropriate source studies and/or data relevant to that combination. For this reason, value estimates may in some cases be underestimates since not all benefits could be valuated. Additionally, caution should be exercised when comparing total benefit values across green infrastructure types, as differences in total value may reflect information gaps rather than real differences in benefit provisioning or the value of such benefits.

4.1. Recommendations for Updating Values

The concept of NBS is becoming increasingly influential in decision-making, and the literature on the benefits of NBS has grown exponentially over the past two decades.[20] As the literature continues to expand, the values proposed in this report should be revisited periodically to include the most up-to-date science, data, modeling and economic methods available, and to adjust other factors relevant to value estimation such as inflation and the social cost of carbon (SCC). A recommended schedule includes:

- Annual Updates
    - Values should be adjusted for inflation on a yearly basis.
    - The value for the SCC should be reassessed every year. The current value, as of June 2022, resulting from Executive Order 13990, calculates a different value for the SCC every year from 2020 to 2050. The estimated value could be updated each year, reflecting the outcomes of climate change over time. Furthermore, future policy updates may adjust this value based on new model assessments or other factors.
- 5-Year Updates
    - Every 5 years, a literature review should be conducted to integrate new research and published values on the benefits of NBS. This could lead to including new benefits in the toolkit, filling in current gaps in the proposed values, or including additional green infrastructure types (in particular, wet ponds and retention basins should be investigated in the future as possible green infrastructure types to be included).

5. Using Values for Green Infrastructure in the FEMA BCA Toolkit

This section provides step-by-step guidance on how to apply the values for green infrastructure in the context of a BCA for a mitigation action or project. Steps are described in the general order in which they are likely to be followed, though subapplicants can follow the steps in a different order depending upon context and needs.

Guidance is provided on how to define the green infrastructure category (or categories) associated with the mitigation project, including definitions for each category with associated dollar values. Additionally, general guidance is provided on feasibility and effectiveness criteria that the subapplicant must meet for each land cover category used. Selecting an appropriate project useful life (PUL) associated with the land cover category comes next. Finally, several conceptual examples describe how each green infrastructure category might be used in the context of a mitigation project.

It should be noted that, in addition to following the criteria and guidance related to the green infrastructure categories discussed in this section, all mitigation projects must comprise eligible risk reduction activities and meet any other relevant FEMA programmatic requirements (e.g., cost-effectiveness, environmental and historic preservation) to be eligible for FEMA funding.

5.1. Identify Green Infrastructure Categories Associated with the Mitigation Action

The subapplicant should first identify the green infrastructure category (or categories) that will be created by the project. As described earlier, economic benefits have been developed for four green infrastructure categories within FEMA's BCA Toolkit: (1) bioretention, (2) permeable pavements, (3) green roofs, and (4) urban trees. Definitions for each green infrastructure category are provided in Section 2.

A dollar value has been developed for each green infrastructure category based on a set of benefits associated with that green infrastructure category. Values are expressed in $/ft^2$/year for bioretention, permeable pavement and green roofs, and in dollars per tree per year ($/tree/year) for urban trees. The BCA Toolkit will automatically calculate the annual and net present value of benefits associated with a mitigation project or action based on the number of units (i.e., square feet [ft^2] or number of trees) of each green infrastructure category that is entered by the subapplicant.

For any mitigation project, any units of green infrastructure entered into the BCA Toolkit must be both part of the project footprint and be newly created as a result of the project. The ecosystem service values associated with each green infrastructure category will capture and reflect the broader area of benefit associated with the project, which may extend beyond the project footprint. For example, for a 500 ft^2 bioretention installation, the subapplicant would input 500 ft^2 of bioretention into the BCA Toolkit; the benefits built into the bioretention value include climate regulation (a global benefit), air quality (a regional benefit) and flood hazard reduction (a downstream benefit).

5.2. Ensure Each Green Infrastructure Category Meets Feasibility and Effectiveness Criteria

In general, to use the economic values for a given green infrastructure category in a FEMA BCA, a project should meet the following criteria:

- New green infrastructure areas associated with the mitigation project should be consistent with the green infrastructure definition provided in Section 2.
- The subapplicant must demonstrate that the amount of green infrastructure will increase in the After-Mitigation (With Action) scenario relative to the Before-Mitigation (No Action) scenario. Specifically, the subapplicant must demonstrate that new areas of green infrastructure will be installed as a result of the project.[iii]
- Design, installation and maintenance of green infrastructure should follow established and accepted principles, guidelines, policies and techniques associated with the specific green infrastructure cover category. The following list includes examples of such resources and guidance to support planning and implementation of green infrastructure:
    - EPA maintains a website that contains a wealth of resources related to green infrastructure, including design and implementation, operations and maintenance (O&M) and performance.[21] The website also includes factsheets for the green infrastructure categories included in this report: bioretention,[22,23] permeable pavements,[24] urban trees,[25] and green roofs.[26]
    - Many states have developed design manuals and technical standards for green infrastructure (often under the umbrella of LID). For example:
        - The Washington State Department of Ecology has developed a *Stormwater Management Manual* for both Western Washington and Eastern Washington (last revised in 2019). The Western Washington manual, for example, provides detailed information to support green infrastructure design, implementation, and maintenance for the green infrastructure categories in this report.[27]
            - At a regional level in Washington State, The *Low Impact Development Technical Guidance Manual for Puget Sound* provides detailed information on design, construction, and materials for many BMPs, including the green infrastructure categories in this report.[28]

[iii] This is in contrast with other natural land cover categories in the BCA Toolkit, such as forest or coastal wetlands, with which a subapplicant can realize ecosystem service values through creation, restoration, or enhancement of those land cover categories.

- The Maryland Department of the Environment has developed a *Stormwater Design Manual* (last revised in 2009), that serves as "... the official guide for stormwater management principles, methods, and practices in Maryland," and includes guidance related to green infrastructure such as performance criteria, selection of BMPs for green infrastructure, site design and construction specifications.[29]

- The NJDEP, in its 2018 report *Evaluating Green Infrastructure: A Combined Sewer Overflow Control Alternative for Long Term Control Plans,* provides guidance on a number of topics related to planning and implementing green infrastructure, including locating and assessing the feasibility of green infrastructure, implementation and performance monitoring, and maintenance considerations.[30]

- The State of Minnesota Pollution Control Agency has developed a *Stormwater Manual* that includes supporting information for the green infrastructure categories in this report, including design criteria, construction specifications and guidance related to O&M and performance monitoring.[31]

o Many local governments, academic institutions and other organizations have developed guidance to support green infrastructure implementation. For example:

- The County of San Diego's *Low Impact Development Handbook* provides detailed guidance related to site planning, design, construction and O&M of green infrastructure features.[32]

- The City of Santa Rosa has developed a *Low Impact Development Technical Design Manual* and many supporting resources, including design guidance for green infrastructure categories.[33]

- *A Design Guide for Green Stormwater Infrastructure Best Management Practices: Scalable Solutions to Local Challenges*, prepared by the Delta Institute and Environmental Consulting and Technology, provides detailed guidance on implementing GSI. The guidance is focused on the Great Lakes region but many of the principles and best practices are broadly applicable.[34]

- The Oregon State University Extension has developed a series of factsheets with guidance to support green infrastructure/LID practices, including bioretention/biofiltration, green roofs and permeable pavements.[35,36]

o The following list illustrates some of the considerations that can arise related to green infrastructure planning, design, installation and/or maintenance, assembled from a selection of the resources above. This list is not exhaustive and should not be considered a substitute for the guidance of experts such as professional engineers, planners, or landscape architects.

- **Planning.** Green infrastructure installations can often be more successful when integrated into larger community planning efforts, including local stormwater plans or hazard mitigation plans. This integration can help to maximize the green infrastructure's functional outcomes (e.g., hazard mitigation, stormwater management, other benefits) and also helps to ensure the project has the support of the relevant communities and agencies.

- **Design and Installation.** Thoughtful design can help to support the functionality, aesthetics and longevity of a green infrastructure installation. Design factors can include:

    - **Site selection.** The selection of an appropriate site plays a crucial role in the efficacy of a green infrastructure installation. Green infrastructure can be incorporated into areas with existing infrastructure (e.g., bioretention or urban trees added to parking lots and rights of way, green roofs added to existing buildings), or installed in a newly-created, dedicated site (e.g., large-scale, centralized bioretention). Topography, soil types, local climatic conditions (e.g., temperature, precipitation, wind) and other factors should be considered. For example, green roofs should generally not be installed in high-wind areas.

    - **Sizing.** The appropriate size for a green infrastructure installation can be determined based on different approaches (e.g., flow-based versus volume-based). The drainage area for green infrastructure installations is also an important factor. For example, bioretention installations are typically limited to treating drainage areas of 5 acres of less.

    - **Pretreatment.** Some green infrastructure installations work best when paired with pretreatment. For example, design engineers typically suggest using pretreatment, such as vegetated filter strips or swales, for bioretention installations that drain more than 0.5 acres. Pretreatment helps to collect debris and reduce the chance/frequency of clogging.

    - **Soil.** The soil media, whether preexisting or installed, can affect the drainage capacity of green infrastructure installations. While some green infrastructure types like bioretention can work with almost any soil type, sometimes an underdrain can be used to supplement green infrastructure installations with low soil permeability.

    - **Vegetation.** Selecting the right vegetation, including grasses, shrubs and trees, can help to ensure the success of a green infrastructure installation from both a functional and aesthetic perspective.

- **Maintenance.** Ongoing inspection and maintenance is a crucial and sometimes overlooked factor for the success of most green infrastructure installations. Lack of maintenance can lead to poor aesthetics, a reduction in functionality, and even failure of the green infrastructure installation. While some issues can be resolved through careful design, some level of maintenance is typically unavoidable. Maintenance activities can include landscaping for bioretention, vacuum sweeping for permeable pavements (to reduce clogging) and gardening and irrigation for green roofs. Maintenance costs are required in the BCA Toolkit, so knowing the maintenance requirements and costs in advance can help ensure the project is both cost-effective and successful.

5.3. Select an Appropriate Project Useful Life

The term PUL refers to the length of time the project or mitigation action will provide benefits. FEMA's BCA Toolkit provides a standard PUL for many eligible mitigation actions, or components of mitigation actions, and in some cases, allows the subapplicant to select from a range of options depending upon the nature of the project and available documentation.

Table 4 summarizes the recommended PUL for each of the green infrastructure types in this report. The standard PULs for bioretention, permeable pavements and green roofs are based on PUL estimates found in the *Hoboken Green Infrastructure Strategic Plan* prepared by a coalition of government, academic and nonprofit partners in the northern New Jersey region.[37] The standard PUL for urban trees is based on a U.S. Forest Service report, which presents the mean life expectancy ranges of urban trees from two studies (one of which is a meta-analysis of 11 studies). The average of both ranges, 25 years (rounded up from 24.5 years), is adopted as the standard value.[38]

Table 4. Project Useful Life Guidance

Project Type	PUL (Years)		Comment
	Standard Value	Acceptable Limits (Documentation Required)	
Bioretention	35	35–50	Feasibility and effectiveness criteria must be met to use the standard value for each green infrastructure category. PUL can be increased up to 50 years depending upon how long the green infrastructure will be maintained, as evidenced through documented assurances, including agency commitments, or the subapplicant's demonstrated history of maintaining the green infrastructure type for that period (though historical data is likely only available for urban trees, given the relative newness of the other green infrastructure types). If the green infrastructure is part of a larger mitigation project that includes other eligible mitigation actions, then the subapplicant can select a PUL equal to that of the primary mitigation action (e.g.,
Green roofs	35	35–50	
Permeable pavement	30	30–50	
Urban trees	25	25–50	

Project Type		PUL (Years)	Comment
			as reflected by total share of project budget). For example, if a bioretention installation is part of a major infrastructure project with a documented PUL of 75 years, then the subapplicant can select 75 years as the PUL of the riparian area. This approach assumes that the land cover will be maintained at least as long as the primary infrastructure associated with the project. Final green infrastructure should be ideally owned or controlled by a government or nonprofit organization but could be located on private property if a maintenance agreement is signed with the property owner.

5.4. Conceptual Examples

The following examples demonstrate in more detail how a subapplicant could incorporate the green infrastructure types defined in Section 2.

Table 5. Conceptual Examples of Mitigation Projects that Include Green Infrastructure Categories

Bioretention	Urban Trees	Permeable Pavement	Green Roofs	Conceptual Example
•	•		•	The City of Lancaster, Pennsylvania, created a concept for greening the facilities of the public library to manage stormwater runoff and reduce combined sewer system overflows.[39] The plan included installing 11,000 ft^2 of green roof on three separate roofs, a tree trench, and 1,000 ft^2 of bioretention.
•	•			A plan for Meander Bend Park, an 18-acre park in Pima County, Arizona, would build green infrastructure in an area with existing 0% tree canopy cover.[40] The project included more than 272,000 ft^2 (about 6.3 acres) of detention basins and vegetated swales for the purpose of harvesting stormwater flow, and planting of 420 trees.
•				Kansas Municipal Utilities created a 5,000 ft^2 rain garden surrounding its new training center in 2018.[41] The rain garden features nearly 1,400 native plants and is designed to manage runoff from the building and parking lot.

Bioretention	Urban Trees	Permeable Pavement	Green Roofs	Conceptual Example
•	•	•		The Maplewood Mall in Maplewood, Minnesota, underwent a redesign of its 35-acre parking lot, with construction taking place between 2009 and 2012.[42] Hundreds of trees were planted to achieve the project's stormwater goals of capturing 1 inch of runoff from 90% of the parking lot area; 200 trees were planted in tree trenches and 175 planted among 55 rain gardens. The project also includes 6,733 ft^2 of permeable pavement.[43] The project is estimated to capture 20 million gallons of stormwater per year.
			•	The city of Binghamton, New York, constructed a green roof on its city hall in 2020.[44] The green roof covers 22,500 ft^2 and includes additional stormwater planters to absorb, store, and evaporate additional rainfall not already captured by the green roof. It is estimated that the system will capture 325,000 gallons of rainwater each year that would normally flow into the city's sewer system.
			•	In 2006, a green roof was installed on the American Banknote Building in the Bronx to help reduce stormwater runoff in the city.[45] The green roof covers 1,024 ft^2 and provided evidence of alternative strategies to gray infrastructure to deal with New York's stormwater problems. Initial studies by the University of Wisconsin showed a green roof could help reduce runoff by as much as 75%.
		•		The City of Portland Environmental Services paved three blocks of streets with permeable pavement in 2004—the first use of permeable pavement on a public street in the city.[46] Three types of permeable pavement were used, totaling approximately 40,000 ft^2. The goal of the project is to reduce combined sewer overflows, stream pollution, and basement sewer backups, and reduce the long-term total volume of wastewater in the city's sewer system.
•		•		EPA's Edison Environmental Center in Edison, New Jersey, designed and installed a parking area incorporating permeable pavement and rain gardens.47 The site is used to capture stormwater runoff from the parking area, nearby sidewalks, and roof. The 1-acre parking lot includes three types of permeable pavements and the 6,100 ft^2 rain garden is divided among six independent cells of different sizes.
		•		The City of Dubuque, Iowa, experienced six flood-related presidential disaster declarations between 1999 and 2011.[48] In response to these repeated disasters, the city is working to resurface 240 alleys (over 1 million ft^2) with permeable pavement, with expected runoff reductions of 80%.

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Appendix A. Bioretention

Summary of Benefits of Bioretention

Benefit Category	2021 USD/ft²/year
Building energy cost savings	
Carbon sequestration and avoided emissions	$0.02
Drought risk reduction	$0.52
Habitat	$0.11
Heat risk reduction	
Property value improvement	$0.40
Removal of air pollutants	$0.004
Stormwater volume and quality	$1.80
Total	**$2.84**

Benefit Values and Methodology

Carbon Sequestration and Avoided Emissions

Summary

Green Infrastructure Category: Bioretention
Benefit: Carbon sequestration and avoided emissions
FEMA Value: $0.02/ft²/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: U.S.
Source Studies:

> **Reference 1:** Clements, J., Henderson, J., Flemming, A. 2021. Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure. The Water Research Foundation, Alexandria, VA, and Denver, CO.
> **Reference 2:** Interagency Working Group on Social Cost of Greenhouse Gases (IWGSCGG). 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990.

Reference 3: EPA. 2022. Power Profiler v 11.0. Retrieved from https://www.epa.gov/egrid/power-profiler#/ on April 13, 2022.
Reference 4: CH2MHill and CDM Smith. 2013. Milwaukee Metropolitan Sewerage District Regional Green Infrastructure Plan. Available online at: https://www.mmsd.com/static/MMSDgreen infrastructureP_Final.pdf
Reference 5: CH2M Hill. 2011. Green Infrastructure Plan. The City of Lancaster, Lancaster, PA. Available online at: https://cityoflancasterpa.com/wp-content/uploads/2014/01/cityoflancaster_giplan_fullreport_april2011_final_0.pdf
Reference 6: NJDEP Division of Water Quality. 2018. Evaluating Green Infrastructure: A Combined Sewer Overflow Control Alternative For Long Term Control Plans. NJDEP; Trenton, NJ. Available online at: https://www.nj.gov/dep/dwq/pdf/CSO_Guidance_Evaluating_Green_Infrastructure_A_CSO_Control_Alternative_for_LTCPs.pdf
Reference 7: National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental information, Climate at a Glance: National Time Series, published April 2022, retrieved on May 2, 2022 from https://www.ncdc.noaa.gov/cag/
Reference 8: City of Calgary. 2019. Renfrew Integrated Stormwater Management Pilot Study. Calgary.
Reference 9: Flynn, K., and R. Traver, 2013. "Green Infrastructure Life Cycle Assessment: A Bio-infiltration Case Study." Ecological Engineering, 55: 9–22.
Reference 10: Kavehei, E., Jenkins, G., Adame, M., and Lemckert, C. 2018. "Carbon Sequestration Potential for Mitigating the Carbon Footprint of Green Stormwater Infrastructure." Renewable and Sustainable Energy Reviews, 94: 1179–1191.
Reference 11: IWGSCGG. 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990.

Methodology Description: We estimate the benefits of avoided carbon emissions by finding the avoided CO_2 emissions from reduced wastewater pumping because of stormwater capture by green infrastructure. First, we estimate annual stormwater capture by green infrastructure by reviewing several green infrastructure and long-term control plans conducted by cities in the U.S. On average, these plans assume that the ratio of drainage area to green infrastructure area for bioretention infrastructure is 16.1 to 1. Assuming an annual average rainfall of 788.4 millimeters (mm) (derived from NOAA's national time series data for the contiguous U.S., 2000–2020) (NOAA 2022), and efficiency factors describing the amount of stormwater captured, the annual water capture of bioretention areas is estimated at 279.2 gallons per square foot per year (gallons/ft^2/year). Clements et al. (2021) calculate an average energy intensity of 2,250 kilowatt-hours per (million gallons) (kWh/MG) for wastewater and stormwater pumping, after applying national assumptions. Applying this estimate to the amount of stormwater captured by green infrastructure, we get an avoided energy use of 0.66 kilowatt hours per square foot per year (kWh/ft^2/year). Next, we apply the national average of CO_2 emissions from the 2022 EPA Emissions and Generation Resource Integrated Database (eGRID) (818.3 pounds carbon dioxide equivalent per mega-watt hour (lbs

CO_2e/MWh)) to find avoided emissions of 0.54 (pounds carbon dioxide equivalent per square foot per year (lbs CO_2e/ft^2/year).[iv]

A review of carbon sequestration literature identified three studies quantifying the carbon sequestration rates of bioretention installations such as raingardens and bioswales. The City of Calgary (2019) included measures of carbon capture of bioretention systems meant for stormwater management. Flynn and Traver (2013) modeled carbon sequestration of a raingarden in Pennsylvania. Kavehei et al. (2018) found carbon capture estimates of vegetated swales in the U.S. composed of grasses, woody vegetation, and shrubs.

We use the SCC to value the avoided emissions and carbon sequestration from bioretention areas. The SCC represents the average societal costs associated with each additional ton of carbon emissions (measured in CO_2e), such as losses to agriculture, impacts to human health, and increased disaster risk. In the context of actions that reduce carbon emissions (e.g., energy efficiency investments) or actively sequester carbon (e.g., green infrastructure), the SCC represents the value of these actions in terms of avoided cost to society. It is used by federal agencies in the U.S. and is updated on a regular basis by the IWGSCGG. The value for carbon sequestration used was derived from the IWGSCGG—a result of Executive Order 13990. Specifically, the 2021 value was used: $52 per metric ton CO_2e, or $54.44 per metric ton CO_2e in 2021 USD.

Finally, carbon emissions reduction benefits and carbon sequestration benefits are added to provide a final value.

Calculations:

Avoided Carbon Emissions Benefit Calculation

Description	Value	Units
Annual stormwater capture	279.2 (0.0003)	gallons/ft^2/year (MG/ft^2/year)
Wastewater pumping energy use	2,250	kwH/MG
Avoided energy use	0.63 (0.0006)	kWh/ft^2/year (MWh/ft^2/year)
Average carbon emissions per unit energy	818.3	lbs CO_2e/MWh
Avoided carbon emissions	0.51 (0.0002)	lbs CO_2e/ft^2/year (metric tons CO_2e/ft^2/year)

[iv] The carbon dioxide equivalent (CO_2e) represents the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas.

Description	Value	Units
SCC*	$54.44	$/metric ton CO_2e
Value of avoided carbon emissions*	**$0.013**	**$/ft²/year**

MG/ft²/year = million gallons per square foot per year; lbs CO_2e/MWh = pounds of carbon dioxide equivalent per megawatt hour; metric tons CO_2e/ft²/year = metric tons of carbon dioxide equivalent per square foot per year

Carbon Sequestration Benefit Calculation

Source Study	Carbon Sequestration Rate (metric tons CO_2e/ft²/year)	SCC ($/metric ton CO_2e)*	Value ($/ft²/year)*
City of Calgary (2019)	1.37E-04	$54.44	$0.007
Flynn and Traver (2013)	3.34E-05	$54.44	$0.002
Kavehi et al. (2018)	4.55E-05	$54.44	$0.002
Average Value			**$0.004**

Total Benefit

Benefit	Value ($/ft²/year)*
Value of avoided carbon emissions	$0.013
Value of carbon sequestration	$0.004
Total value	**$0.02**

*Values are presented in 2021 USD

Discussion: There are two mechanisms by which bioretention areas can affect the amount of carbon in the atmosphere. First, green infrastructure can decrease energy consumption, and therefore CO_2 emissions, by reducing the amount of stormwater going through treatment and pumping. Clements et al. (2021) note that electricity production accounts for 25% of greenhouse gas emissions in the U.S. While emission rates depend on many factors beyond energy production and vary across the U.S., we apply national averages to arrive at a broadly applicable benefit estimate for green infrastructure-related avoided costs. Second, vegetation removes CO_2 from the atmosphere during photosynthesis and stores carbon in its biomass, acting as a carbon sink. Since bioretention areas involve vegetation, these practices will provide carbon sequestration benefits. To construct a broadly applicable value for the U.S., we selected studies that cover a variety of bioretention practices and vegetation types. A common method of valuing the benefits of carbon capture and avoided emissions is to use the SCC. The SCC value used was standardized from the latest data produced by the IWGSCGG, a group appointed by the White House.

Drought Risk Reduction

Summary

Green Infrastructure Category: Bioretention
Benefit: Drought risk reduction
FEMA Value: $0.52/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Stated preference
Geographic Area of Studies: Austin, TX; Long Beach, CA; Orlando, FL; and San Francisco, CA.
Source Study:

> **Reference 1:** Raucher, R., Clements, J., Donovan, C., Chapman, D., Bishop, R., Johns, G., Hanemann, M., Rodkin, S., and Garrett, J. 2011. The Value of Water Supply Reliability in the Residential Sector. Water Use Research Foundation. Alexandria, VA.

Methodology Description: Bioretention systems are designed for and installed in locations that allow water to infiltrate into soil and groundwater sources. By infiltrating most of the stormwater on-site, these green infrastructure systems help support a reliable water supply. To appropriately estimate the water supply benefits of bioretention systems, the first step is calculating the average national annual water capture facilitated by these practices. To do so, information about the typical loading ratio of bioretention areas is used in conjunction with the average national annual rainfall for the contiguous U.S. between 2000 and 2020 and the approximate infiltration efficiency factor associated with urban green infrastructure (i.e., the fraction of runoff that can be infiltrated into the ground). Using that information, we calculate that a square foot of bioretention systems in the U.S. can capture 279.2 gallons of water per year.

To quantify the monetary value of water supply benefits provided by a square foot of bioretention systems, this study multiplies the 279.2 gallons/ft^2/year by a national estimate of the annual value of a liter of water. The stated preference approach is used to estimate the value of having a more reliable water supply thanks to the stormwater that infiltrates into the groundwater sources through permeable pavement. The estimate is based on the findings by Raucher et al. (2011), who surveyed more than 2,000 households in five U.S. cities to understand how much households would be willing to pay per year to avoid water supply shortages. Specifically, the referenced study used a stated choice experiment to elicit how much households in the various cities would pay to avoid a 15% restriction of their use of water for lawn irrigation. We then incorporated city-specific data on average household water use for homes with a yard to estimate the volume corresponding to a 15% reduction in each city and converted the result to a per-acre measure. Accordingly, the final estimate reported here corresponds to the average across four of the cities in the Raucher et al. (2011) study household willingness to pay (WTP) per year and in acre-foot units (one of the cities in the study by Raucher and colleagues was not identified and therefore the average household water use for homes with a yard could not be identified).

Calculations:

Description	Value	Units
Annual stormwater capture	279.2	gallons/ft²/year
Average WTP to avoid water restrictions*	$776 ($0.0024)	$/acre-foot/year ($/gallons/year)
Groundwater infiltration efficiency factor	77.5%	percent
Value of drought risk reduction*	**$0.52**	**$/ft²/year**

*Values are presented in 2021 USD

Discussion: The monetary value of a reliable water supply, which can include drought risk reduction, depends on the level of water scarcity in the region, local infrastructure costs, and available alternatives for water replenishment among other factors. Here we used a stated preference methodology that incorporates values from four different areas and does not double count with the existing avoided costs of providing alternative drinking water sources already in the BCA Toolkit. The existing BCA Toolkit value is based on water for potable uses, while the value presented in this report depends on nonpotable use of water. Furthermore, including a stated preference value is beneficial as it represents another value apart from avoided costs that is held by water users. Water rights transfer data that provide direct market prices are limited and only available for a handful of states, which makes them challenging to use to produce a broadly applicable estimate for the U.S. Finally, direct-market pricing methods, such as those using retail utility water rates or wholesale bulk water purchases, are likely to understate the full value of having a more reliable water supply system because these price structures typically reflect policy preferences and thus are an imperfect tool for providing a clear price signal that can measure drought risk reduction.

Habitat and Biodiversity

Summary

green infrastructure Category: Bioretention
Benefit: Biodiversity and habitat
FEMA Value: $0.11/ft²/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Meta-analysis, hedonic pricing
Geographic Area of Studies: Global
Source Study:

> **Reference 1:** Bockarjova, M., Botzen, W.J., Koetse, M.J. 2020. “Economic valuation of green and blue nature in cities: A meta-analysis.” Ecological Economics 169: 106480.

Methodology Description: Bockarjova et al. (2020) created a meta-analysis describing the value of green infrastructure and open space from 147 observations across 60 studies conducted around the world, including studies valuing bioretention areas. We performed a function transfer—a type of benefit transfer method—to construct a U.S.–specific value from Model 2, which had an adjusted R^2 of 0.699. The model structure is as follows:

$$y_{ij} = \alpha + \beta X_{ij} + \mu_j + \varepsilon_{ij}$$

Where the dependent variable y is the annual per hectare value; the subscript i represents each observation; the subscript j represents each study in the meta-analysis; the vector X includes socioeconomic, study, and site characteristics; the vector β contains the model coefficients; and μ and ε contain residuals. Model variables were set as follows: (1) For the "type of nature variables," the small urban green and green connected to gray variables were set to 1 (these are defined to include relatively small green areas with typically some built component included, and most closely matches the definition of bioretention areas in this report), and the other greenspace type variables (forest, park, multi-landscape, and blue nature) were set to 0; (2) the biodiversity and habitat variable was set to 1 and all other ecosystem service variables (local climate regulation, noise reduction, flood regulation, cultural, recreation, and aesthetics) were set to 0; (3) gross domestic product (GDP) per capita was calculated by converting 2020 U.S. GDP per capita to the units specified by the model; (4) population density was calculated using the average population density in urban areas in the U.S.,[49] converted to the units specified by the model; and (5) all other variables were set to their mean value. The dependent variable is reported as 2016 USD per hectare per year, which we converted to 2021 USD/ft^2/year.

Calculations:

Source Study	Study Location	Value (\$/ft^2/year)*
Bockarjova et al. (2020)	Global	$0.11
Average		**$0.11**

*Values are presented in 2021 USD

Discussion: Meta-analyses produce value estimates from the results of typically dozens or hundreds of studies at once, controlling for wide variations in ecosystem characteristics, human preferences, and methodological aspects of valuation studies. They are increasingly used to synthesize environmental literature and are a powerful tool that can produce customized value estimates where domestic valuation literature is scarce.

While the Bockarjova et al. study is one of the most robust, recent, and relevant meta-analyses specific to urban green spaces and green infrastructure, limitations could include:

1. Interpretation of ecosystem services from the literature used in the meta-analysis can often be subjective, as primary study authors sometimes do not give precise descriptions of the environmental benefits being studied.

2. Very small green spaces may be undervaluated: benefits typically increase with decreasing size of green spaces, and the majority of studies included in the meta-analysis value areas greater than 20 acres.

3. Intensity of use of green areas is not considered by the model: this type of information is not recorded in every study, and presumably smaller green spaces would have mainly local population benefits while larger green spaces may have more regional effects, as well as effects for nonlocals.

Property Value Improvement

Summary

Green Infrastructure Category: Bioretention
Benefit: Property value improvement
FEMA Value: $0.40/ft^2/year
Currency Year: 2021 USD

Source Study and Value Derivation

Valuation Method: Meta-analysis, hedonic pricing
Geographic Area of Studies: Global
Source Study:

Reference 1: Bockarjova, M., Botzen, W.J., Koetse, M.J. 2020. "Economic valuation of green and blue nature in cities: A meta-analysis." Ecological Economics 169: 106480.

Methodology Description: Bockarjova et al. (2020) created a meta-analysis describing the value of green infrastructure and open space from 147 observations across 60 studies conducted around the world, including studies valuing bioretention areas. We performed a function transfer—a type of benefit transfer method—to construct a U.S.–specific value from Model 2, which had an adjusted R^2 of 0.699. The model structure is as follows:

$$y_{ij} = \alpha + \beta X_{ij} + \mu_j + \varepsilon_{ij}$$

Where the dependent variable y is the annual per hectare value; the subscript i represents each observation; the subscript j represents each study in the meta-analysis; the vector X includes socioeconomic, study, and site characteristics; the vector β contains the model coefficients; and μ and ε contain residuals. Model variables were set as follows: (1) For the "type of nature variables," the small urban green and green connected to gray variables were set to 1 (these are defined to include relatively small green areas with typically some built component included, and most closely matches the definition of bioretention areas in this report); (2) the aesthetics variable was set to 1 (as a common method for valuing aesthetic views is through variations in housing prices, as property near green spaces often has higher value), and all other ecosystem service variables (local climate regulation, biodiversity and habitat, noise reduction, flood regulation, cultural, and recreation) were set to 0; (3) GDP per capita was calculated by converting 2020 U.S. GDP per capita to the units specified by the model; (4) population density was calculated using the average population density in urban areas in the U.S.,[50] converted to the units specified by the model; and (5) all other variables were set to their mean value. The dependent variable is reported as 2016 USD per hectare per year, which we converted to 2021 USD/ft^2/year.

Calculations:

Source Study	Study Location	Value ($/ft^2/year)*
Bockarjova et al. (2020)	Global	$0.40
Average		**$0.40**

*Values are presented in 2021 USD

Discussion: Meta-analyses produce value estimates from the results of typically dozens or hundreds of studies at once, controlling for wide variations in ecosystem characteristics, human preferences, and methodological aspects of valuation studies. They are increasingly used to synthesize environmental literature and are a powerful tool that can produce customized value estimates where domestic valuation literature is scarce.

While the Bockarjova et al. study is one of the most robust, recent, and relevant meta-analyses specific to urban green spaces and green infrastructure, limitations could include:

1. Interpretation of ecosystem services from the literature used in the meta-analysis can often be subjective, as primary study authors sometimes do not give precise descriptions of the environmental benefits being studied.

2. Very small green spaces may be undervaluated: benefits typically increase with decreasing size of green spaces, and the majority of studies included in the meta-analysis value areas greater than 20 acres.

3. Intensity of use of green areas is not considered by the model: this type of information is not recorded in every study, and presumably smaller green spaces would have mainly local population benefits while larger green spaces may have more regional effects, as well as effects for nonlocals.

Removal of Air Pollutants

Summary

green infrastructure Category: Bioretention
Benefit: Removal of air pollutants
FEMA Value: $0.004/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: U.S.
Source Studies:

Reference 1: Nowak, D.J., Crane, D.E., Stevens, J.C., and Ibarra, M. 2002. Brooklyn's Urban Forest. U. S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. Available: https://www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/2002/gtrne290.pdf.

Reference 2: Nowak, D.J., S. Hirabayashi, A. Bodine, and E. Greenfield. 2014. "Tree and Forest Effects on Air Quality and Human Health in the United States." Environmental Pollution, 193: 119–129.

Methodology Description: We follow the methodology presented in a recent comprehensive tool for valuing green infrastructure in the U.S.[51] This tool constructs a value for the air pollution removal capacity of bioretention areas using a study by Nowak et al. (2014). This study models average pollution removal rates and benefits for urban trees throughout the U.S. for four pollutant types: nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matter with diameter smaller than 2.5 microns ($PM_{2.5}$). We apply the pollutant removal efficiency ratio comparing trees against herbaceous/scrub cover (which characterizes bioretention systems) as estimated by Nowak et al. (2002) to arrive at estimates of pollution removal for bioretention systems. Nowak et al. (2014) calculates the value of pollutant removal based on the avoided cost of adverse health outcomes due to air pollution; these values are updated to 2021 USD and applied to the removal rates for herbaceous and shrub cover.

Calculations:

Pollutant	Removal Rate, Tree (metric tons/ft²/year)	Removal Efficiency Ratio	Removal Rate, Herbaceous/Shrub (metric tons/ft²/year)	Value of Removal ($/metric ton)*	Value ($/ft²/year)*
NO_2	6.50E-08	75.6%	4.92E-08	$541.80	<$0.0001
O_3	5.02E-07	79.1%	3.97E-07	$3,558.99	$0.0014
$PM_{2.5}$	2.60E-08	79.9%	2.08E-08	$145,523.43	$0.0030
SO_2	3.16E-08	85.6%	2.70E-08	$183.91	<$0.0001
Total					**$0.004**

*Values are presented in 2021 USD; metric tons/ft²/year = metric tons per square foot per year; < = less than

Discussion: The public health impacts of air pollutants are well-documented and linked to respiratory illness, cardiovascular effects, and even premature death. Vegetation associated with green infrastructure can reduce these effects by intercepting particulate matter and absorbing pollutants. While this benefit is well-studied for urban tree cover, values for other vegetation types commonly present in bioretention areas are sparse. This methodology depends on the removal efficiency ratios of herbaceous vegetation compared to trees, calculated by one study conducted in New York. Additionally, the study measured particulate matter with a diameter of 10 microns or less (PM_{10}) rather than the particulate matter with a diameter of 2.5 microns or less ($PM_{2.5}$) modeled in Nowak et al. (2014), though comparing the difference in removal efficiency ratios between PM_{10} and the average across all pollutants does not affect the final result of the value calculation.

Stormwater Volume and Quality

Summary

Green Infrastructure Category: Bioretention
Benefit: Stormwater volume and quality
FEMA Value: $1.80/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Alternative cost
Geographic Area of Studies: National
Source Studies:

Reference 1: NJDEP Division of Water Quality. 2018. Evaluating Green Infrastructure: A Combined Sewer Overflow Control Alternative For Long Term Control Plans. NJDEP; Trenton, NJ.
Reference 2: CH2MHill and CDM Smith. 2013. Milwaukee Metropolitan Sewerage District Green Infrastructure Plan.
Reference 3: NOAA, National Centers for Environmental Information 2022. Climate at a Glance. National Time Series [Data Set]. https://www.ncdc.noaa.gov/cag/national/time-series/
Reference 4: Xiao, Q., McPherson, E. G., Zhang, Q., Ge, X., and Dahlgren, R. 2017. Performance of two bioswales on urban runoff management. Infrastructures, 2(4), 12.
Reference 5: Guo, J., Urbonas, B., MacKenzie, K. 2013. Water Quality Capture Volume for Storm Water BMP and LID Designs. Dept. of Civil Engineering, University of Colorado.
Reference 6: Nordman, E. E., Isely, E., Isely, P., and Denning, R. 2018. Benefit-cost analysis of stormwater green infrastructure practices for Grand Rapids, Michigan, USA. Journal of Cleaner Production, 200, 501-510.
Reference 7: EPA, 2014. The Economic Benefits of Green Infrastructure. A Case Study of Lancaster, PA.
Reference 8: McPherson, E. G., Xiao, Q., Wu, C., and Bartens, J. 2013. Metro Denver Urban Forest Assessment. Technical Report. Davis, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Reference 9: Clements, J., Henderson, J., Flemming, A., 2021. Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure. Prepared for the Water Research Foundation. Corona Environmental Consulting and Kennedy Jenks.

Methodology Description: Bioretention installations capture and filter precipitation and stormwater runoff from impervious areas that would otherwise need to be managed by urban stormwater systems. Bioretention installations capture precipitation that lands directly on their footprint, as well as stormwater runoff that drains from impervious surfaces. By managing stormwater runoff, bioretention installations help to reduce the capital, and O&M costs associated with managing stormwater using traditional infrastructure. The hypothetical cost of such traditional infrastructure represents the alternative cost, which is the least-cost means of providing at least the same amount of physical benefit using traditional stormwater infrastructure. Two alternative cost methods were used, generating two values, and the average of the two values ($1.80/ft^2/year) was used. Each method is described below in more detail.

Method 1: Alternative cost of stormwater management (by volume)

This method estimates the value of bioretention based on the alternative cost of managing an equivalent amount of water volume using traditional infrastructure.

Step 1. Estimate the physical stormwater capture potential of bioretention
If designed, sited, installed, and maintained correctly (see "Feasibility and Effectiveness Criteria" discussion in Section 5.2 of this report), it is assumed that every 1 ft^2 of bioretention installation can drain runoff from approximately 15.1 ft^2 of impervious surface (i.e., 16.1 ft^2 total, if the footprint of the bioretention is included). This assumption is based on the average loading ratio provided in two reports, a term that refers to the number of units of impervious surface that drains to a single unit of bioretention (e.g., 1 ft^2).The first report, a green infrastructure guidance document prepared for local agencies in New Jersey (NJDEP 2018), recommends a loading ratio range of between 12:1 and 22:1 for raingardens and biofiltration basins, and a range of 9:1 to 20:1 for bioswales. The second report, a green infrastructure plan prepared for the Milwaukee Metropolitan Sewerage District (CH2MHill and CDM Smith 2013), recommends a loading ratio of 12:1. The average ratio across all of the categories for both studies was 15.1 to 1, which was used as the final loading ratio for the bioretention category. This means that each 1 ft^2 can drain 16.1 ft^2 if the footprint of the bioretention is included.

The volume of water captured by bioretention on their footprint and drainage area depends on annual rainfall.[v] In this case, because the goal is to develop a national value, the average rainfall in the U.S. was used to represent a typical site. Average rainfall in the U.S. from 2000 to 2020 was

[v] Other factors, such as soil type, can also play an important role.

reported to be 788.4 millimeters per year (mm/year) (NOAA 2022). A depth of 788.4 mm across an area of 16.1 ft^2 is a volume of 312 gallons/year.

While bioretention installations, if sited and designed correctly, are highly effective at capturing stormwater runoff, they do not always capture 100% of runoff. Based on the average value reported in two available studies (Xiao et al., 2017; Guo et al., 2013), it was assumed that bioretention facilities have a water capture efficacy of 90% (i.e., they capture 90% of runoff). Thus, it was estimated that 1 ft^2 of bioretention captures an annual volume of **279.2 gallons** (90% of 312 gallons).

Step 2. Estimate the alternative cost of managing an equivalent volume of stormwater
The costs of stormwater management using traditional infrastructure can be estimated on a $ per gallon basis and can be used to represent the alternative cost of managing stormwater. Several cost estimates were found in the literature, which came from the Cities of Lancaster, PA; Grand Rapids, MI; Boulder, CO; and Milwaukee, WI. Combined, these studies reported an average cost of $0.0046 per gallon of stormwater managed. These studies and their values are summarized in the table below.

Calculations:

Source Study	Study Location	Stormwater Management Cost (2021 USD/gallon)
Nordman et al. (2018)	City of Grand Rapids, MI	$0.0003
EPA (2014)	City of Lancaster, PA	$0.0016
McPherson (2013)	City of Boulder, CO	$0.0154
Clements et al. (2021)	City of Milwaukee, WI	$0.0013
Average Value		**$0.0046**

As calculated in the previous step, it is estimated that each ft^2 of bioretention can capture 279.2 gallons of stormwater. Therefore, it was estimated that the value of each 1 ft^2 of bioretention was (279.2 gallons/year * $0.0046/gallon =) **$1.29/ft^2/year.**

Method 2: Alternative cost of stormwater volume management (by area managed)
This method estimates the value of bioretention based on the alternative cost of managing an equivalent area of impervious surface using traditional infrastructure.

Step 1. Estimate the area of impervious surface managed by bioretention
If designed, sited, installed, and maintained correctly (see "Feasibility and Effectiveness Criteria" discussion in Section 5.2 of this report), it is assumed that every 1 ft^2 of bioretention installation can drain runoff from approximately **16.1 ft^2** of impervious surface. This assumption is based on the

average "loading ratio" provided in two studies, a term that refers to the number of units of impervious surface that drains to a single unit of bioretention (e.g., 1 ft^2). The first report, a green infrastructure guidance document prepared for local agencies in New Jersey (NJDEP 2018), recommends a loading ratio range of between 12:1 and 22:1 for raingardens and biofiltration basins, and a range of 9:1 to 20:1 for bioswales. The second report, a green infrastructure plan prepared for the Milwaukee Metropolitan Sewerage District (CH2MHill and CDM Smith 2013), recommends a loading ratio of 12:1. The average ratio across all of the categories for both studies was 15.1 to 1, which was used as the final loading ratio for the bioretention category.

Step 2. Estimate the alternative cost of managing an equivalent area of impervious surface

Utilities commonly estimate the costs of stormwater management according to the area of (effective) impervious surface managed (e.g., \$/acre of impervious area). Existing cost estimates for managing impervious areas using traditional infrastructure can be used to represent the alternative cost of managing stormwater. The WRF, in the methods section for its 2021 Green Stormwater Infrastructure Triple Bottom Line tool (Clements et al., 2021), reports that the cost estimating software RS Means contains a default capital cost of \$3/ft^2 (or \$130,680/acre) of impervious surface to represent a typical gray infrastructure scenario in 2020 USD, or \$3.18/ft^2 (\$138,507/acre) in 2021 USD. To convert this into an annual average value, we assume upfront capital costs of \$138,507/acre, ongoing O&M costs equal to 3.5% of capital costs, and an asset life of 100 years. These assumptions result in an average alternative cost of \$6,223/acre/year. As calculated in the previous step, it is estimated that each 1 ft^2 of bioretention can manage 16.1 ft^2 of impervious area – equivalent to 0.00037 acres. The annual value of managing that area is (\$6,233/acre/year * 0.00037 acres =) **\$2.31/ft^2/year.**

Final Value Calculation

The stormwater volume and quality benefit of bioretention was estimated at **\$1.80/ft^2/year**, which was the average of the results of the two alternative cost methods described above (\$1.29/ft^2/year and \$2.31/ft^2/year).

Appendix B. Urban Trees

Summary of Benefits of Urban Trees

Benefit Category	2021 USD/tree/year
Building energy cost savings	$17.05
Carbon sequestration and avoided emissions	$6.33
Drought risk reduction	$5.53
Habitat	$40.18
Heat risk reduction	$910.28
Property value improvement	$53.15
Removal of air pollutants	$2.50
Stormwater volume and quality	$20.17
Total	**$1,055.19**

Benefit Values and Methodology

Building Energy Cost Savings

Summary

Green Infrastructure Category: Urban trees
Benefit: Building energy cost savings
FEMA Value: $17.05/tree/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: Albuquerque, NM; Berkeley, CA, Bismarck, ND; Boise, ID; Boulder, CO; Charleston, SC, Charlotte, NC; Cheyenne, WY; Denver, CO; Fort Colins, CO; Glendale, AZ; Minneapolis, MN; New York City, NY; Orlando, FL. In addition, estimates of the value of street trees were taken from regional studies of California, the Midwest, and the Pacific Northwest (i.e., Oregon and Washington).

Source Studies:

Reference 1: McPherson, E.G., Simpson, J.R., Gardner, S.L., Vargas, K.E., Xiao, Q., and Watt, F. 2007. New York City, New York: Municipal Forest Resource Analysis.

Reference 2: McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Vargas, K.E., and Xiao, Q. 2005. City of Boulder, Colorado municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 66 p.

Reference 3: McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Vargas, K.E., Maco, S.E., and Xiao, Q. 2005. City of Charlotte, North Carolina municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 57 p.

Reference 4: McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Vargas, K.E., Maco, S.E., and Xiao, Q. 2006. City of Charleston, South Carolina Municipal Forest Resource Analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 60 p.

Reference 5: McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Gardner, S.L., Cozad, S.K., and Xiao, Q. 2006. Midwest community tree guide: benefits, costs, and strategic planting. Gen. Tech. Rep. PSW-GTR-199. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 99 p, 199.

Reference 6: McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Gardner, S.L., Vargas, K.E., and Xiao, Q. 2005. City of Minneapolis, Minnesota municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 42 p.

Reference 7: McPherson, E.G., Xiao, Q., van Doorn, N.S., de Goede, J., Bjorkman, J., Hollander, A., Boynton, R.M., Quinn, J.F. and Thorne, J.H. 2017. The structure, function and value of urban forests in California communities. Urban Forestry and Urban Greening, 28, pp.43–53.

Reference 8: McPherson, G., Simpson, J.R., Peper, P.J., Maco, S.E., and Xiao, Q. 2005. Municipal forest benefits and costs in five U.S. cities. Journal of Forestry, 103(8), 411-416.

Reference 9: Peper, P.J., McPherson, E.G., Simpson, J.R., and Xiao, Q. 2009. City of Orlando, Florida municipal forest resource analysis. Technical Report. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 65 p.

Reference 10: Peper, P.J., McPherson, E.G., Simpson, J.R., Gardner, S.L., Vargas, K.E., and Xiao, Q. 2007. City of Boise, Idaho Municipal Forest Resource Analysis. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 66 p.

Reference 11: Vargas, K.E., McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., and Xiao, Q. 2006. City of Albuquerque, New Mexico, municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 55 p.

Reference 12: McPherson, E.G., Xiao, Q., Wu, C., and Bartens, J. 2013. Metro Denver Urban Forest Assessment. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Methodology Description: The effects of tree cover on building energy use have been studied through multiple approaches. The studies chosen for this report follow the methods outlined by McPherson and Simpson (1999) and calculate annual building energy use for both commercial and residential properties based on computer simulations that incorporate building traits, climate, and shading effects.[52] Changes in energy consumption are calculated on a per-tree basis by comparing results before and after adding trees. The computer simulations incorporate building characteristics based on age of construction. In addition, shading effects are differentiated by tree species in the study areas and are simulated at various tree-to-building distances for multiple orientations and for different tree sizes.

In summary, average energy savings per tree are calculated as a function of building and tree characteristics, proximity, and orientation using distribution data specific to each of the study areas. Because homes adjacent to neighborhoods with shade trees may also benefit from these cooling effects, the studies account for both localized and neighborhood effects. The value of energy savings is the interaction of electricity prices at a typical summer rate in the study areas and the estimated difference in energy consumption.

Calculations:

Source Study	Study Location	Value ($/tree/year)*
McPherson et al. 2006	Albuquerque, NM	$10.65
McPherson et al. 2005	Berkeley, CA	$21.03
McPherson et al. 2005	Bismarck, ND	$6.57
McPherson et al. 2007	Boise, ID	$18.64
McPherson et al. 2005	Boulder, CO	$6.88
McPherson et al. 2017	CA	$12.51
McPherson et al. 2006	Charleston, SC	$10.67
McPherson et al. 2005	Charlotte, NC	$14.89
McPherson et al. 2005	Cheyenne, WY	$15.25
McPherson et al. 2013	Denver metro area, CO	$2.37
McPherson et al. 2005	Fort Colins, CO	$5.02
McPherson et al. 2005	Glendale, AZ	$7.54
McPherson et al. 2006	Midwest-average	$41.07
McPherson et al. 2005	Minneapolis, MN	$30.04
McPherson et al. 2007	NYC, NY	$61.36

Source Study	Study Location	Value ($/tree/year)*
McPherson et al. 2009	Orlando, FL	$8.25
Average		**$17.05**

*Values are presented in 2021 USD

Discussion: It is important to note that the value of trees in terms of energy savings will vary by season and is largely contingent on tree location with respect to the built environment. Urban trees can increase energy efficiency in summer if they provide protective shade at the eastern and western walls of buildings. In the winter, trees that allow the sun to strike the southern side of the building can help keep interiors warm. Trees also affect air movement into buildings and associated energy transfers. Thus, understanding prevailing wind patterns throughout the year can help inform an optimal tree distribution.

Carbon Sequestration and Avoided Emissions

Summary

Green Infrastructure Category: Urban trees
Benefit: Carbon sequestration and avoided carbon emissions
FEMA Value: $6.33/tree/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: Albuquerque, NM; Berkeley, CA, Bismarck, ND; Boise, ID; Boulder, CO; Charleston, SC, Charlotte, NC; Cheyenne, WY; Denver, CO; Fort Colins, CO; Glendale, AZ; Minneapolis, MN; New York City, NY; Orlando, FL. In addition, estimates of the value of street trees were taken from regional studies of California, the Midwest, and the Pacific Northwest (i.e., Oregon and Washington), and the U.S.
Source Studies:

Reference 1: Clements, J., Henderson, J., Flemming, A. 2021. Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure. The Water Research Foundation, Alexandria, VA and Denver, CO.
Reference 2: IWGSCGG 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990.
Reference 3: EPA. 2022. Power Profiler v 11.0. Retrieved from https://www.epa.gov/egrid/power-profiler#/ on April 13, 2022.
Reference 4: Peper, P. J., McPherson, E. G., Simpson, J. R., and Xiao, Q. I. N. G. F. U. 2009. City of Orlando, Florida municipal forest resource analysis. Technical Report. US Department of Agriculture, Forest Service, Pacific Southwest Research Station. 65 p.

Reference 5: Vargas, K. E., McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., and Xiao, Q. 2006. City of Albuquerque, New Mexico, municipal forest resource analysis. [Technical Report]. US Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 55 p.

Reference 6: McPherson, E. G., Simpson, J. R., Gardner, S. L., Vargas, K. E., Xiao, Q., and Watt, F. 2007. New York City, New York: Municipal Forest Resource Analysis.

Reference 7: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., and Xiao, Q. 2006. City of Charleston, South Carolina Municipal Forest Resource Analysis. [Technical Report]. US Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 60 p.

Reference 8: McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2005. City of Minneapolis, Minnesota municipal tree resource analysis. [Technical Report]. US Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 42 p.

Reference 9: McPherson, E. G., Maco, S. E., Simpson, J. R., Peper, P. J., Xiao, Q., VanDerZanden, A. M., and Bell, N. (2002). Western Washington and Oregon Community tree guide: benefits, costs and strategic planting.

Reference 10: McPherson, E. G., Xiao, Q., Wu, C., and Bartens, J. 2013. Metro Denver Urban Forest Assessment. Technical Report. Davis, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Reference 11: McPherson, E.G., Xiao, Q., van Doorn, N.S., de Goede, J., Bjorkman, J., Hollander, A., Boynton, R.M., Quinn, J.F. and Thorne, J.H., 2017. The structure, function and value of urban forests in California communities. Urban Forestry and Urban Greening, 28, pp.43-53.

Reference 12: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., and Xiao, Q. 2005. City of Charlotte, North Carolina municipal forest resource analysis. [Technical Report]. US Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 57 p.

Reference 13: Peper, P. J., McPherson, E. G., Simpson, J. R., Gardner, S. L., Vargas, K. E., and Xiao, Q. I. N. G. F. U. 2007. City of Boise, Idaho Municipal Forest Resource Analysis. Technical Report. Davis, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station. 66 p.

Reference 14: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2005. City of Boulder, Colorado municipal tree resource analysis. [Technical Report]. US Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 66 p.

Reference 15: McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Cozad, S. K., and Xiao, Q. 2006. Midwest community tree guide: benefits, costs, and strategic planting. Gen. Tech. Rep. PSW-GTR-199. Albany, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station. 99 p, 199.

Reference 16: McPherson, G., Simpson, J. R., Peper, P. J., Maco, S. E., and Xiao, Q. 2005. Municipal forest benefits and costs in five US cities. Journal of forestry, 103(8), 411-416.

Methodology Description: Urban trees influence atmospheric levels of carbon through two principal mechanisms: CO_2 capture and release from trees' natural processes (including decomposition) and avoided CO_2 emissions from reduced energy consumption.

McPherson and colleagues estimate the carbon sequestration benefits and avoided emissions from building electricity use for heating and cooling for many cities throughout the U.S. (References 4-16). To estimate avoided emissions from electricity use for heating and cooling, the studies use information on local fuel mix for the sector and emission factors for each energy source. To approximate CO_2 sequestration per tree (i.e., the net rate of CO_2 storage in above- and below-ground biomass over the course of one growing season), the studies chosen for this report use tree growth and biomass equations, tree survival rates that are specific to the study areas, and estimated CO_2 release during tree maintenance. The studies report these two values as a combined total.

Urban trees also provide avoided emissions benefits by reducing wastewater pumping because of stormwater capture. We estimate these benefits independent of the carbon sequestration and avoided building electricity emissions. McPherson and colleagues also estimate stormwater reduction volumes by urban trees in many cities throughout the U.S. (see References 4–15 above). On average, these studies find the amount of stormwater reduced by a single urban tree is 2,992 gallons per tree per year. Clements et al. (2021) calculate an average national energy intensity of 2,250 kWh/MG for wastewater and stormwater pumping. Applying this estimate to the amount of stormwater captured by green infrastructure, we get an avoided energy use of 0.66 kWh/ft^2/year. Next, we apply the national average of CO_2 emissions from the 2022 EPA eGRID (818.3 lbs CO_2e/MWh) to find avoided emissions of 0.54 lbs CO_2e/ft^2/year.

Finally, we use the SCC to value the avoided emissions and sequestered carbon. The value for carbon sequestration was derived from the IWGSCGG—a result of Executive Order 13990. Specifically, the 2021 value was used: \$52/metric ton CO_2e, or \$54.44/metric ton CO_2e in 2021 USD.

Calculations:

Avoided Emissions from Reduced Stormwater Pumping

Description	Value	Units
Annual stormwater capture	2,992 (0.0030)	gallons/tree/year (MG/tree/year)
Wastewater pumping energy use	2,250	kwH/MG
Avoided energy use	6.73 (0.0067)	kWh/tree/year (MWh/tree/year)
Average carbon emissions per unit energy	818.3	lbs CO_2e/MWh
Avoided carbon emissions	5.51	lbs CO_2e/tree/year

Description	Value	Units
	(0.0025)	(metric tons CO_2e/tree/year)
SCC*	54.44	$/metric ton CO_2e
Value of avoided carbon emissions*	**$0.14**	**$/tree/year**

Carbon Sequestration and Avoided Emissions from Building Heating and Cooling

Source Study	Study Location	Value ($/tree/year)*
Vargas et al. 2006	Albuquerque, NM	$5.90
McPherson et al. 2005	Berkeley, CA	$4.93
McPherson et al. 2005	Bismarck, ND	$5.55
McPherson et al. 2007	Boise, ID	$2.12
McPherson et al. 2005	Boulder, CO	$6.48
McPherson et al. 2017	CA	$2.24
McPherson et al. 2006	Charleston, SC	$5.58
McPherson et al. 2005	Charlotte, NC	$8.46
McPherson et al. 2005	Cheyenne, WY	$6.22
McPherson et al. 2013	Denver metro area, CO	$0.88
McPherson et al. 2005	Fort Colins, CO	$4.75
McPherson et al. 2005	Glendale, AZ	$2.03
McPherson et al. 2007	Midwest (average)	$5.07
McPherson et al. 2005	Minneapolis, MN	$15.11
McPherson et al. 2007	NYC, NY	$10.39
Peper et al. 2009	Orlando, FL	$10.84
Clements et al. 2021	U.S.	$6.34
Average		**$6.19**

Total Benefit

Benefit	Value ($/tree/year)*
Avoided Emissions from Reduced Stormwater Pumping	$0.14
Carbon Sequestration and Avoided Emissions from Building Heating and Cooling	$6.19
Total value	**$6.33**

*Values are presented in 2021 USD

Discussion: There are two mechanisms by which urban trees can affect the amount of carbon in the atmosphere: avoided carbon emissions and carbon sequestration. Urban trees can decrease energy consumption—and therefore CO_2 emissions—by reducing the amount of stormwater going through treatment and pumping and reducing heating and cooling costs of buildings. Clements et al. (2021) note that electricity production accounts for 25% of greenhouse gas emissions in the U.S. While emission rates depend on many factors beyond energy production and vary across the U.S., we apply national averages to arrive at a broadly applicable benefit estimate for urban tree-related avoided costs. CO_2 sequestration rates depend on tree species, age, and conditions of the surrounding environment. Tree survival is the main determinant of CO_2 release and capture. The calculations in the selected studies claim to be conservative because of their assumptions about tree decomposition and dead tree management practices—the studies assume that dead trees are removed and mulched in the same year the death occurs so that 80% of their stored carbon is released to the atmosphere as CO_2 in the same year. Finally, a common method of valuing the benefits of carbon capture is to use the SCC. The SCC value used was standardized from the latest data produced by the IWGSCGG, a group appointed by the White House.

Drought Risk Reduction

Summary

Green Infrastructure Category: Urban trees
Benefit: Drought risk reduction
FEMA Value: $5.53/tree/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Stated preference
Geographic Area of Studies: Austin, TX; Long Beach, CA; Orlando, FL; San Francisco, CA; Boise, ID; Boulder, CO; Charleston, SC, Charlotte, NC; Denver, CO; Minneapolis, MN; New York City, NY; Orlando, FL. In addition, estimates of the value of street trees were taken from regional studies of California, the Midwest, and the Pacific Northwest (i.e., Oregon and Washington).

Source Studies:

Reference 1: Raucher, R., J. Clements, C. Donovan, D. Chapman, R. Bishop, G. Johns, M. Hanemann, S. Rodkin, and J. Garrett. 2011. The Value of Water Supply Reliability in the Residential Sector. Water Use Research Foundation. Alexandria, VA

Reference 2: McPherson, E. G., Maco, S. E., Simpson, J. R., Peper, P. J., Xiao, Q., VanDerZanden, A. M., and Bell, N. (2002). Western Washington and Oregon Community tree guide: benefits, costs and strategic planting.

Reference 3: McPherson, E. G., Simpson, J. R., Gardner, S. L., Vargas, K. E., Xiao, Q., and W, F. 2007. New York City, New York: Municipal Forest Resource Analysis.

Reference 4: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2005. City of Boulder, Colorado municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 66 p.

Reference 5: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., and Xiao, Q. 2005. City of Charlotte, North Carolina municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 57 p.

Reference 6: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., and Xiao, Q. 2006. City of Charleston, South Carolina Municipal Forest Resource Analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 60 p.

Reference 7: McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Cozad, S. K., and Xiao, Q. 2006. Midwest community tree guide: benefits, costs, and strategic planting. Gen. Tech. Rep. PSW-GTR-199. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 99 p, 199.

Reference 8: McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2005. City of Minneapolis, Minnesota municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 42 p.

Reference 9: McPherson, E.G., Xiao, Q., van Doorn, N.S., de Goede, J., Bjorkman, J., Hollander, A., Boynton, R.M., Quinn, J.F. and Thorne, J.H., 2017. The structure, function and value of urban forests in California communities. Urban Forestry and Urban Greening, 28, pp.43-53.

Reference 10: Peper, P. J., McPherson, E. G., Simpson, J. R., and Xiao, Q. 2009. City of Orlando, Florida municipal forest resource analysis. Technical Report. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 65 p.

Reference 11: Peper, P. J., McPherson, E. G., Simpson, J. R., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2007. City of Boise, Idaho Municipal Forest Resource Analysis. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 66 p.

Reference 12: McPherson, E. G., Xiao, Q., Wu, C., and Bartens, J. 2013. Metro Denver Urban Forest Assessment. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Methodology Description: Urban trees allow water to infiltrate into soil and groundwater sources. By conveying stormwater into the groundwater system, urban trees help support a reliable water supply. To appropriately estimate the water supply benefits of urban trees, the first step is calculating the average national annual water capture facilitated by them. To do so, we first find a national estimate of captured stormwater per tree. McPherson and colleagues have estimated stormwater reduction by urban trees in many cities throughout the U.S. (see References 2–12). On average, these studies find the amount of stormwater reduced by a single urban tree is 2,992.38 gallons per tree per year. Using information about the approximate infiltration efficiency factor associated with urban green infrastructure (i.e., the fraction of runoff that can be infiltrated into the ground), it is calculated that the average urban tree in the U.S. can capture 2,319 gallons of water per year.

To quantify the monetary value of water supply benefits provided by each urban tree, this study multiplies the 2,319 gallons/tree/year by a national estimate of the annual value of a liter of water (2,319 gallons equals 8,779 liters). The stated preference approach is used to estimate the value of having a more reliable water supply thanks to the stormwater infiltration benefit provided by urban trees. The estimates are based on the findings by Raucher et al. (2011), who surveyed more than 2,000 households in five U.S. cities to understand how much households would be willing to pay per year to avoid water supply shortages.

Specifically, the referenced study used a stated choice experiment to elicit how much households in the various cities would pay to avoid a 15% restriction of their use of water for lawn irrigation. We then incorporated city-specific data on average household water use for homes with a yard to estimate the volume corresponding to a 15% reduction in each city and converted the result to a per-tree measure. Accordingly, the final estimate reported here corresponds to the average annual household WTP across four of the cities in the Raucher et al. (2011) study (one of the cities in the study by Raucher and colleagues was not identified and therefore the average household water use for homes with a yard could not be found).

Calculations:

Description	Value	Units
Annual stormwater capture	2,992 (0.0030)	gallons/tree/year (MG/tree/year)
Infiltration efficiency factor associated with urban green infrastructure	77.5%	percent
Average household annual WTP per liter of water for lawn irrigation purposes*	$776	2021 USD/acre-foot/year
Value of drought risk reduction*	**$5.53**	$/tree/year

*Values are presented in 2021 USD

Discussion: The monetary value of a reliable water supply—which can include drought risk reduction—depends on the level of water scarcity in the region, local infrastructure costs, and available alternatives for water replenishment among other factors. Here we used a stated preference methodology that incorporates values from four different areas and does not double count with the existing avoided costs of providing alternative drinking water sources already in the BCA Toolkit. The existing BCA Toolkit value is based on water for potable uses, while the value presented in this report depends on nonpotable use of water. Furthermore, including a stated preference value is beneficial as it represents another value apart from avoided costs that is held by water users. Water rights transfer data that provide direct market prices are limited and only available for a handful of states, which makes them challenging to use to produce a broadly applicable estimate for the U.S. Finally, direct market pricing methods, such as those using retail utility water rates or wholesale bulk water purchases are likely to understate the full value of having a more reliable water supply system, because these price structures typically reflect policy preferences and thus are an imperfect tool for providing a clear price signal that can measure drought risk reduction.

Habitat and Biodiversity

Summary

Green Infrastructure Category: Urban trees
Benefit: Habitat and biodiversity
FEMA Value: $40.18/tree/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Meta-analysis, hedonic pricing
Geographic Area of Studies: Global
Source Studies:

> **Reference 1:** Bockarjova, M., Botzen, W.J., Koetse, M.J. 2020. "Economic valuation of green and blue nature in cities: A meta-analysis." *Ecological Economics* 169: 106480.
> **Reference 2:** McPherson, E. Gregory; van Doorn, Natalie S.; Peper, Paula J. 2016. Urban tree database. Fort Collins, CO: U.S. Forest Service Research Data Archive. Updated 21 January 2020. https://doi.org/10.2737/RDS-2016-0005

Methodology Description: Bockarjova et al. (2020) created a meta-analysis describing the value of green infrastructure and open space from 147 observations across 60 studies conducted around the world, including studies valuing street trees and urban forests. We performed a function transfer—a type of benefit transfer method—to construct a U.S.–specific value from Model 2, which had an adjusted R^2 of 0.699. The model structure is as follows:

$$y_{ij} = \alpha + \beta X_{ij} + \mu_j + \varepsilon_{ij}$$

Where the dependent variable y is the annual per hectare value; the subscript i represents each observation; the subscript j represents each study in the meta-analysis; the vector X includes socioeconomic, study, and site characteristics; the vector β contains the model coefficients; and μ and ε contain residuals. Model variables were set as follows: (1) For the "type of nature variables," the green connected to gray variable, which is defined to include street trees (which most closely matches the definition of urban trees used in this report), was set to 1, and the other greenspace type variables (small urban green, forest, park, multi-landscape, and blue nature) were set to 0; (2) the biodiversity and habitat variable was set to 1, and all other ecosystem service variables (local climate regulation, noise reduction, flood regulation, cultural, recreation, and aesthetics) were set to 0; (3) GDP per capita was calculated by converting 2020 U.S. GDP per capita to the units specified by the model; (4) population density was calculated using the average population density in urban areas in the U.S.,[53] converted to the units specified by the model; and (5) all other variables were set to their mean value. The dependent variable is reported as 2016 USD per hectare per year, which we converted to 2021 USD using CPI data from the U.S. Bureau of Labor Statistics. To convert to a per tree per year value, we divide by the average urban area covered by a tree canopy, as determined from the Urban Tree Database, a collection of data on urban trees from over 14,000 trees in 17 U.S. cities. In general, a tree canopy is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above. A way to measure the extent of canopy cover provided by a single tree is estimating the crown diameter of that tree. The width of a crown can be measured by projecting the edges of the crown to the ground and measuring the length along one axis from edge to edge through the crown center. The Urban Tree Database includes crown diameter measurements. We use the average crown diameter measurement (9.5 meters) to estimate an average area of canopy cover per tree (767 ft^2).

Calculations:

Source Study	Study Location	Value ($/tree/year)*
Bockarjova et al. (2020)	Global	$40.18
Average		**$40.18**

*Values are presented in 2021 USD

Discussion: Meta-analyses produce value estimates from the results of typically dozens or hundreds of studies at once, controlling for wide variations in ecosystem characteristics, human preferences, and methodological aspects of valuation studies. They are increasingly used to synthesize environmental literature and are a powerful tool that can produce customized value estimates where domestic valuation literature is scarce.

While the Bockarjova et al. study is one of the most robust, recent, and relevant meta-analyses specific to urban green spaces and green infrastructure, limitations could include:

1. Interpretation of ecosystem services from the literature used in the meta-analysis can often be subjective, as primary study authors sometimes do not give precise descriptions of the environmental benefits being studied.

2. Very small green spaces may be undervaluated: benefits typically increase with decreasing size of green spaces, and the majority of studies included in the meta-analysis value areas greater than 20 acres.

3. Intensity of use of green areas is not considered by the model: this type of information is not recorded in every study, and presumably smaller green spaces would have mainly local population benefits while larger green spaces may have more regional effects and effects for nonlocals.

Heat Risk Reduction

Summary

Green Infrastructure Category: Urban trees
Benefit: Heat risk reduction
FEMA Value: $910.28/tree/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: Albuquerque, NM; Atlanta, GA; Chicago, IL; Houston, TX; Los Angeles, CA; Miami, FL; Minneapolis, MN; New York, NY

Source Studies:

Reference 1: Gronlund, C.J., Zanobetti, A., Schwartz, J.D., Wellenius G.A., O'Neill, M.S. 2014. Heat, heat waves, and hospital admissions among the elderly in the United States, 1992–2006. Environmental Health Perspectives 122:1187.
Reference 2: McDonald, R.I., Kroeger, T., Zhang, P., and Hamel, P. 2020. The value of US urban tree cover for reducing heat-related health impacts and electricity consumption. Ecosystems, 23(1), 137–150.
Reference 3: Medina-Ramon, M., and Schwartz, J. 2007. Temperature, temperature extremes, and mortality: a study of acclimatization and effect modification in 50 US cities. Occupational and Environmental Medicine, 64(12), 827–833.
Reference 4: Sinha, P., Coville, R.C., Hirabayashi, S., Lim, B., Endreny, T.A., and Nowak, D.J. 2021. Modeling lives saved from extreme heat by urban tree cover. Ecological Modelling, 449, 109553.
Reference 5: Sinha, P., Coville, R.C., Hirabayashi, S., Lim, B., Endreny, T.A., and Nowak, D.J. 2022. "Variation in estimates of heat-related mortality reduction because of tree cover in US cities." Journal of Environmental Management 301, 113751.

Methodology Description: Mortality and morbidity risks increase with elevated temperatures. Urban green spaces and trees can reduce the urban heat island (UHI) effect by providing shade and cooling the air via evapotranspiration, thereby helping mitigate UHI impacts on human health. To derive a value of public health benefits brought about by urban trees in multiple U.S. cities, this analysis builds on the work by Sinha et al. (2021, 2022) to estimate a general health impact function (HIF), which is combined with costs of hospitalization and the value of a statistical life (VSL; the FEMA standard value for fatalities is $11.6 million in 2020 USD or $12.1 million in 2021 USD) to assign an economic value to changes in UHI and the associated changes in mortality and morbidity.

The HIF is estimated using local population data and underlying parameters from the literature, and the cities chosen to derive the estimate are among the most frequently examined by the UHI literature. In addition, because the public health literature shows that the population over 65 is more sensitive to extreme heat, the final estimate is based on changes in health outcomes of populations aged 65 and older associated to exposure to extreme heat events.

The parameters required to calculate changes in mortality and morbidity because of temperature reductions associated with urban tree cover correspond to national averages and are taken from Medina-Ramon and Schwartz (2007) and Gronlund et al. (2014), respectively. To approximate the number of days with extreme heat (i.e., days where the maximum temperature recorded is equal to or exceeds the 99th percentile of daily maximum temperatures recorded between 2010 and 2020) that are avoided because of the effects of the existing tree canopy in each selected city, temperature reductions attributed to tree canopy cover are taken from McDonald et al. (2020) for each of the selected cities and combined with historical records of maximum daily temperature from the Global Historical Climatology Network. Finally, hospitalization costs and the VSL are taken from the Hospitalization Cost and Utilization Project and FEMA, respectively. Hospitalization costs correspond to the national average charge for all hospital stays per person for patients 65 and older. The estimated heat risk reduction benefit per tree in USD 2021 is $4.60 in avoided hospitalization costs and $905.68 in avoided losses of VSL.

Calculations:

Description	Value	Units
Average cost of hospitalization per person (age 65+)	$53,703	2021 USD
VSL	$12,144,952	2021 USD
Average temperature reduction owing to the cooling effect of trees in eight U.S. cities	0.25	Degrees Celsius
Avoided annual hospitalizations of people age 65+ in eight U.S. cities owing to the cooling effect of trees	3,294	Hospitalizations of people age 65+/year
Avoided annual deaths of people age 65+ in eight U.S. Cities owing to the cooling effect of trees	3,785	Deaths of people age 65+/year

Description	Value	Units
Avoided annual hospitalization costs in eight U.S. cities owing to the cooling effect of trees	$261.13	$/acre/year
Avoided annual losses of VSL in eight U.S. cities owing to the cooling effect of trees	$51,389.53	$/acre/year
Average tree canopy cover in eight U.S. cities	778,378	acres
Approximate number of trees in 1 acre of tree canopy	56.74	Number of trees
Average avoided cost of hospitalizations per tree	$4.60	$/year/tree
Average avoided losses of VSL per tree	$905.68	$/year/tree
Average value per tree *	**$910.28**	$/tree/year

*Values are presented in 2021 USD

Discussion: Urban green spaces and trees can reduce UHI. This is a benefit that is difficult to estimate but important to recognize, and the literature is both robust and evolving. Several improvements can be made on the methodology presented here. These include incorporating more granular data on land cover types, heat effects, and health responses in order to estimate neighborhood effects rather than city-level aggregates; expanding or refining the definition of vulnerable populations; using other metrics to measure heat effects on health (e.g., heat waves, their duration, and the time of their occurrence as opposed to number of extreme heat events); accounting for the role of humidity in mortality and morbidity; accounting for adaptations to heat; and including measures of lost work productivity and other effects from health impacts (e.g., increased pressure on emergency response systems).

Property Value Improvement

Summary

Green Infrastructure Category: Urban trees
Benefit: Property value improvement
FEMA Value: $53.15/tree/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Hedonic pricing

Geographic Area of Studies: Albuquerque, NM; Berkeley, CA, Bismarck, ND; Boise, ID; Boulder, CO; Charleston, SC, Charlotte, NC; Cheyenne, WY; Denver, CO; Fort Colins, CO; Glendale, AZ; Minneapolis, MN; New York, NY; Orlando, FL. In addition, estimates of the value of street trees were taken from regional studies of California, and the Pacific Northwest (i.e., Oregon and Washington).

Source Studies:

Reference 1: McPherson, E.G., Simpson, J.R., Gardner, S.L., Vargas, K.E., Xiao, Q., and Watt, F. 2007. New York, NY: Municipal Forest Resource Analysis.

Reference 2: McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Vargas, K.E., and Xiao, Q. 2005. City of Boulder, Colorado municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 66 p.

Reference 3: McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Vargas, K.E., Maco, S.E., and Xiao, Q. 2005. City of Charlotte, North Carolina municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 57 p.

Reference 4: McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Vargas, K.E., Maco, S.E., and Xiao, Q. 2006. City of Charleston, South Carolina Municipal Forest Resource Analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 60 p.

Reference 5: McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Gardner, S.L., Vargas, K.E., and Xiao, Q. 2005. City of Minneapolis, Minnesota municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 42 p.

Reference 6: McPherson, E.G., Xiao, Q., van Doorn, N.S., de Goede, J., Bjorkman, J., Hollander, A., Boynton, R.M., Quinn, J.F. and Thorne, J.H., 2017. The structure, function and value of urban forests in California communities. Urban Forestry and Urban Greening, 28, pp.43-53.

Reference 7: McPherson, G., Simpson, J. R., Peper, P. J., Maco, S. E., and Xiao, Q. 2005. Municipal forest benefits and costs in five U.S. cities. Journal of forestry, 103(8), 411-416.

Reference 8: Peper, P. J., McPherson, E. G., Simpson, J. R., and Xiao, Q. 2009. City of Orlando, Florida municipal forest resource analysis. Technical Report. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 65 p.

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Reference 10: Vargas, K. E., McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., and Xiao, Q. 2006. City of Albuquerque, New Mexico, municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 55 p.

Reference 11: McPherson, E. G., Xiao, Q., Wu, C., and Bartens, J. 2013. Metro Denver Urban Forest Assessment. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Methodology Description: The selected studies for this report calculate increases in property value based on hedonic price research comparing home resale values. After determining an average percentage increase in property value attributed to large trees in the property, the studies use the median value of single-family homes for the study region and calculate the aesthetic value of one mature and well-maintained tree. These studies account for tree proximity via a decay function to model the diminishing impact on property values of trees located further away from homes.

Calculations:

Source Study	Study Location	Value ($/tree/year)*
McPherson et al. 2006	Albuquerque, NM	$18.44
McPherson et al. 2005	Berkeley, CA	$93.17
McPherson et al. 2005	Bismarck, ND	$28.62
McPherson et al. 2007	Boise, ID	$31.57
McPherson et al. 2005	Boulder, CO	$74.26
McPherson et al. 2017	CA	$103.74
McPherson et al. 2006	Charleston, SC	$34.83
McPherson et al. 2005	Charlotte, NC	$44.98
McPherson et al. 2005	Cheyenne, WY	$34.83
McPherson et al. 2013	Denver metro area, CO	$47.45
McPherson et al. 2005	Fort Colins, CO	$71.58
McPherson et al. 2005	Glendale, AZ	$30.18
McPherson et al. 2010	Midwest-average	$21.78
McPherson et al. 2005	Minneapolis, MN	$49.60
McPherson et al. 2007	New York, NY	$115.87
McPherson et al. 2009	Orlando, FL	$51.48
Average		**$53.15**

*Values are presented in 2021 USD

Discussion: Well-maintained urban trees provide economically measurable aesthetic benefits. Research comparing sales prices of residential properties suggests people are willing to pay a premium for properties in locations with trees. The value that trees bring to a neighborhood in terms of scenic quality are likely influenced by a myriad of local features, including distance to other green spaces, access to recreation areas, and of course, median household income, among other factors. Depending on average home prices and the size of the effect, this added benefit can also contribute significantly to property tax revenues. The studies selected for this valuation methodology take estimates from the literature of a 0.88% increase in sales price associated each large front-yard tree and adjust it to account for tree age. Although based on selected studies in the literature, the 0.88% increase in sales price per tree (compared to the city's median home sale price) represents a low-bound estimate according to recent literature. A meta-analysis of 21 hedonic property values by Kovacs and colleagues finds that a 1% change in the percentage of tree cover around a home is associated to change in property values between 0.3% and 1.3% depending on the starting percentage of tree cover in the neighborhood.54 Using tree measurement data from a national database covering over 14,000 trees in 17 U.S. cities,55 it is estimated that a single tree can occupy about 0.02 acres, which is about 6% of the area of the average lot size of new single-family houses built for sale in the U.S. between 2015 and 2021.[56] If the property value increase estimated by Kovacs et al. is linear, a 6% increase in canopy cover ranges from 1.8% to 7.8%. Therefore, using the 0.88% increase in property value assumption is a conservative estimate.

Removal of Air Pollutants

Summary

Green Infrastructure Category: Urban trees
Benefit: Removal of air pollutants
FEMA Value: $2.50/tree/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: Albuquerque, NM; Berkeley, CA, Bismarck, ND; Boise, ID; Boulder, CO; Charleston, SC, Charlotte, NC; Cheyenne, WY; Denver, CO; Fort Colins, CO; Glendale, AZ; Minneapolis, MN; New York, NY; Orlando, FL. In addition, estimates of the value of street trees were taken from regional studies of California, the Midwest, and the Pacific Northwest (i.e., Oregon and Washington).

Source Studies:

Reference 1: McPherson, E. G., Simpson, J. R., Gardner, S. L., Vargas, K. E., Xiao, Q., and Watt, F. 2007. New York, NY: Municipal Forest Resource Analysis.
Reference 2: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2005. City of Boulder, Colorado municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 66 p.
Reference 3: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., and Xiao, Q. 2005. City of Charlotte, North Carolina municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 57 p.
Reference 4: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., and Xiao, Q. 2006. City of Charleston, South Carolina Municipal Forest Resource

Analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 60 p.

Reference 5: McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Cozad, S. K., and Xiao, Q. 2006. Midwest community tree guide: benefits, costs, and strategic planting. Gen. Tech. Rep. PSW-GTR-199. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 99 p, 199.

Reference 6: McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2005. City of Minneapolis, Minnesota municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 42 p.

Reference 7: McPherson, E.G., Xiao, Q., van Doorn, N.S., de Goede, J., Bjorkman, J., Hollander, A., Boynton, R.M., Quinn, J.F. and Thorne, J.H., 2017. The structure, function and value of urban forests in California communities. Urban Forestry and Urban Greening, 28, pp.43-53.

Reference 8: McPherson, G., Simpson, J. R., Peper, P. J., Maco, S. E., and Xiao, Q. 2005. Municipal forest benefits and costs in five U.S. cities. Journal of forestry, 103(8), 411-416.

Reference 9: Peper, P. J., McPherson, E. G., Simpson, J. R., and Xiao, Q. 2009. City of Orlando, Florida municipal forest resource analysis. Technical Report. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 65 p.

Reference 10: Peper, P. J., McPherson, E. G., Simpson, J. R., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2007. City of Boise, Idaho Municipal Forest Resource Analysis. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 66 p.

Reference 11: Vargas, K. E., McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., and Xiao, Q. 2006. City of Albuquerque, New Mexico, municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 55 p.

Reference 12: McPherson, E. G., Xiao, Q., Wu, C., and Bartens, J. 2013. Metro Denver Urban Forest Assessment. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Methodology Description: Urban trees improve air quality through multiple mechanisms: absorbing pollutants, intercepting particulate matter, and releasing oxygen through photosynthesis. Shading and evapotranspiration also reduce local air temperatures and reduce ozone levels. The studies chosen for this valuation methodology focus on air quality improvements in terms of volatile organic hydrocarbons (VOCs), nitrogen dioxide (NO_2), Ozone (O_3), sulfur dioxide (SO_2), and particulate matter with diameter smaller than 10 microns (PM_{10}). They determine hourly pollutant deposition per tree using various sources of data (e.g., EPA, local monitoring meteorological stations). To approximate the monetary value of reduced air pollutant loads, changes in average annual pollutant loads are calculated using utility-specific emission factors for electricity and heating fuels, emissions concentrations, and population estimates. The price of reduced pollutant loads are derived from transaction costs specific to the air quality management district of the different study areas or from models that calculate the marginal cost of controlling different pollutants to meet air quality standards.

Calculations:

Source Study	Study Location	Value ($/tree/year)*
McPherson et al. 2006	Albuquerque, NM	$1.49
McPherson et al. 2005	Berkeley, CA	$-0.78
McPherson et al. 2005	Bismarck, ND	$0.29
McPherson et al. 2007	Boise, ID	$0.35
McPherson et al. 2005	Boulder, CO	$1.10
McPherson et al. 2017	CA	$2.24
McPherson et al. 2006	Charleston, SC	$3.20
McPherson et al. 2005	Charlotte, NC	$0.59
McPherson et al. 2005	Cheyenne, WY	$1.87
McPherson et al. 2013	Denver metro area, CO	$0.00
McPherson et al. 2005	Fort Colins, CO	$0.83
McPherson et al. 2005	Glendale, AZ	$2.10
McPherson et al. 2008	Midwest-average	$5.28
McPherson et al. 2005	Minneapolis, MN	$7.68
McPherson et al. 2007	New York, NY	$11.63
McPherson et al. 2009	Orlando, FL	$2.13
Average		**$2.50**

*Values are presented in 2021 USD

Discussion: While urban trees improve air quality through multiple mechanisms, most trees also emit various biogenic volatile organic compounds (BVOCs) that can contribute to ozone formation. Determining the contribution of these BVOCs to atmospheric ozone is complicated as the processes are complex. Some of the studies referenced for this report account for BVOC emissions to calculate the net quality improvement from urban trees, and some do not.

Stormwater Volume and Quality

Summary

Green Infrastructure Category: Urban trees
Benefit: Stormwater volume and quality
FEMA Value: $20.17/tree/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: Albuquerque, NM; Berkeley, CA, Bismarck, ND; Boise, ID; Boulder, CO; Charleston, SC, Charlotte, NC; Cheyenne, WY; Denver, CO; Fort Collins, CO; Glendale, AZ; Minneapolis, MN; New York, NY; Orlando, FL. In addition, estimates of the value of street trees were taken from regional studies of California, the Midwest, and the Pacific Northwest (i.e., Oregon and Washington).

Source Studies:

Reference 1: McPherson, E. G., Simpson, J. R., Gardner, S. L., Vargas, K. E., Xiao, Q., and Watt, F. 2007. New York, New York: Municipal Forest Resource Analysis.

Reference 2: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2005. City of Boulder, Colorado municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 66 p.

Reference 3: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., and Xiao, Q. 2005. City of Charlotte, North Carolina municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 57 p.

Reference 4: McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., Maco, S. E., and Xiao, Q. 2006. City of Charleston, South Carolina Municipal Forest Resource Analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 60 p.

Reference 5: McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Cozad, S. K., and Xiao, Q. 2006. Midwest community tree guide: benefits, costs, and strategic planting. Gen. Tech. Rep. PSW-GTR-199. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 99 p, 199.

Reference 6: McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2005. City of Minneapolis, Minnesota municipal tree resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 42 p.

Reference 7: McPherson, E.G., Xiao, Q., van Doorn, N.S., de Goede, J., Bjorkman, J., Hollander, A., Boynton, R.M., Quinn, J.F. and Thorne, J.H., 2017. The structure, function and value of urban forests in California communities. Urban Forestry and Urban Greening, 28, pp.43-53.

Reference 8: McPherson, G., Simpson, J. R., Peper, P. J., Maco, S. E., and Xiao, Q. 2005. Municipal forest benefits and costs in five U.S. cities. Journal of forestry, 103(8), 411-416.
Reference 9: Peper, P. J., McPherson, E. G., Simpson, J. R., and Xiao, Q. 2009. City of Orlando, Florida municipal forest resource analysis. Technical Report. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 65 p.
Reference 10: Peper, P. J., McPherson, E. G., Simpson, J. R., Gardner, S. L., Vargas, K. E., and Xiao, Q. 2007. City of Boise, Idaho Municipal Forest Resource Analysis. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 66 p.
Reference 11: Vargas, K. E., McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., and Xiao, Q. 2006. City of Albuquerque, New Mexico, municipal forest resource analysis. [Technical Report]. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 55 p.
Reference 12: McPherson, E. G., Xiao, Q., Wu, C., and Bartens, J. 2013. Metro Denver Urban Forest Assessment. Technical Report. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Methodology Description: Urban trees can reduce stormwater runoff and improve water quality through various mechanisms: leaves and branches can intercept and store rainfall (hence reducing runoff volumes and delaying the onset of peak flows); root systems can increase the rate at which rainfall infiltrates into the soil which reduces surface flow; tree canopies protect soil quality, which influences runoff volume, by mitigating the impact raindrops have on land surfaces. The studies chosen for this valuation methodology use numerical models that account for rainfall interception and water storage. Hourly meteorological data and precipitation are also used to estimate the effect of trees on the volume of stormwater runoff in the study areas. In general, the selected studies follow the same approach to valuation where an estimated amount of rainfall interception attributed to the trees is multiplied by a stormwater reduction price. The studies use different strategies to price stormwater reductions. For example, in some geographies, the price is based on the cost of treating sanitary wastewater, while in others the price is based on total life cycle expenditures for stormwater projects (including costs of basin land acquisition, construction, and annual O&M costs).

Calculations:

Source Study	Study Location	Value ($/tree/year)*
McPherson et al. 2006	Albuquerque, NM	$3.49
McPherson et al. 2005	Berkeley, CA	$8.20
McPherson et al. 2005	Bismarck, ND	$38.64
McPherson et al. 2007	Boise, ID	$5.41
McPherson et al. 2005	Boulder, CO	$20.80
McPherson et al. 2017	CA	$5.13

Source Study	Study Location	Value ($/tree/year)*
McPherson et al. 2006	Charleston, SC	$15.11
McPherson et al. 2005	Charlotte, NC	$34.22
McPherson et al. 2005	Cheyenne, WY	$4.51
McPherson et al. 2013	Denver metro area, CO	$9.89
McPherson et al. 2005	Fort Colins, CO	$18.10
McPherson et al. 2005	Glendale, AZ	$2.41
McPherson et al. 2009	Midwest (average)	$4.75
McPherson et al. 2005	Minneapolis, MN	$63.57
McPherson et al. 2007	New York, NY	$78.57
McPherson et al. 2009	Orlando, FL	$9.98
Average		**$20.17**

*Values are presented in 2021 USD

Discussion: Urban trees can reduce the amount of runoff and pollutant loading (e.g., sediment, metals, nutrients) in receiving water bodies. Stormwater runoff reductions from urban trees is a highly localized effect and the overall impact on water quality will ultimately depend on local conditions of the soil and points of pollution discharge relative to the tree cover. In addition, the cost of managing stormwater runoff will also vary greatly by geography. Factors like urban extent, impervious surface coverage, industrial activity, topography and conditions of existing drainage and sewage systems will influence these costs. Other factors related to management practices can further determine the price of treating excess runoff. Moreover, some communities may experience the negative effects of stormwater runoff (e.g., accelerated decay of roads, reduced opportunities to engage in recreational activities, higher exposure to pollutants and traffic, missed days of work/school) more heavily than others, and these communities may also be more vulnerable. All these considerations are important to keep in mind when assigning a general value to stormwater runoff reduction that is broadly extensible to the U.S.

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Appendix C. Permeable Pavement

Summary of Benefits of Permeable Pavement

Benefit Category	2021 USD/ft²/year
Building Energy Cost Savings	
Carbon Sequestration and Avoided Emissions	\$0.003
Drought Risk Reduction	\$0.13
Habitat	
Heat Risk Reduction	
Property Value Improvement	
Removal of Air Pollutants	
Stormwater Volume and Quality	\$0.51
Total	**\$0.64**

Benefit Values and Methodology

Carbon Sequestration and Avoided Emissions

Summary

Green Infrastructure Category: Permeable pavement
Benefit: Carbon sequestration and avoided emissions
FEMA Value: \$0.003/ft²/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: U.S.
Source Studies:

Reference 1: Clements, J., Henderson, J., Flemming, A. 2021. Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure. The Water Research Foundation, Alexandria, VA, and Denver, CO.
Reference 2: IWGSCGG. 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990.

Reference 3: EPA. 2022. Power Profiler v 11.0. Retrieved from https://www.epa.gov/egrid/power-profiler#/ on April 13, 2022.
Reference 4: CH2MHill and CDM Smith. 2013. Milwaukee Metropolitan Sewerage District Regional Green Infrastructure Plan. Available online at: https://www.mmsd.com/static/MMSDgreen infrastructureP_Final.pdf
Reference 5: CH2M Hill. 2011. Green Infrastructure Plan. The City of Lancaster, Lancaster, PA. Available online at: https://cityoflancasterpa.com/wp-content/uploads/2014/01/cityoflancaster_giplan_fullreport_april2011_final_0.pdf
Reference 6: NJDEP Division of Water Quality. 2018. Evaluating Green Infrastructure: A Combined Sewer Overflow Control Alternative For Long Term Control Plans. NJDEP; Trenton, NJ. Available online at: https://www.nj.gov/dep/dwq/pdf/CSO_Guidance_Evaluating_Green_Infrastructure_A_CSO_Control_Alternative_for_LTCPs.pdf
Reference 7: NOAA National Centers for Environmental information, Climate at a Glance: National Time Series, published April 2022, retrieved on May 2, 2022 from https://www.ncdc.noaa.gov/cag/

Methodology Description: We estimate the benefits of avoided carbon emissions by finding the avoided CO_2 emissions from reduced wastewater pumping because of stormwater capture by green infrastructure. First, we estimate annual stormwater capture by green infrastructure by reviewing several green infrastructure and long-term control plans conducted by cities in the U.S. On average, these plans assume that the ratio of drainage area to green infrastructure area for permeable pavement is 5 to 1. Assuming an annual average rainfall of 788.4 mm (derived from NOAA national time series data for the contiguous U.S., 2000–2020) (NOAA 2022), and efficiency factors describing the amount of stormwater captured, the annual water capture of permeable pavement is estimated at 67.7 gallons/ft^2/year. Clements et al. (2021) calculate an average energy intensity of 2,250 kWh/MG for wastewater and stormwater pumping, after applying national assumptions. Applying this estimate to the amount of stormwater captured by permeable pavement, we get an avoided energy use of 0.15 kWh/square foot/year. Next, we apply the national average of CO_2 emissions from the 2022 EPA (eGRID (818.3 lbs CO_2e/MWh) to find avoided emissions. Finally, we use the SCC to value the avoided emissions. The value for carbon sequestration used was derived from the IWGSCGG—a result of Executive Order 13990. Specifically, the 2021 value was used: \$52/metric ton CO_2e, or \$54.44/metric ton CO_2e in 2021 USD.

Calculations:

Description	Value	Units
Annual stormwater capture	67.7 (0.0001)	gallons/ft^2/year (MG/ft^2/year)
Wastewater pumping energy use	2,250	kwH/MG
Avoided energy use	0.15 (0.0002)	kWh/ft^2/year (MWh/ft^2/year)

Description	Value	Units
Average carbon emissions per unit energy	818.3	lbs CO_2e/MWh
Avoided carbon emissions	0.12 (0.0001)	lbs CO_2e/ft^2/year (metric tons CO_2e/ft^2/year)
SCC*	54.44	$/metric ton CO_2e
Value of avoided carbon emissions*	**$0.003**	**$/ft²/year**

*Values are presented in 2021 USD

Discussion: Green infrastructure can decrease energy consumption—and therefore CO2 emissions—by reducing the amount of stormwater going through treatment and pumping. As permeable pavement doesn't typically include vegetation that can sequester carbon, only emissions reduction is included for this benefit. Clements et al. (2021) note that electricity production accounts for 25% of greenhouse gas emissions in the U.S. While emission rates depend on many factors beyond energy production and vary across the U.S., we apply national averages to arrive at a broadly applicable benefit estimate for avoided costs attributable to permeable pavement. A common method of valuing the benefits of carbon capture is to use the SCC. The SCC value used was standardized from the latest data produced by the IWGSCGG, a group appointed by the White House.

Drought Risk Reduction

Summary

Green Infrastructure Category: Permeable pavement
Benefit: Drought risk reduction
FEMA Value: $0.13/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Stated preference
Geographic Area of Studies: Austin, TX; Long Beach, CA; Orlando, FL; and San Francisco, CA.
Source Studies:

> **Reference 1:** Raucher, R., J. Clements, C. Donovan, D. Chapman, R. Bishop, G. Johns, M. Hanemann, S. Rodkin, and J. Garrett. 2011. The Value of Water Supply Reliability in the Residential Sector. Water Use Research Foundation. Alexandria, VA

Methodology Description: Permeable pavement allows water to infiltrate into soil and groundwater sources. By absorbing stormwater on-site, permeable pavement helps support a reliable water supply. To appropriately estimate the water supply benefits of permeable pavement, the first step is calculating the average national annual water capture facilitated by permeable pavement. To do so, information about the typical loading ratio of permeable paving systems (5:1) is used in conjunction with the average national annual rainfall for the contiguous U.S. between 2000 and 2020 and the approximate infiltration efficiency factor (70%) associated with permeable pavement (i.e., the fraction of runoff that can be infiltrated into the ground). Using that information, we calculate that a square foot of permeable pavements in the U.S. can capture 67.7 gallons of water per year.

To quantify the monetary value of water supply benefits stemming from a square foot of permeable pavement practices, this study multiplies the 67.7 gallons/ft^2/year by a national estimate of the annual value of a gallon of water ($776/acre-foot/year). The stated preference approach is used to estimate the value of having a more reliable water supply thanks to the stormwater that infiltrates into the groundwater sources through permeable pavement.

The estimates are based on the findings by Raucher et al. (2011), who surveyed more than 2,000 households in five U.S. cities to understand how much households would be willing to pay per year to avoid water supply shortages. Specifically, the referenced study used a stated choice experiment to elicit how much households in the various cities would pay to avoid a 15% restriction of their use of water for lawn irrigation. We then incorporated city-specific data on average household water use for homes with a yard to estimate the volume corresponding to a 15% reduction in each city and converted the result to a per-acre measure. Accordingly, the final estimate reported here corresponds to the annual average WTP across four of the cities in the Raucher et al. (2011) study (one of the cities in the study by Raucher and colleagues was not identified and therefore the average household water use for homes with a yard could not be found).

Calculations:

Description	Value	Units
Annual stormwater capture	67.7	gallons/ft^2/year
Infiltration efficiency factor associated with urban green infrastructure	77.5%	percent
Average WTP to avoid water restrictions*	$776 ($0.0024)	$/acre-foot/year ($/gallons/year)
Value of drought risk reduction*	**$0.13**	$/ ft^2/year

*Values are presented in 2021 USD

Discussion: The monetary value of a reliable water supply—which can include drought risk reduction—depends on the level of water scarcity in the region, local infrastructure costs, and available alternatives for water replenishment among other factors. Here we used a stated preference methodology that incorporates values from four different areas and does not double count with the existing avoided costs of providing alternative drinking water sources already in the BCA Toolkit. The existing BCA Toolkit value is based on water for potable uses, while the value presented in this report depends on nonpotable use of water. Furthermore, including a stated preference value is beneficial as it represents another value apart from avoided costs that is held by water users. Water rights transfer data that provide direct market prices are limited and only available for a handful of states, which makes them challenging to use to produce a broadly applicable estimate for the U.S. Finally, direct market pricing methods, such as those using retail utility water rates or wholesale bulk water purchases are likely to understate the full value of having a more reliable water supply system, because these price structures typically reflect policy preferences and thus are an imperfect tool for providing a clear price signal that can measure drought risk reduction.

Stormwater Volume and Quality

Summary

Green Infrastructure Category: Permeable pavement
Benefit: Stormwater volume and quality
FEMA Value: $0.51/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Alternative cost
Geographic Area of Studies: National
Source Studies:

Reference 1: NJDEP Division of Water Quality. 2018. Evaluating Green Infrastructure: A Combined Sewer Overflow Control Alternative For Long Term Control Plans. NJDEP; Trenton, NJ.
Reference 2: CH2MHill and CDM Smith. 2013. Milwaukee Metropolitan Sewerage District Green Infrastructure Plan.
Reference 3: NOAA, National Centers for Environmental Information. 2022. Climate at a Glance. National Time Series [Data Set]. https://www.ncdc.noaa.gov/cag/national/time-series/
Reference 4: Selbig, W., Buer, N., 2018. Evaluating the Potential Benefits of Permeable Pavement on Quantity and Quality of Stormwater Runoff. Scientific Investigations Report 2018–5037. U.S. Geological Survey, U.S. Department of the Interior.
Reference 5: Nordman, E. E., Isely, E., Isely, P., and Denning, R. 2018. Benefit-cost analysis of stormwater green infrastructure practices for Grand Rapids, Michigan, USA. Journal of Cleaner Production, 200, 501-510.
Reference 6: EPA. 2014. The Economic Benefits of Green Infrastructure. A Case Study of Lancaster, PA.
Reference 7: McPherson, E. G., Xiao, Q., Wu, C., and Bartens, J. 2013. Metro Denver Urban Forest Assessment. Technical Report. Davis, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station.
Reference 8: Clements, J., Henderson, J., Flemming, A., 2021. Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater

Infrastructure. Prepared for the Water Research Foundation. Corona Environmental Consulting and Kennedy Jenks.

Methodology Description: Permeable pavement installations capture and filter precipitation and stormwater runoff from impervious areas that would otherwise need to be managed by urban stormwater systems. Permeable pavement installations capture precipitation that lands directly on their footprint, as well as stormwater runoff that drains from impervious surfaces. By managing stormwater runoff, permeable pavement installations help to reduce the capital and OandM costs associated with managing stormwater using traditional infrastructure. The hypothetical cost of such traditional infrastructure represents the alternative cost, which is the least-cost means of providing at least the same amount of physical benefit using traditional stormwater infrastructure. Two alternative cost methods were used, generating two values, and the average of the two values ($0.51/ft^2/year) was used. Each method is described below in more detail.

Method 1: Alternative cost of stormwater management (by volume)

This method estimates the value of permeable pavement based on the alternative cost of managing an equivalent amount of water volume using traditional infrastructure.

Step 1. Estimate the physical stormwater capture potential of permeable pavement

If designed, sited, installed, and maintained correctly (see "Feasibility and Effectiveness Criteria" discussion in Section 5.2 of this report), it is assumed that every 1 ft^2 of permeable pavement installation can drain runoff from approximately 4 ft^2 of impervious surface (i.e., 5 ft^2 total, if the footprint of the permeable pavement is included). This assumption is based on the average "loading ratio" provided in two studies, a term that refers to the number of units of impervious surface that drains to a single unit of permeable pavement (e.g., 1 ft^2). The first report, a green infrastructure guidance document prepared for local agencies in New Jersey (NJDEP 2018), recommends a loading ratio of 4:1 for permeable pavement. The second report, a green infrastructure plan prepared for the Milwaukee Metropolitan Sewerage District (CH2MHill and CDM Smith 2013), also recommends a loading ratio of 4:1. The average ratio across both studies was 4:1, which was used as the final loading ratio for the permeable pavement category. This means that each 1 ft^2 can drain 5 ft^2 if the footprint of the permeable pavement is included.

The volume of water captured by permeable pavement on their footprint and drainage area depends on annual rainfall.[vi] In this case, because the goal is to develop a national value, the average rainfall in the U.S. was used to represent a typical site. Average rainfall in the U.S. from 2000 to 2020 was reported to be 788.4 mm/year (NOAA 2022). A depth of 788.4 mm across an area of 5 ft^2 is a volume of 96.7 gallons.

[vi] Other factors, such as soil type, can also play an important role.

While permeable pavement installations, if sited and designed correctly, are highly effective at capturing stormwater runoff, they do not always capture 100% of runoff. Based on a study by Selbig and Buer (2018), it was assumed that permeable pavement facilities have a water capture efficacy of 70% (i.e., they capture 70% of runoff). Thus, it was estimated that 1 ft^2 of permeable pavement captures an annual volume of **67.7 gallons** (70% of 96.7 gallons).

Step 2. Estimate the alternative cost of managing an equivalent volume of stormwater
The costs of stormwater management using traditional infrastructure can be estimated on a $ per gallon basis and can be used to represent the alternative cost of managing stormwater.

Several cost estimates were found in the literature, which came from the Cities of Lancaster, PA; Grand Rapids, MI; Boulder, CO; and Milwaukee, WI. Combined, these studies reported an average cost of $0.0046 per gallon of stormwater managed. These studies and their values are summarized in the table below.

Calculations:

Source Study	Study Location	Stormwater Management Cost (2021 USD/gallon)
Nordman et al. (2018)	City of Grand Rapids, MI	$0.0003
EPA (2014)	City of Lancaster, PA	$0.0016
McPherson (2013)	City of Boulder, CO	$0.0154
Clements et al. (2021)	City of Milwaukee, WI	$0.0013
Average Value		**$0.0046**

As calculated in the previous step, it is estimated that each ft^2 of permeable pavement can capture 67.7 gallons of stormwater per year. Therefore, it was estimated that the value of each 1 ft^2 of permeable pavement was (67.7 gallons/year * $0.0046/gallon =) **$0.312/ft^2/year**.

Method 2: Alternative cost of stormwater volume management (by area managed)
This method estimates the value of permeable pavement based on the alternative cost of managing an equivalent area of impervious surface using traditional infrastructure.

Step 1. Estimate the area of impervious surface managed by permeable pavement
If designed, sited, installed, and maintained correctly (see "Feasibility and Effectiveness Criteria" discussion in Section 5.2 of this report), it is assumed that every 1 ft^2 of permeable pavement installation can drain runoff from approximately **5 ft^2** of impervious surface. This assumption is based on the average "loading ratio" provided in two studies, a term that refers to the number of units of impervious surface that drains to a single unit of permeable pavement (e.g., 1 ft^2). The first report, a green infrastructure guidance document prepared for local agencies in New Jersey (NJDEP

2018), recommends a loading ratio of 4:1 for permeable pavement. The second report, a green infrastructure plan prepared for the Milwaukee Metropolitan Sewerage District (CH2MHill and CDM Smith 2013), also recommends a loading ratio of 4:1. The average ratio across the two studies was 4:1, which was used as the final loading ratio for the permeable pavement category. Including the footprint of permeable pavement results in a ratio of 5:1.

Step 2. Estimate the alternative cost of managing an equivalent area of impervious surface
Utilities commonly estimate the costs of stormwater management according to the area of (effective) impervious surface managed (e.g., $/acre of impervious area). Existing cost estimates for managing impervious areas using traditional infrastructure can be used to represent the alternative cost of managing stormwater. The WRF, in the methods section for its 2021 Green Stormwater Infrastructure Triple Bottom Line tool (Clements et al. 2021), reports that the cost estimating software RS Means contains a default capital cost of \$3/ft^2 (or \$130,680/acre) of impervious surface to represent a typical gray infrastructure scenario in 2020 USD, or \$3.18/ft^2 (\$138,507/acre) in 2021 USD. To convert this into an annual average value, we assume upfront capital costs of \$138,507/acre, ongoing O&M costs equal to 3.5% of capital costs, and an asset life of 100 years. These assumptions result in an average alternative cost of \$6,223/acre/year. As calculated in the previous step, it is estimated that each 1 ft^2 of permeable pavement can manage 5 ft^2 of impervious area, equivalent to 0.00011 acres. The annual value of managing that area is (\$6,233/acre/year * 0.00011 acres =) **\$0.715/ft^2/year**.

Final Value Calculation

The stormwater volume and quality benefit of permeable pavement was estimated at **\$0.51/ft^2/year**, which was the average of the results of the two alternative cost methods described above (\$0.312/ft^2/year and \$0.715/ft^2/year).

Appendix D. Green Roofs

Summary of Benefits of Green Roofs

Benefit Category	2021 USD/ft^2/year
Avoided carbon emissions	$0.0004
Building energy cost savings	$0.05
Carbon sequestration	$0.01
Drought risk reduction	
Habitat	$0.05
Heat risk reduction	
Property value improvement	$0.19
Removal of air pollutants	$0.001
Stormwater volume and quality	$0.09
Total	**$0.40**

Benefit Values and Methodology

Building Energy Cost Savings

Summary

Green Infrastructure Category: Green roofs
Benefit: Building energy cost savings
FEMA Value: $0.05/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: U.S.

Source Studies:

Reference 1: Arizona State University (ASU). n.d. "Green Roof Energy Calculator." ASU Urban Climate Research Center. Available at: https://sustainability-innovation.asu.edu/urban-climate/green-roof-calculator/.

Reference 2: Energy Information Administration (EIA). 2022. “Electricity Data Browser: Average Retail Price of Electricity by State and Sector.” Available at: https://www.eia.gov/electricity/data/browser/. Accessed May 13, 2022.

Methodology Description: Dr. David Sailor and colleagues have created the National Green Roof Energy Calculator (ASU n.d.), a tool that calculates the energy savings of green roofs compared to conventional or white roofs. The tool integrates 8,000 simulations on energy performance of different building and roof types for 100 cities throughout the U.S. and Canada. Green roof characteristics included in the simulations are irrigation status, vegetation cover, soil depth, building type, and age. Dr. Sailor, Director of the Urban Climate Research Center at ASU, generously shared the data that backs up the Green Roof Energy Calculator for use in calculating an average benefit for green roofs to be included in the BCA Toolkit. The simulations output electricity and gas use per square meter of roof. We compared the national average electricity and gas use for green roofs and conventional dark roofs from this data. We then used data from EIA on average electricity costs and natural gas costs for commercial customers to estimate this benefit in dollars.

Calculations:

Description	Savings per Unit*	Price per Unit	Benefit per Unit ($/ft^2)**
Electricity	4.25 kWh/m^2	$0.11/kWh	$0.04
Natural gas	0.18 therms/m^2	$0.34/therm	$0.01
Total Benefit			**$0.05**

* Courtesy of David Sailor, Director of the Urban Climate Research Center, ASU
** Values are presented in 2021 USD

Discussion: Green roofs better insulate buildings than conventional roofs, reducing energy demand for both heating and cooling. Energy savings from green roofs depend on local climate, building characteristics such as height and insulation, and characteristics of the green roof itself. Soil depth of the green roof, vegetative density, moisture content, and irrigation are all factors that affect a green roof’s ability to reduce energy demand.

Carbon Sequestration and Avoided Emissions

Summary

Green Infrastructure Category: Green roofs
Benefit: Carbon sequestration and avoided emissions
FEMA Value: $0.01/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost

Geographic Area of Studies: Michigan, U.S.; Maryland, U.S.; Japan; Spain; U.S.

Source Studies:

Reference 1: Getter, K., Rowe, D., Robertson, G., Cregg, B., and Andresen, J. 2009. "Carbon Sequestration Potential of Extensive Green Roofs." Environmental Science and Technology, 43 (19): 7564–7570.

Reference 2: Kuronuma, T., H. Watanabe, T. Ishihara, D. Kou, K. Toushima, M. Ando, and S. Shindo. 2018. "CO_2 Payoff of Extensive Green Roofs with Different Vegetation Species." Sustainability, 10: 2256.

Reference 3: Ondoño, S., J. Martínez-Sánchez, and J. Moreno, 2016. "The Composition and Depth of Green Roof Substrates Affect the Growth of Silene vulgaris and Lagurus ovatus Species and the C and N Sequestration under Two Irrigation Conditions." Journal of Environmental Management, 166: 330–40.

Reference 4: Whittinghill, L., B. Rowe, R. Schutzkic, and B. Cregg, 2014. "Quantifying Carbon Sequestration of Various Green Roof and Ornamental Landscape Systems." Landscape and Urban Planning, 123: 41–48.

Reference 5: Clements, J., Henderson, J., Flemming, A. 2021. Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure. The Water Research Foundation, Alexandria, VA, and Denver, CO.

Reference 6: EPA. 2022. Power Profiler v 11.0. Retrieved from https://www.epa.gov/egrid/power-profiler#/ on April 13, 2022.

Reference 7: CH2Mhill and CDM Smith. 2013. Milwaukee Metropolitan Sewerage District Regional Green Infrastructure Plan. Available online at: https://www.mmsd.com/static/MMSDgreen infrastructureP_Final.pdf

Reference 8: CH2M Hill. 2011. Green Infrastructure Plan. The City of Lancaster, Lancaster, PA. Available online at: https://cityoflancasterpa.com/wp-content/uploads/2014/01/cityoflancaster_giplan_fullreport_april2011_final_0.pdf

Reference 9: NJDEP Division of Water Quality. 2018. Evaluating Green Infrastructure: A Combined Sewer Overflow Control Alternative For Long Term Control Plans. NJDEP; Trenton, NJ. Available online at: https://www.nj.gov/dep/dwq/pdf/CSO_Guidance_Evaluating_Green_Infrastructure_A_CSO_Control_Alternative_for_LTCPs.pdf

Reference 10: NOAA National Centers for Environmental information, Climate at a Glance: National Time Series, published April 2022, retrieved on May 2, 2022 from https://www.ncdc.noaa.gov/cag/

Reference 11: IWGSCGG. 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990.

Methodology Description: Green roofs influence atmospheric levels of carbon through two principal mechanisms: CO_2 capture and storage and avoided CO_2 emissions from reduced energy consumption from reducing stormwater flows.

Carbon sequestration benefits were calculated in two parts. First, a review of carbon literature presented four studies quantifying the carbon sequestration of green roofs. Getter et al. (2009) measure carbon sequestration from green roofs of various ages in Michigan and Maryland primarily composed of *Sedum* species. Whittinghill et al. (2014) measured carbon storage of green roofs in Michigan over three years. These green roofs were composed of *Sedum*, herbaceous plants, or vegetables and herbs. Kuronoma et al. (2018) assessed carbon sequestration of green roofs composed mostly of grasses in Japan. Ondoño et al. (2016) assessed carbon sequestration of green roofs with varying substrates in Spain.

These values were then mapped to the SCC to calculate a dollar value of carbon sequestration. The SCC represents the average societal costs associated with each additional ton of carbon emissions (measured in CO_2e), such as losses to agriculture, impacts to human health, and increased disaster risk. In the context of actions that reduce carbon emissions (e.g., energy efficiency) or actively sequester carbon (e.g., green infrastructure), the SCC represents the value of these actions in terms of avoided cost to society and is used by federal agencies in the U.S. and updated on a regular basis by the IWGSCGG. The value for carbon sequestration was derived from the IWGSCGG—a result of Executive Order 13990. Specifically, the 2021 value was used: \$52/metric ton CO_2e, or \$54.44/metric ton CO_2e in 2021 USD.

We estimate the benefits of avoided carbon emissions by finding the avoided CO_2 emissions from reduced wastewater pumping because of stormwater capture by green infrastructure. First, we estimate annual stormwater capture by green infrastructure by reviewing several green infrastructure and long-term control plans conducted by cities in the U.S. On average, these plans assume that the ratio of drainage area to square foot of green infrastructure area for green roofs is 1 to 1. Assuming an annual average rainfall of 788.4 mm (derived from NOAA national time series data for the contiguous U.S., 2000 to 2020) (NOAA 2022), and efficiency factors describing the amount of stormwater captured, the annual water capture of green roofs is estimated at 9.7 gallons/ft^2/year. Clements et al. (2021) calculate an average energy intensity of 2,250 kWh/MG for wastewater and stormwater pumping, after applying national assumptions. Applying this estimate to the amount of stormwater captured by green roofs, we get an avoided energy use of 0.022 kWh/square foot/year. Next, we apply the national average of CO_2 emissions from the 2022 EPA eGRID (818.3 lbs CO_2e/MWh) to find avoided emissions of 0.02 lbs CO_2e/ft^2/year. Finally, we use the SCC to value the avoided emissions. The value for carbon sequestration used was derived from the IWGSCGG—a result of Executive Order 13990. Specifically, the 2021 value was used: \$52/metric ton CO_2e, or \$54.44/metric ton CO_2e in 2021 USD.

Calculations:

Description	Value	Units
Annual stormwater capture	9.7 (1E-5)	gallons/ft^2/year (MG/ft^2/year)
Wastewater pumping energy use	2,250	kwH/MG
Avoided energy use	0.022 (2E-5)	kWh/ft^2/year (MWh/ft^2/year)
Average carbon emissions per unit energy	818.3	lbs CO2e/MWh
Avoided carbon emissions	0.02 (1E-5)	lbs CO2e/ft^2/year (metric tons CO_2e/ft^2/year)
SCC*	$54.44	$/metric ton CO_2e
Value of avoided carbon emissions*	**$0.0004**	**$/ft^2/year**

*Values are presented in 2021 USD

Source Study	Carbon Sequestration Rate (metric tons CO_2e/ft^2/year)	SCC ($/metric ton CO_2e)*	Value ($/ft^2/year)*
Getter et al. (2009)	6.46E-05	$54.44	$0.004
Kuronuma et al. (2018)	1.94E-04	$54.44	$0.011
Ondoño et al. (2016)	2.47E-04	$54.44	$0.013
Whittinghill et al. (2014)	3.82E-04	$54.44	$0.021
Average			**$0.01**

*Values are presented in 2021 USD

Discussion: Vegetation removes CO_2 from the atmosphere during photosynthesis and stores carbon in its biomass and in soil, acting as a carbon sink; the vegetation of green roofs provides this carbon sequestration benefit. International literature was included in this valuation methodology because of the limited number of studies assessing the carbon sequestration potential of green roofs. Carbon sequestration rates of green roofs vary based on plant species, soil depth, climate, irrigation, and other factors. The studies above represent a range of those factors. A common method of valuing the benefits of carbon capture is through the SCC. The SCC value used was standardized by the latest data produced by the IWGSCGG, a group appointed by the White House.

green infrastructure can decrease energy consumption—and therefore CO_2 emissions—by reducing the amount of stormwater going through treatment and pumping. Clements et al. (2021) note that electricity production accounts for 25% of greenhouse gas emissions in the U.S. While emission rates depend on many factors beyond energy production and vary across the U.S., we apply national averages to arrive at a broadly applicable benefit estimate for avoided costs attributable to permeable pavement. A common method of valuing the benefits of carbon capture is to use the SCC. The SCC value used was standardized from the latest data produced by the I IWGSCGG, a group appointed by the White House.

Habitat and Biodiversity

Summary

Green Infrastructure Category: Green roofs
Benefit: Habitat and biodiversity
FEMA Value: $0.05/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Meta-analysis, hedonic pricing
Geographic Area of Studies: Global
Source Study:

> **Reference 1:** Bockarjova, M., Botzen, W.J., and Koetse, M.J. 2020. "Economic valuation of green and blue nature in cities: A meta-analysis." Ecological Economics 169: 106480.

Methodology Description: Bockarjova et al. (2020) created a meta-analysis describing the value of green open spaces from 147 observations across 60 studies conducted around the world. We performed a function transfer—a type of benefit transfer method—to construct a U.S.–specific value from Model 2, which had an adjusted R^2 of 0.699. The model structure is as follows:

$$y_{ij} = \alpha + \beta X_{ij} + \mu_j + \varepsilon_{ij}$$

Where the dependent variable y is the annual per hectare value; the subscript i represents each observation; the subscript j represents each study in the meta-analysis; the vector X includes socioeconomic, study, and site characteristics; the vector β contains the model coefficients; and μ and ε contain residuals. Model variables were set as follows: (1) the green connected to gray variable was set to 1, and the other greenspace type variables (small urban green, forest, park, multi-landscape, and blue nature) were set to 0; (2) the biodiversity and habitat variable was set to 1, and all other ecosystem service variables (local climate regulation, aesthetics, noise reduction, flood regulation, cultural, and recreation) were set to 0; (3) GDP per capita was calculated by converting 2020 U.S. GDP per capita to the units specified by the model; (4) population density was calculated using the average population density in urban areas in the U.S.,[57] converted to the units specified by the model; and (5) all other variables were set to their mean value. The dependent variable is reported as 2016 USD per hectare per year, which we converted to 2021 USD per square foot per year.

Calculations:

Source Study	Study Location	Value ($/ft²/year)*
Bockarjova et al. (2020)	Global	$0.05
Average		**$0.05**

*Values are presented in 2021 USD

Discussion: Meta-analyses produce value estimates from the results of typically dozens or hundreds of studies at once, controlling for wide variations in ecosystem characteristics, human preferences, and methodological aspects of valuation studies. They are increasingly used to synthesize environmental literature and are a powerful tool that can produce customized value estimates where domestic valuation literature is scarce.

While the Bockarjova et al. study is one of the most robust, recent, and relevant meta-analyses specific to urban green spaces and green infrastructure, limitations could include:

1. Interpretation of ecosystem services from the literature used in the meta-analysis can often be subjective, as primary study authors sometimes do not give precise descriptions of the environmental benefits being studied.

2. Very small green spaces may be undervaluated: benefits typically increase with decreasing size of green spaces, and the majority of studies included in the meta-analysis value areas greater than 20 acres.

Property Value Improvement

Summary

Green Infrastructure Category: Green roofs
Benefit: Property value improvement
FEMA Value: $0.19/ft²/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Meta-analysis, hedonic pricing
Geographic Area of Studies: Global
Source Study:

Reference 1: Bockarjova, M., Botzen, W.J., Koetse, M.J. 2020. "Economic valuation of green and blue nature in cities: A meta-analysis." Ecological Economics 169: 106480.

Methodology Description: Bockarjova et al. (2020) created a meta-analysis describing the value of green open spaces from 147 observations across 60 studies conducted around the world. We performed a function transfer—a type of benefit transfer method—to construct a U.S.–specific value from Model 2, which had an adjusted R^2 of 0.699. The model structure is as follows:

$$y_{ij} = \alpha + \beta X_{ij} + \mu_j + \varepsilon_{ij}$$

Where the dependent variable y is the annual per hectare value; the subscript I represents each observation; the subscript j represents each study in the meta-analysis; the vector X includes socioeconomic, study, and site characteristics; the vector β contains the model coefficients; and μ and ε contain residuals. Model variables were set as follows: (1) the green connected to gray variable was set to 1, and the other greenspace type variables (small urban green, forest, park, multi-landscape, and blue nature) were set to 0; (2) the aesthetics variable was set to 1, and all other ecosystem service variables (local climate regulation, biodiversity and habitat, noise reduction, flood regulation, cultural, and recreation) were set to 0; (3) GDP per capita was calculated by converting 2020 U.S. GDP per capita to the units specified by the model; (4) population density was calculated using the average population density in urban areas in the U.S.,[58] converted to the units specified by the model; and (5) all other variables were set to their mean value. The dependent variable is reported as 2016 USD per hectare per year, which we converted to 2021 USD/ft^2/year.

Calculations:

Source Study	Study Location	Value ($/ft^2/year)*
Bockarjova et al. (2020)	Global	$0.19
Average		**$0.19**

*Values are presented in 2021 USD

Discussion: Meta-analyses produce value estimates from the results of typically dozens or hundreds of studies at once, controlling for wide variations in ecosystem characteristics, human preferences, and methodological aspects of valuation studies. They are increasingly used to synthesize environmental literature and are a powerful tool that can produce customized value estimates where domestic valuation literature is scarce.

While the Bockarjova et al. study is one of the most robust, recent, and relevant meta-analyses specific to urban green spaces and green infrastructure, limitations could include:

1. Interpretation of ecosystem services from the literature used in the meta-analysis can often be subjective, as primary study authors sometimes do not give precise descriptions of the environmental benefits being studied.

2. Very small green spaces may be undervaluated: benefits typically increase with decreasing size of green spaces, and the majority of studies included in the meta-analysis value areas greater than 20 acres.

Removal of Air Pollutants

Summary

Green Infrastructure Category: Green roofs
Benefit: Removal of air pollutants
FEMA Value: $0.001/ft^2/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Avoided cost
Geographic Area of Studies: Washington DC; Toronto, Canada; Manchester, UK; Chicago, U.S.; Melbourne, Australia
Source Studies:

Reference 1: Deutsch, B., Whitlow, H., Sullivan, M., and Savineau, A. 2005. Re-greening Washington DC: A Green Roof Vision Based on Environmental Benefits for Air Quality and Stormwater Management. Conference: The 3rd Annual International Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show, Washington, DC (U.S.), 4-6 May 2005.
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Reference 5: Nowak, D.J., S. Hirabayashi, A. Bodine, and E. Greenfield. 2014. "Tree and Forest Effects on Air Quality and Human Health in the United States." Environmental Pollution, 193: 119-129.

Methodology Description: A recent tool for valuing green infrastructure in the U.S. has presented a comprehensive literature review on the air pollution benefits of green roofs.[59] All studies included in this methodology relied on modeled, rather than measured, data. These studies presented removal rates for green roofs for nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3), which we averaged. Nowak et al. (2014) calculates the value of pollutant removal based on the avoided cost of adverse health outcomes due to air pollution. These values are updated to 2021 USD and applied to the removal rates for green roofs. Finally, we sum the values for all pollutant types to arrive at the total value of pollution removal.

Calculations:

Pollutant	Removal Rate (metric ton/ft²/year)	Value of Removal ($/metric ton)*	Value ($/ft²/year)*
NO_2	1.23 E-07	$541.80	$0.0001
O_3	9.45E-08	$3,558.99	<$0.0001
SO_2	2.82E-07	$183.91	$0.0010
Total			**$0.001**

*Values are presented in 2021 USD

Discussion: The public health impacts of air pollutants are well-documented and linked to respiratory illness, cardiovascular effects, and even premature death. Vegetation associated with green roofs can reduce these effects by intercepting particulate matter and absorbing pollutants. International literature was included because of the limited number of studies assessing the carbon sequestration potential of green roofs. Review of the studies above reveals that pollutant removal rates of green roofs can vary based on the season, wind conditions, plant characteristics, species planted, classification of green roof (i.e., intensive or extensive), and location of the green roof.

Stormwater Volume and Quality

Summary

Green Infrastructure Category: Green roofs
Benefit: Stormwater volume and quality
FEMA Value: $0.09/ft²/year
Currency Year: 2021 USD

Source Studies and Value Derivation

Valuation Method: Alternative cost
Geographic Area of Studies: National
Source Studies:

Reference 1: NJDEP Division of Water Quality. 2018. Evaluating Green Infrastructure: A Combined Sewer Overflow Control Alternative For Long Term Control Plans. NJDEP; Trenton, NJ.
Reference 2: CH2MHill and CDM Smith. 2013. Milwaukee Metropolitan Sewerage District Green Infrastructure Plan.
Reference 3: NOAA, National Centers for Environmental Information 2022. Climate at a Glance. National Time Series data set. https://www.ncdc.noaa.gov/cag/national/time-series/
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Reference 5: Nordman, E. E., Isely, E., Isely, P., and Denning, R. 2018. Benefit-cost analysis of stormwater green infrastructure practices for Grand Rapids, Michigan, USA. Journal of Cleaner Production, 200, 501–510.
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Reference 8: Clements, J., Henderson, J., Flemming, A., 2021. Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure. Prepared for the Water Research Foundation. Corona Environmental Consulting and Kennedy Jenks.

Methodology Description: Green roofs capture and filter precipitation and stormwater runoff from impervious areas that would otherwise need to be managed by urban stormwater systems. Green roofs capture precipitation that lands directly on their footprint. By managing stormwater runoff, green roofs help to reduce the capital and O&M costs associated with managing stormwater using traditional infrastructure. The hypothetical cost of such traditional infrastructure represents the alternative cost, which is the least-cost means of providing at least the same amount of physical benefit using traditional stormwater infrastructure. Two alternative cost methods were used, generating two values, and the average of the two values ($0.09/ft^2/year) was used. Each method is described below in more detail.

Method 1: Alternative cost of stormwater management (by volume)

This method estimates the value of green roofs based on the alternative cost of managing an equivalent amount of water volume using traditional infrastructure.

Step 1. Estimate the physical stormwater capture potential of green roofs

If designed, sited, installed, and maintained correctly (see "Feasibility and Effectiveness Criteria" discussion in Section 5.2 of this report), it is assumed that every 1 ft^2 of green roof can capture precipitation that lands on its footprint only. This assumption is based on the average "loading ratio" provided in two studies, a term that refers to the number of units of impervious surface that drains to a single unit of bioretention (e.g., 1 ft^2). The first report, a green infrastructure guidance document prepared for local agencies in New Jersey (NJDEP 2018), recommends a loading ratio of 1:1 for green roofs. The second report, a green infrastructure plan prepared for the Milwaukee Metropolitan Sewerage District (CH2MHill and CDM Smith 2013), also recommends a loading ratio of 1:1. The average ratio across all of the categories for the two studies was 1:1, which was used as the final loading ratio for the green roof category.

The volume of water captured by green roofs on their footprint depends on annual rainfall.[vii] In this case, because the goal is to develop a national value, the average rainfall in the U.S. was used to represent a typical site. Average rainfall in the U.S. from 2000 to 2020 was reported to be 788.4 mm/year (NOAA 2022). A depth of 788.4 mm across an area of 1 ft^2 is a volume of 19.3 gallons.

While green roofs, if sited and designed correctly, are effective at capturing precipitation, they do not always capture 100% of that precipitation. Based on a study by Berghage et al. (2009), it was assumed that green roofs have a water capture efficacy of 50% (i.e., they capture 50% of precipitation that lands on them). Thus, it was estimated that 1 ft^2 of green roofs captures an annual volume of **9.7 gallons** (50% of 19.3 gallons).

Step 2. Estimate the alternative cost of managing an equivalent volume of stormwater

The costs of stormwater management using traditional infrastructure can be estimated on a $ per gallon basis and can be used to represent the alternative cost of managing stormwater.

Several cost estimates were found in the literature, which came from the Cities of Lancaster, PA; Grand Rapids, MI; Boulder, CO; and Milwaukee, WI. Combined, these studies reported an average cost of $0.0046 per gallon of stormwater managed. These studies and their values are summarized in the table below.

Calculations:

Source Study	Study Location	Stormwater Management Cost (2021 USD/gallon)
Nordman et al. (2018)	City of Grand Rapids, MI	$0.0003
EPA (2014)	City of Lancaster, PA	$0.0016
McPherson (2013)	City of Boulder, CO	$0.0154
Clements et al. (2021)	City of Milwaukee, WI	$0.0013
Average Value		**$0.0046**

As calculated in the previous step, it is estimated that each ft^2 of bioretention can capture 9.7 gallons of stormwater. Therefore, it was estimated that the value of each 1 ft^2 of bioretention was (9.7 gallons/year * $0.0046/gallon =) **$0.04/ft^2/year**.

Method 2: Alternative cost of stormwater volume management (by area managed)

This method estimates the value of green roofs based on the alternative cost of managing an equivalent area of impervious surface using traditional infrastructure.

[vii] Other factors, such as soil type, can also play an important role.

Step 1. Estimate the area of impervious surface managed by bioretention

If designed, sited, installed, and maintained correctly (see "Feasibility and Effectiveness Criteria" discussion in Section 5.2 of this report), it is assumed that every 1 ft^2 of bioretention installation can only capture precipitation that lands directly on its footprint, and does not drain an area beyond that. This assumption is based on the average "loading ratio" provided in two studies, a term that refers to the number of units of impervious surface that drains to a single unit of bioretention (e.g., 1 ft^2). The first report, a green infrastructure guidance document prepared for local agencies in New Jersey (NJDEP 2018), recommends a loading ratio of 1:1 for green roofs. The second report, a green infrastructure plan prepared for the Milwaukee Metropolitan Sewerage District (CH2MHill and CDM Smith 2013), also recommends a loading ratio of 1:1. The average ratio for the two studies was 1:1, which was used as the final loading ratio for the green roof category.

Step 2. Estimate the alternative cost of managing an equivalent area of impervious surface

Utilities commonly estimate the costs of stormwater management according to the area of (effective) impervious surface managed (e.g., $/acre of impervious area). Existing cost estimates for managing impervious areas using traditional infrastructure can be used to represent the alternative cost of managing stormwater. The WRF, in the methods section for its 2021 Green Stormwater Infrastructure Triple Bottom Line tool (Clements et al., 2021), reports that the cost estimating software RS Means contains a default capital cost of $3/$ft^2$ (or $130,680/acre) of impervious surface to represent a typical gray infrastructure scenario in 2020 USD, or $3.18/$ft^2$ ($138,507/acre) in 2021 USD. To convert this into an annual average value, we assume upfront capital costs of $138,507/acre, ongoing O&M costs equal to 3.5% of capital costs, and an asset life of 100 years. These assumptions result in an average alternative cost of $6,223/acre/year. As calculated in the previous step, it is estimated that each 1 ft^2 of green roof can manage an area of 1 ft^2 – equivalent to 0.00002 acres. The annual value of managing that area is ($6,233/acre/year * 0.00002 acres =) **$0.14/$ft^2$/year**.

Final Value Calculation

The stormwater volume and quality benefit of green roofs was estimated at **$0.09/$ft^2$/year**, which was the average of the results of the two alternative cost methods described above ($0.04/$ft^2$/year and $0.14/$ft^2$/year).

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