GSI Impact Calculator: Methods & Data Sources

The GSI Impact Calculator was developed by One Water Econ and is a component of the GSI Impact Hub, a larger project that provides resources and support related to specific GSI co-benefits. The GSI Impact Hub is a collaboration between The Nature Conservancy, Green Infrastructure Leadership Exchange, One Water Econ, government agencies and technical partners.

This document describes the methods and data used to develop the GSI Impact Calculator, including specific assumptions, calculations, and sources. It is organized by Calculator section, including:

- Define Scenario
- Refine GSI Portfolio
- Evaluate Benefits
- Review Costs
- Explore Results

A separate *GSI Impact Calculator: User Guide* is also available to assist in navigating the inputs required for the Calculator.

Define Scenario

This section of the Calculator includes five input pages that require users to enter data and information that is used in subsequent benefit calculations:

1. Project and Site Information
2. Stormwater Management Goal
3. BMP Selection
4. Benefit-Specific Inputs
5. Economic Assumptions

Not all five input pages are described below (e.g., BMP Selection and Benefit-Specific Inputs tabs are not included below); the omitted pages require only yes or no answers or selections. Answers to these questions affect benefit calculations that are described later in this document.

Project and Site Information

Location: The Calculator currently includes data/benefit calculations for 138 U.S. cities. It relies on city-, state-, and/or region-specific data to quantify and monetize the value of GSI benefits.

For some cities, the information necessary to calculate the full range of benefits that rely on city-specific data is not available. In these cases, the project team matched the city to the nearest location for which relevant data is available. Additional detail on matching cities to benefit data is provided in the descriptions of benefits methodology below.

The Calculator currently does not include Canadian cities. However, Canadian users can select cities close to them, both in geographic proximity and climate. The Calculator will apply default inputs from these cities to provide reasonable co-benefit estimates.

Impact Area: The Calculator estimates GSI benefits within a Project Impact Area, which captures the area over which GSI benefits accrue to households and businesses. Figure 1 depicts the concept of the Project Impact Area as compared with the GSI drainage or management area and the GSI footprint (i.e., the size of GSI practices).

The Calculator is designed to estimate benefits at the city-block scale and/or across multiple city blocks. A typical city block is two to five acres.

Land Cover: The Calculator estimates the amount of impervious area within the Project Impact Area based on land cover categories defined by the United States Geological Survey National Land Cover Database (NLCD). Table 1 describes each land cover category included in the Calculator, the corresponding NLCD code, and the impervious area percentage that the Calculator assumes for each category. The impervious percentage assumptions are based on assumptions built into the Water Research Foundation's (WRF's) Community-Enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) Tool.[i]

Figure 1. Depiction of Project Impact Area, GSI Management/Drainage Area, and BMP Footprint.

Table 1. Land cover categories included in Calculator

Land cover category	Description	Corresponding NLCD category	% imperviousness assumed in Calculator
Open space	Can include parks, golf courses, and large single family home lots, as well as natural forests, wetlands, shrublands, and cultivated agricultural areas.	21, 31– 95	15
Low intensity development	Most commonly represent average lot sized single-family homes.	22	35
Medium intensity development	Most commonly represent average lot sized single-family homes.	23	65
High intensity development	Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial areas.	24	90

The amount of impervious area within the Project Impact Area is a function of the NLCD categories entered by the users and the Calculator assumptions related to imperviousness of those categories, as follows:

$$\text{Impervious area} = (\%\ \text{Open Space} * 0.15) + (\%\ \text{Low Intensity Development} * 0.35) \\ + (\%\ \text{Medium Intensity Development} * 0.65) + (\%\ \text{High Intensity Development} * 0.90)$$

This information is used later in the Calculator to estimate the total volume of stormwater runoff managed by GSI Best Management Practices (BMPs).

Population and Homes: The Calculator asks the user to enter the population of the Project Impact Area, as well as the percentage of homes within the Impact Area that are single family (attached or detached) or duplexes. The user guidance describes sources where this can be estimated using data from the U.S. Census American Community Survey (ACS) if it is not known.

To estimate the number of households within the Project Impact Area, the Calculator assumes an average of 2.5 people per household, which was the 5-year national average from 2019 – 2023, per the U.S. Census. This information is used to calculate benefits that depend on the number of people or households within the Project Impact Area.

Stormwater Management Goal

This tab asks users to enter some basic information related to their stormwater management goal; the Calculator uses these inputs to estimate the GSI BMP volume capacity needed, BMP footprint, and annual runoff volume managed through GSI BMPs.

Annual Rainfall (inches): The Calculator estimates annual rainfall for the city in which the Project Impact Area is located (as selected by the user). The source of this information is U.S. Climate

Normals Data.[1][ii] This is the total annual rainfall for the city and is intended as a starting point; it can be changed by the user.

The user is also asked to enter the percentile design storm to be managed and the associated rainfall depth, as well as the percent of Impervious Area that is managed by GSI BMPs. These data inputs and information on where to find this information are detailed in the GSI Impact Calculator User Guide.

Impervious Area Managed: The Calculator quantifies total impervious acres within the Project Impact Area, as described in the previous section. Recognizing that all impervious area within the Impact Area may not be managed via GSI (refer to Figure 1 above), the Calculator multiplies the % Impervious Area Managed via GSI BMPs by the total impervious acres within the Project Impact Area to determine total impervious acres managed. This is a very simple approach to estimating acres managed as it does not account for runoff curves associated with different land cover types – it focuses on impervious area only.

Economic Assumptions

The Calculator assumes that the GSI BMPs the user is analyzing are constructed in one year. This means that capital costs are not discounted in the overall benefit cost analysis (they are assumed to occur in Year 1 of the project's lifecycle).

Refine GSI Portfolio

The Calculator estimates the total volume of BMP capacity (cubic feet, cft) needed to manage the desired design storm event (as entered by the user on the Stormwater Management Goal tab), as follows:

BMP capacity volume (cft) =
Design storm depth (in) / 12 * 43,560 * Impervious acres managed * 0.98

Where:

- Design storm depth (in) / 12 converts rainfall depth of the design storm in inches to feet
- 43,560 converts impervious acres managed to square feet
- 0.98 represents the amount of rainfall (98%) that runs off the impervious area

The Calculator uses the Simple Method to calculate annual stormwater runoff managed by all BMPs:

Annual stormwater runoff managed (cft):
Annual Rainfall (in) / 12 * 43,560 * Impervious acres managed * Design storm percentile (%) * 0.98

Based on the land cover mix within the Project Impact Area and the BMPs selected by the user, the Calculator estimates the percentage of stormwater managed by BMP type. This initial estimate is based on assumptions from the WRF CLASIC Tool related to the BMPs that are suitable for different types of development (e.g., high vs. low intensity development, see Table 2). The percentage of stormwater runoff managed by BMP is weighted based on the land cover mix for the Project Impact Area, as entered by the user.

Table 2. Percentage of stormwater runoff managed by GSI BMP and land cover type

	Land cover category			
GSI BMP	**Open Space**	**Low Intensity**	**Medium Intensity**	**High Intensity**
Raingardens	8%	2%	0%	0%
Bioretention facilities	13%	20%	25%	15%
Green roofs	0%	0%	10%	15%
Tree planting/street trees	16%	20%	10%	2%
Permeable pavement	0%	5%	5%	15%
Water harvesting	3%	3%	5%	10%
Constructed wetlands basins/channels	20%	15%	10%	3%
Wet ponds	10%	15%	10%	15%
Biofiltration/grass or vegetated swale	30%	20%	25%	25%
Total	100%	100%	100%	100%

Source: Assumptions taken from WRF CLASIC Tool

For each BMP type, volume capacity, area, number are calculated based on the design specifications for GSI BMPs presented in Table 3. These assumptions are largely based on assumptions from the CLASIC tool and the WRF Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (WRF GSI TBL Tool.)[iii]

Evaluate Benefits

This step in the Calculator reports the total present value (PV) benefits associated with the GSI Scenario being evaluated. The following sections describe the assumptions and methods applied to calculate each benefit. Throughout this section, all dollar values are reported in 2023 USD.

Table 3. GSI BMP Design Specifications

GSI Practice (BMP)	Depth (inches)	Ponding Depth (inches)	Porosity (0 to 1)	Volume capacity (cft)
Rain gardens	18	6	0.437	
Bioretention facilities	24	6	0.437	
Green roofs	6	0.5	0.35	
Tree planting/street trees				107
Permeable pavement	12	0.5	0.437	
Cisterns				401
Rain barrels				14.7
Constructed wetland	30		0.72	
Wet ponds	32		1.0	
Biofiltration/Swales	4		1.0	

Avoided Infrastructure Costs

GSI reduces the amount of stormwater entering combined and separate storm sewer systems and local waterways. This in turn can reduce the need (and associated costs) for traditional or gray infrastructure practices that would otherwise be necessary to meet municipal water quality and/or quantity goals.

The Calculator calculates avoided infrastructure costs differently depending on whether the project is located within a separate or combined sewer area. This question is asked on the Benefit-Specific Input tab under the Define Scenario step.

If the project is located within a municipal separate storm sewer system (MS4) area, the Calculator applies an avoided cost of $3.58 per square foot of impervious area managed to estimate avoided capital costs. This is the stormwater management allowance cost from RS Means, a proprietary, comprehensive database of construction cost information that engineers often use to estimate the cost of construction projects. It is included in RS Means as being representative of a typical gray infrastructure scenario, “absent further information” or specific cost detail. The cost includes markups and does not include surface infrastructure and conveyance, which may or may not be offset by GSI. For avoided operations and maintenance (O&M) costs, the Calculator assumes 0.5% of capital per year ($0.18 per square foot per year).

Because stormwater is not typically pumped or treated in MS4 communities (i.e., it is directly discharged to local rivers and waterways through the storm drainage system), the Calculator assumes there are no avoided stormwater pumping and treatment costs for projects located in MS4 communities.

For projects located in combined sewer systems, the user has options for selecting the type of infrastructure offset, reduced, or avoided as a result of their GSI Scenario. Depending on the user's selection the following costs are applied:

- Deep tunnels
  - $6.05 per gallon of BMP capacity (capital)
  - $0.03 per gallon managed per year (O&M)
- Sewer separation –
  - $119,184 per drainage acre (capital)
  - 0.5% of capital costs per year (O&M)
- Other traditional gray infrastructure (same as for MS4 communities)
  - $3.58 impervious square foot managed (capital)
  - 0.5% of capital costs per year (O&M)

For deep tunnels, the Calculator estimates avoided costs using the cost equation reported by Wise et al. (undated)[iv], updating results to 2023 USD. For sewer separation, it assumes an average cost for 21 cities, as reported in a Long-Term Control Plan for the City of Elkhart, Indiana.[v]

To estimate avoided stormwater pumping and treatment costs for combined sewer communities, the Calculator applies a cost of $1.51 per thousand gallons of stormwater runoff managed (applies to infiltrated stormwater that is no longer sent to the combined system). This estimate is from the WRF GSI TBL Tool,[vi] which relied on an extensive review of data and literature related to these costs. It assumes that both stormwater pumping and treatment are avoided.

Avoided costs for non-stormwater infrastructure

Implementing green roofs and permeable pavement avoids maintenance and replacement costs associated with their traditional alternatives (i.e., traditional roofs, asphalt/concrete). The Calculator applies the following assumptions to estimate these avoided costs:

- Green roofs avoid $0.08 per square foot in maintenance costs for traditional roofs.
- Green roofs avoid the replacement of traditional roofs every 17 years, at a cost of $12.55 per square foot per replacement cycle.
- Permeable pavement avoids annual maintenance costs of $0.11 per square foot for traditional pavement (reflects weighted average costs assuming permeable pavement replaces 80% asphalt streets and/or concrete and 20% asphalt parking lots).

Energy savings

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

Green roof energy savings: To estimate the energy savings associated with green roofs, the GSI Impact Calculator relies on a dataset provided by a researcher at the University of Arizona for the National Green Roof Energy Calculator. This dataset includes electricity and natural gas savings per square foot of green roof for 100 cities in the U.S. and Canada based on different variables (i.e., age and type of building, depth of green roof, leaf area index, whether it requires irrigation).

The Calculator assumes that green roofs do not require regular irrigation, have a leaf area index area of two, and a soil depth of six inches, on average. Energy savings are calculated based on the average for multi-family and office buildings and buildings built before and after 2004. This calculation yields average electricity (kWh) and natural gas (Therms) savings (relative to traditional roofs) per square foot of green roof in each location.

The Calculator contains commercial and residential energy cost data (for electricity and natural gas), by state, from the Energy Information Administration (EIA) for 2023. Average state-level commercial/residential energy costs are applied to the estimated energy savings benefits to calculate avoided energy costs ($/sq. foot of green roof for applicable city).

For cities in the Calculator for which the Green Roof Energy Calculator data is not available, the project team selected a proxy city for which the data is available, based on relative location and climate similarities. For example, Casper, WY is not included in the Green Roof Energy Calculator but it is included in the GSI Impact Calculator. To estimate the energy savings benefits of green roofs in Casper we applied data for Cheyenne, WY, which is included in the Green Roof Energy Calculator.

Tree related energy savings: The Calculator relies on data from the WRF GSI TBL Tool to estimate the energy savings benefits of trees. This data was developed using tools from the U.S. Forest Service (USFS) that allow practitioners to inventory and assess the benefits and costs of trees in various settings. These tools include the Urban Tree Database[vii] and the National Tree Benefit Calculator.[viii]

The WRF GSI TBL Tool relies on tree growth equations from the Urban Tree Database[ix] to estimate the diameter at breast height (dbh, a common size measurement for trees) over time for the 15 to 20 most common street tree species in each of 16 U.S. climate zones (Figure 2). Dbh is a key input into the NTBC, a web application that integrates i-Tree Streets data[2] into an accessible online tool, allowing users to estimate the per-tree energy savings (and other benefits) associated with street trees based on tree size (dbh), tree species, region, and type of adjacent structures (e.g., residential, commercial, industrial).[3] Table 4 shows the average dbh (at 30-years) and associated energy savings for street trees in each region. To estimate these benefits over time, the Calculator applies a tree growth model that correlates tree growth to annual energy savings provided.

To monetize energy savings, the Calculator applies average energy costs (per kWh for electricity and per Btu for natural gas) by state, for residential and commercial customers.

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[2] I-Tree Streets is now a legacy i-Tree package that is no longer supported by USFS.

[3] NTBC was first developed in 2009 by Casey Trees and Davey Tree, in partnership with the USFS. Available at http://www.treebenefits.com/calculator/.

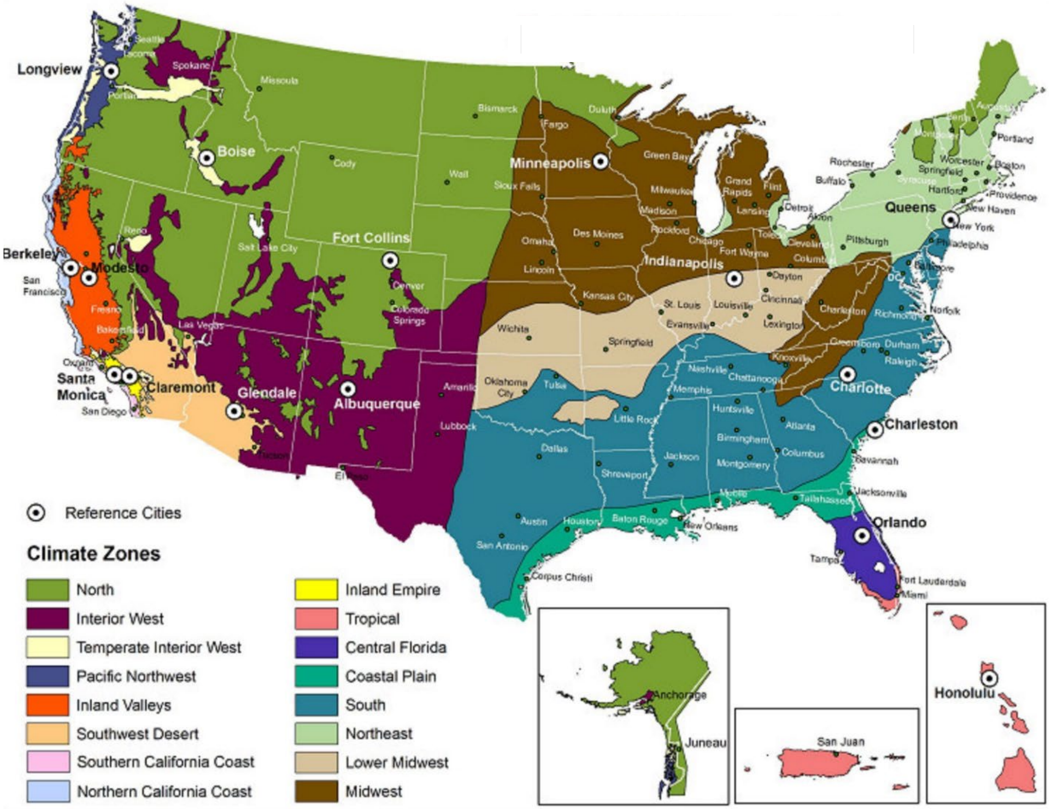

Figure 2. U.S. Climate Zones.
Source: U.S. Forest Service, undated

Avoided energy use for stormwater pumping and treatment: This benefit only applies in combined sewer systems. If a user indicates the project is located within a combined sewer area, the Calculator multiplies the annual volume of stormwater that would no longer be pumped and treated (including the volume infiltrated and/or captured for stormwater harvesting) by the average energy use required for these purposes. Based on research published by the Electric Power Research Institute (EPRI) and WRF[x] , the Calculator assumes an average energy intensity of 2,000 kWh/MG for treatment at WWTPs. It assumes 2,520 kWh/MG to quantify energy savings associated with avoided stormwater pumping.[xi] The monetary value of this benefit is included in the avoided gray infrastructure costs described above. It is therefore not monetized in this step of the Calculator to avoid double counting. However, the estimated avoided energy use serves as a key input for estimating air quality benefits.

Energy savings from potable water supply offsets: The Calculator applies an average energy intensity of 1,850 kWh/MG (based on data from EPRI/WRF 2013) to estimate energy savings associated with potable water supply offsets. This estimate represents the national average energy use associated with raw water conveyance, treatment, and distribution for groundwater and surface water systems. Water supply-related energy savings are calculated based on the total volume of potable water supply offsets resulting from use of rainwater harvesting systems (see next section) multiplied by the average energy use of 1,850 kWh. The monetary value of this benefit is included in the avoided water supply costs described in the next section. It is therefore not monetized in this step of the Calculator to avoid double counting. However, the estimated avoided energy use serves as a key input for estimating air quality benefits.

Table 4. Average Annual Energy Savings for Cooling and Heating for Common Street Tree Species at Year 30, by U.S. Climate Zone.

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

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

Water supply

GSI can offset potable water use and recharge local groundwater:

- Water collected in rainwater harvesting systems can be used for outdoor irrigation, as well as for several (non-potable) indoor uses. This can significantly reduce potable water demand for households, businesses, and other water users.

- Water infiltrated into the soil or injected into aquifers through GSI practices can augment local groundwater supplies; groundwater serves as an important source of water supply in many communities.[xii]

GSI practices that reuse or infiltrate stormwater can be particularly beneficial in areas experiencing (or expecting to experience) water scarcity. Offsetting potable water use through rainwater harvesting and/or recharging groundwater can increase water supply reliability, reduce the need to expand or upgrade existing water infrastructure, and/or avoid the development of more expensive water supply alternatives.

Rainwater harvesting: Rainwater harvesting systems can be implemented at various scales, with storage capacities ranging from small household rain barrels to large cisterns. The water supply benefits of rainwater harvesting depend on the quantity and timing of on-site water demand relative to the quantity and timing of stormwater runoff available for capture. These factors are influenced by local climate, system storage capacity, and system operation and maintenance.[xiii]

The Calculator assumes that rain barrels are used for residential purposes only and that two 55-gallon rain barrels are used per household (a total of 110-gallon storage capacity). To estimate water supply benefits of rain barrels, the Calculator applies findings from a 2014 study that estimates the percentage of household outdoor irrigation demand met annually with a 62-gallon rain barrel from a 500 sq. ft. of roof area (one downspout) in 70 U.S. cities.[xiv] The Calculator scales these results to estimate the total irrigation demand (gallons) met by two 55-gallon rain barrels, each servicing 500 square feet of roof area. This reflects the total volume of captured stormwater that could be used for irrigation (thereby resulting in a potable water supply offset), accounting for the timing of rainfall and irrigation demand within different cities/locations.

For cities in the Calculator that are not covered in the 2014 study, the project team selected a proxy city for which the data is available, based on relative location and climate similarities.

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

For cisterns, the Calculator assumes the following:

- Cisterns can handle the design storm input by the user as part of the GSI scenario for the equivalent amount of roof area. For example, to handle a 1" storm, a 1,000-gallon cistern could manage runoff from an approximately 1,600 square feet of roof.
- The amount of stormwater managed is based on the total precipitation that falls during the growing season (based on results for the 70 U.S. cities included in Litofsky and Jennings, 2014). Cisterns do not operate in winter months with freezing conditions.
- The Calculator applies an efficiency factor of 85% (meaning 15% of the captured water is not available for use) to account for water loss due to evaporation, inefficient gutter systems and other factors.
- Stormwater captured via cisterns is used for outdoor irrigation and toilet flushing and that the total volume captured is used to meet household water demands for these purposes (minus the 15%/85% efficiency factor).

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

Without extensive modeling, it is necessary to approximate the amount of groundwater that could be recharged through specific GSI practices. If the user indicates on the “Benefits-Specific Inputs” tab that the water retained with GSI will recharge a groundwater source that can later be used for water supply, the Calculator assumes that 50% of the stormwater managed by relevant GSI practices (bioretention, raingardens, street trees, wetlands, and permeable pavement) could result in water supply benefits.

The Calculator also applies an efficiency factor of 75%, based on a 2014 study by NRDC.[xvi] This study assumes that in areas where conditions are considered favorable for infiltration (i.e., NRCS Hydrologic Soil group A or B), between 75% and 90% of the runoff could be infiltrated into the ground, with the remaining portion lost to evaporation or transpiration. Where soil conditions require a longer drawdown time for the water to infiltrate (e.g., NRCS group C soils), the authors assumed that 65% to 80% of the runoff could be infiltrated into the ground.

Monetary value of water supply benefits: To value potable water supply offsets, the Calculator applies retail water rates, by state. These estimates are taken from a study conducted for the U.S. EPA[xvii] that estimates average retail water rates by state based on published rates available on municipal and water supply company websites. To estimate the monetary value of groundwater recharge, the Calculator incorporates annual average values for groundwater per acre-foot (AF), by state, also estimated in the EPA study.

Air quality

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

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

The public health and environmental impacts of specific air pollutants are well-documented.[xviii] NO_2 and SO_2 are both linked to respiratory illness, and NO_x and sulfur oxides (SO_x) contribute to an array of adverse respiratory and cardiovascular effects. Ground-level O_3 and PM are linked to premature deaths, chronic bronchitis, asthma, respiratory infections, and other illnesses. O_3 can also damage crops and increase the vulnerability of some tree species to various diseases, while PM can reduce visibility in urban areas.[xix]

Energy-related emissions reductions. The U.S. EPA maintains extensive data on electricity power generation and energy-related emissions through its Emissions & Generation Resource Integrated Database (eGRID). eGrid contains data on the environmental characteristics of almost all electric power generated in the United States, including emission rates (i.e., pounds of pollutant emitted per MWh or MMBtu generated) for three greenhouse gas gases (GHGs) and for NO_x and SO_2. The Calculator applies regional eGrid emission rates to GSI-related energy savings to estimate the associated reduction in emissions/pollutants.

Per EPA recommendations, the Calculator applies emission rates by eGrid subregion and uses non-baseload emission rates to estimate the emission-related benefits associated with reduced energy use. Non-baseload emission rates are representative of marginal reductions in energy use at times of peak demand.[xx] The Calculator also uses regional grid loss factors (published in eGrid) to account for transmission and distribution losses when applying eGRID emission rates.

Figure 3 shows the 26 EPA eGrid subregions; Table 5 shows the electricity non-baseload emissions rates (lbs/MWh) and natural gas input emissions factors (lbs/MMBtu) for each subregion, as well as the gross grid loss factors.

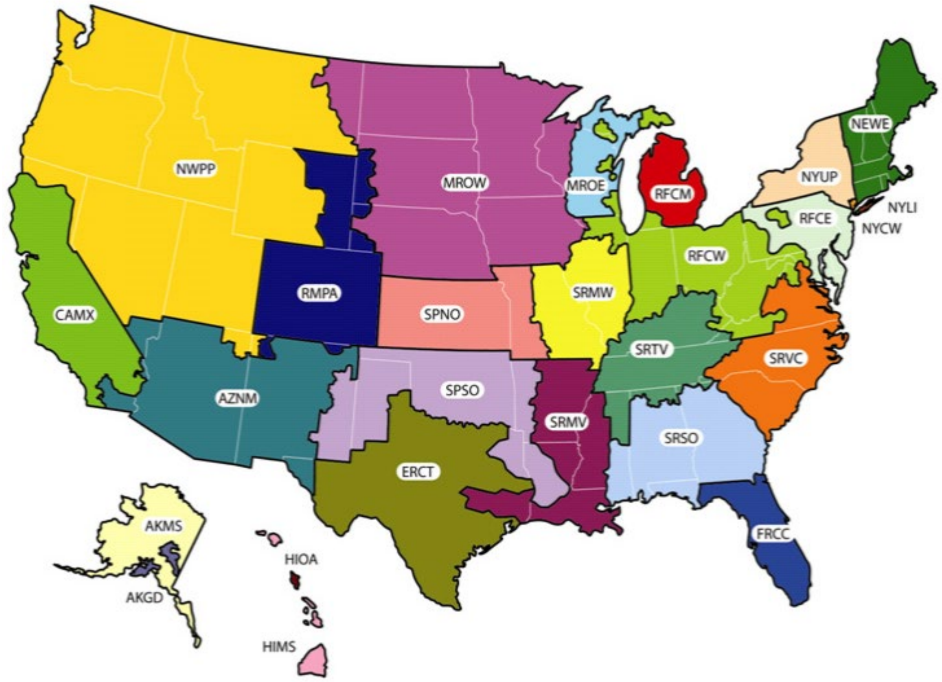

Figure 3. EPA eGrid Subregions. *Source: U.S. EPA 2020*

eGrid does not track direct $PM_{2.5}$ emissions associated with energy generation. However, EPA's AVoided Emissions and geneRation Tool (AVERT) publishes avoided (direct) $PM_{2.5}$ emissions associated with energy efficiency projects for 10 U.S. sub-regions (for electricity generation only). The most recent EPA data shows that avoided $PM_{2.5}$ emissions associated with reductions in marginal electricity consumption range from 0.04 lb/MWh in California to 0.22 lbs/MWh in the Tennessee region, with an average emissions rate of 0.09 lbs/MWh for the U.S. overall.[xxi] The Calculator applies these rates to the energy savings generated through implementation of GSI.

eGrid only applies to electricity; it does not contain emissions rates for natural gas (i.e., input natural gas emissions rates published through eGrid should not be directly applied to reductions in natural gas to calculate avoided emissions. Given the relatively low emissions rates for natural gas, and the relatively low natural gas savings associated with most GSI, the Calculator does not quantify air quality benefits associated with reductions in natural gas use due to building energy savings.

Table 5. eGrid 2022 Emission Rates & Transmission Loss %, by eGrid Subregion. *Source: EPA 2024.*

eGRID subregion acronym	eGRID subregion name	Non-baseload output emission rates, electricity (lb/MWh)		Grid Gross Loss (%)
		Annual NO_x	SO_2	
AKGD	ASCC Alaska Grid	5.05	0.42	5.00%
AKMS	ASCC Miscellaneous	7.85	0.68	5.10%
AZNM	WECC Southwest	0.42	0.12	5.10%
CAMX	WECC California	0.47	0.03	5.10%
ERCT	ERCOT All	0.47	0.41	5.10%
FRCC	FRCC All	0.30	0.14	5.10%
HIMS	HICC Miscellaneous	7.19	3.07	5.10%
HIOA	HICC Oahu	3.87	6.35	5.40%
MROE	MRO East	0.98	0.31	5.10%
MROW	MRO West	0.76	0.91	5.10%
NEWE	NPCC New England	0.31	0.12	5.10%
NWPP	WECC Northwest	0.53	0.32	5.10%
NYCW	NPCC NYC/Westchester	0.25	0.03	5.10%
NYLI	NPCC Long Island	0.92	0.47	5.10%
NYUP	NPCC Upstate NY	0.11	0.04	5.10%
PRMS	Puerto Rico Miscellaneous	3.06	4.26	5.10%
RFCE	RFC East	0.28	0.30	5.10%
RFCM	RFC Michigan	0.64	0.93	5.10%
RFCW	RFC West	0.52	0.62	5.10%
RMPA	WECC Rockies	0.61	0.35	5.10%
SPNO	SPP North	0.54	0.16	5.10%
SPSO	SPP South	0.76	0.86	5.10%
SRMV	SERC Mississippi Valley	0.49	0.60	5.10%
SRMW	SERC Midwest	1.00	2.41	5.10%
SRSO	SERC South	0.39	0.15	5.10%
SRTV	SERC Tennessee Valley	0.39	0.54	5.1%

Pollutant removal through added vegetation: To estimate the pollutant removal from trees associated with GSI improvements, the Calculator relies on data provided by the United States Forest Service on average pollutant removal rates for NO_2, O_2, $PM_{2.5}$, and SO_2 for trees in urban areas, by state.[xxii] As shown in Table 6, the pollutant removal rates published by Nowak et al. (2014) are based on tree canopy area (g/m^2). The Calculator estimates tree canopy area using data from the USFS Urban Tree Database for the most common 15 to 20 street tree species in each of 16 U.S. climate zones. The Calculator accounts for tree growth over time to estimate per-tree pollutant removal benefits over a 30-year analysis period.

Table 6. Average pollution removal, urban areas, by state (g/m2 of tree cover)

State	NO_2	O_3	$PM_{2.5}$	SO_2
Alabama	0.44	5.43	0.34	0.36
Arizona	1.07	5.70	0.10	0.22
Arkansas	0.63	5.76	0.29	0.32
California	1.13	6.93	0.18	0.23
Colorado	1.96	5.88	0.14	0.28
Connecticut	0.62	4.56	0.19	0.17
Delaware	0.91	5.72	0.29	0.49
District of Columbia	1.06	4.81	0.24	0.54
Florida	0.65	6.89	0.30	0.21
Georgia	0.67	5.83	0.36	0.35
Idaho	0.63	4.59	0.42	0.16
Illinois	0.96	4.24	0.24	0.35
Indiana	0.70	4.43	0.30	0.44
Iowa	0.48	4.02	0.22	0.14
Kansas	0.60	4.65	0.18	0.52
Kentucky	0.50	4.70	0.25	0.51
Louisiana	0.57	6.32	0.36	0.80
Maine	0.87	5.51	0.28	0.30
Maryland	1.11	5.55	0.27	0.35
Massachusetts	0.89	5.59	0.28	0.40
Michigan	0.59	4.83	0.20	0.44
Minnesota	0.46	3.74	0.15	0.06

State	NO_2	O_3	$PM_{2.5}$	SO_2
Mississippi	0.49	6.14	0.37	0.38
Missouri	0.61	5.14	0.27	0.72
Montana	0.32	5.32	0.26	0.61
Nebraska	0.18	3.30	0.16	0.28
Nevada	0.95	5.06	0.14	0.16
New Hampshire	0.46	4.96	0.20	0.51
New Jersey	0.87	4.90	0.20	0.19
New Mexico	0.89	5.67	0.10	0.10
New York	0.65	5.03	0.24	0.36
North Carolina	0.68	5.58	0.29	0.25
North Dakota	0.22	3.40	0.19	0.06
Ohio	0.64	4.82	0.30	0.46
Oklahoma	0.53	5.42	0.33	0.25
Oregon	0.74	4.31	0.40	0.26
Pennsylvania	0.73	4.40	0.36	0.45
Rhode Island	0.45	5.37	0.23	0.23
South Carolina	0.65	6.17	0.31	0.29
South Dakota	0.20	4.52	0.17	0.04
Tennessee	0.54	5.19	0.28	0.53
Texas	0.72	5.88	0.27	0.28
Utah	0.89	4.97	0.16	0.36
Vermont	0.60	4.23	0.21	0.20
Virginia	0.58	5.45	0.29	0.41
Washington	0.71	4.32	0.33	0.25
West Virginia	0.45	4.04	0.28	0.56
Wisconsin	0.57	4.05	0.16	0.29
Wyoming	0.35	6.52	0.18	0.52
Grand Total	0.70	5.40	0.28	0.34

Source: USFS/Nowak, developed for Nowak et al. 2014

To estimate the pollutant removal rates for GSI practices that incorporate other types of vegetation (e.g., bioretention), the Calculator applies the ratio of tree to shrub/herbaceous cover removal efficiencies (Table 7) to the tree pollutant removal estimates reported in Table 6.[xxiii]

Table 7. Removal Rate of Shrubs and Herbaceous Cover Relative to Trees

Pollutant	Ratio of vegetation air pollutant removal to tree cover removal
NO_2	75.60%
O_3	79.10%
PM_{10}	77.70%
SO_2	85.60%
Total	79.90%

Source: Nowak et al. 2002

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

In 2018, EPA used BenMAP-CE to calculate the benefit-per-ton of reducing $PM_{2.5}$ and $PM_{2.5}$ precursor emissions in 17 industry sectors. Table 8 shows the resulting benefit-per-ton values for the electricity generating sector (in terms of the monetary value of avoided mortality and morbidity risk). To value the emissions reductions associated with energy savings, the Calculator applies these values to the reductions in emissions associated with GSI-related energy savings.

Table 8. Dollar Value (Mortality and Morbidity) per Ton of Directly Emitted PM2.5 and PM2.5 Precursors Reduced in 2016 From the Electricity Generating Sector. (2023 USD, 3% discount ratea,b)

	Benefit per ton[c]		
	NO_x	SO_2	Directly emitted $PM_{2.5}$
Mortality and morbidity risk estimate	$12,862	$84,819	$302,144

Source: U.S. EPA 2018b

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

Finally, to estimate the value per ton of pollutant removal from trees and other vegetation, the Calculator uses regression equations developed by Nowak et al.[xxiv] that reflect the avoided health care costs where y = dollars per tonne (metric ton), and x = population density. These equations are as follows:

$$\text{NO2: } y = 0.7298 + 0.6264x \ (r2 = 0.91)$$

$$\text{O3: } y = 9.4667 + 3.5089x \ (r2 = 0.86)$$

$$\text{PM2.5: } y = 428.0011 + 121.7464x \ (r2 = 0.83)$$

$$\text{SO2: } y = 0.1442 + 0.1493x \ (r2 = 0.86)$$

Once calculated, values are updated to 2023 USD using the Consumer Price Index.

Neighborhood beautification (measured via property value changes)

Trees and plants improve urban aesthetics and community livability, which can result in increased sale prices and rental rates for homes and commercial space. Simply put, people are willing to pay more to live and work in places with more greenery. To measure this value, economists employ "hedonic pricing" methods that use statistical analysis to estimate the effect of different factors on the price of a home or property. Hedonic models attempt to isolate the effect of a specific characteristic, such as proximity to GSI, on a property's market value by controlling for all other factors. To estimate property value benefits associated with different types and scales of GSI, the Calculator applies findings from existing well-executed studies on this topic. This approach is known as benefits transfer.

The Calculator draws on inputs from the Define Scenario/Project and Site Information tab to determine the number of single-family homes, condos, and duplexes within the GSI Impact Area. It then estimates the aggregate value of these properties based on national averages reported in the U.S. Census American Community Survey (ACS).

Next, the Calculator applies a weighted average percent increase to the aggregate property value for the Impact Area. The weighted average increase is based on 1) findings from studies that have used hedonic models to estimate the percentage increase in property values resulting from different GSI practices and 2) the mix of GSI practices in the user's GSI Scenario. Table 9 shows the range of values from various studies by GSI practice type, as compiled in the WRF GSI TBL Tool.[xxv] The Calculator applies the mid-range of these estimates for each practice type.

Table 9. Range of property value increases associated with GSI practices

GSI practice	Low	Mid	High
Green roofs	7%	9%	16%
Trees	3%	7% - 10%	10 - 15%
Rain gardens, bioretention, biofiltration	0.44%	3.5% - 5%	7%
Wetlands, wet ponds	0%	5.7%	7.5%

Source: Clements et al. 2021

As an important note, property value increases associated with GSI can reflect a willingness-to-pay (WTP) for a range of benefits, including many of the benefits incorporated in the Tool. In this sense, increases in property values related to GSI serve as a measure of the value of GSI rather than a stand-alone benefit. In theory, changes in property values linked to GSI can reflect associated differences in neighborhood aesthetics, air quality, water quality, energy usage, increased shade, and other benefits. A property in an area with good air quality should sell for a higher amount relative to another property in an area with low air quality, all else equal. Thus, to simply add property value benefits with the benefits from improved air quality would be double counting (at least to some extent). To avoid double counting benefits, the Calculator applies a 70% adjustment factor to estimate neighborhood beautification benefits.

Urban heat island reduction

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

According to the National Weather Service, heat is a leading weather-related killer in the United States.[xxvi] In addition to causing increased mortality (i.e., premature fatality), EHEs have also been associated with a range of illnesses, many of which result in emergency room visits and/or hospitalizations. Climate change is expected to exacerbate the occurrence of heat-related deaths and illnesses, as extreme temperatures are projected to rise in many areas, bringing more frequent and intense heat waves.[xxvii]

Reductions in urban temperatures and heat-related mortalities: The heat-mortality relationship has been particularly well-studied and applied across multiple locations. In 2017, EPA's Climate Change Impacts and Risk Analysis (CIRA) projected the number of deaths attributable to extreme temperatures in 49 U.S. cities under various future climate scenarios. The CIRA study is based on previous research that established city-specific relationships between deaths and extreme temperatures using historical (daily) mortality and weather data.[xxviii] These studies define extremely hot days as those with a daily *minimum* temperature that is warmer than 99% of the days in the historical reference period and is at least 20°C (68°F). Statistical analysis is then used to estimate deaths that can be attributed to weather on those days.

While at first perhaps counterintuitive, extremely hot days are defined based on minimum temperatures because the urban heat island (UHI) is often driven by days when hot temperatures do not cool off at night. During a heat event, people need the relief of lower nighttime temperatures to recover from compounding heat stress that builds throughout the day.[xxix] However, the UHI effect often becomes more pronounced after sunset due to the slow release of heat from urban infrastructure; thus, this relief does not always occur.[xxx]

The Calculator uses an approach applied in the WRF GSI TBL Tool to estimate the heat reduction benefits of GSI.[xxxi] This approach relies on the EPA data referenced above, which includes the following information for each of the 49 U.S. cities:

- Estimated increases in mortality on extremely hot days, defined as days on which the daily minimum temperature is greater than or equal to the 99th percentile value from the distribution of daily minimum temperatures for that location, and is greater than 68 degrees F.
- The relevant minimum temperature threshold (i.e., the 99th percentile value)
- Number of days between 1986 and 2005 on which temperatures did not fall below the threshold (i.e. the number of extremely hot days), and the minimum temperature on those days.
- Daily temperature projections for 2050 and 2100, including number of days on which temperatures do not fall below the minimum temperature threshold.[xxxii]

For cities in the Calculator that are not included in the EPA database, the project team selected a proxy city for which the data is available, based on relative location and climate similarities.

The next step is to link planned increases in GSI to reductions in urban temperatures. This step relies on results from Sailor (2003), which estimated reductions in average daily temperatures associated with a 10-percentage point increase in vegetation in nine U.S. cities.[xxxiii] Because only nine cities were included in that study, the Calculator uses average results for these cities by U.S. climate region.

To estimate reductions in average daily temperatures associated with increases in surface albedo from installation of permeable pavement, the Calculator relies on results from Sailor and Dietsch (2007).[xxxiv] The equations developed for this study indicate that increasing albedo in urban areas by 0.10 percentage points results in an approximately 44% greater temperature reduction compared to increasing vegetative cover by 0.10. The cooling effect associated with permeable pavement is based in part on the assumption that permeable pavement will increase surface reflectivity/albedo. However, this depends on the type of permeable pavement installed relative to a baseline. For example, replacing traditional black asphalt with black permeable asphalt does not change the surface albedo.

To apply the estimates from the studies referenced above, the Calculator assumes that relevant GSI practices provide a “contributory” effect to reducing urban temperatures. Thus, even if a project does not increase the amount of vegetative cover and/or surface albedo within the Impact Area by 10 percentage points, the contributory benefits are calculated based on the ratio of the population within the GSI Impact Area to the population of the city overall.

Finally, to link temperature reductions to decreased mortalities, the Calculator incorporates the following methodology:

- Calculate the change in the days each year (i.e., without GSI – with GSI) when the city is over the minimum mortality temperature (MMT) by subtracting the change in temperature from Sailor et al. 2003 and/or Sailor and Dietsch (2007) from the minimum daily temperature for the historical reference period (included in the EPA database).
- Use the change in days over MMT and the change in the temperature for days over the MMT to calculate a new average annual mortality rate
- Estimate mortality risk reduction (avoided fatalities) based on the population of the GSI Impact Area compared to the population of the city overall.

Reductions in heat-related emergency room visits and hospitalizations: To estimate the reduction in heat-related illnesses associated with the cooling effect of GSI, the Calculator applies the ratio of heat-related mortalities to heat-related emergency room visits and hospitalizations by state, using data from the CDC’s National Environmental Public Health Tracking Network. This source includes data for only 19 states; thus, the Calculator applies ratios for non-Tracking states by using averages from states within the same climate region. To calculate heat-related illnesses, the Tool multiplies the relevant ratio (based on data from Table 10) by the number of heat-related fatalities determined in the previous step.

Monetizing avoided heat-related mortalities and illnesses: When conducting a benefit-cost analysis of new environmental policies, U.S. EPA uses estimates of how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution. These estimates of willingness to pay (WTP) for small reductions in mortality risks are often referred to as the "value of a statistical life” (VSL). This is because these values are typically reported in units that match the aggregate dollar amount that a large group of people would be willing to pay for a reduction in their individual risks of dying in a year, such that we would expect one fewer death among the group during that year on average.[xxxv] To estimate the value of avoided heat-related fatalities associated with GSI implementation, the Calculator applies the VSL dollar value of $11.2 million per avoided death (2023 USD).

Table 10. Ratio of Heat-Related Emergency Room Visits and Hospitalizations per Heat-Related Mortality for NEHTN States[a]

State	ER visits per mortality	Hospitalizations per mortality
Arizona	7.1	2.0
California	53.0	9.5
Florida	146.1	27.5
Iowa	0.0	0.0
Kansas	11.7	6.6
Kentucky	69.5	13.2
Louisiana	90.8	12.0
Maryland	29.0	5.0
Michigan	N/A	11.4
Minnesota	38.6	6.0
Missouri	87.6	10.1
New Jersey	44.5	8.4
New Mexico	15.5	2.4
New York	31.5	7.7
Pennsylvania	N/A	7.8
South Carolina	103.8	11.9
Tennessee	95.0	11.0
Washington	N/A	30.7
Wisconsin	50.6	6.2

Source: Developed based on data from CDC 2019

a. Estimates reflect annual average for 2000 – 2016; however, data is not available for most states for every year.

To estimate the monetary value of avoided heat-related emergency room visits and hospitalizations, the Calculator applies the corresponding avoided health care costs, using estimates from EPA's BenMAP-CE. Detailed information and sources of all values used in BenMAP-CE are available in the BenMAP documentation and technical appendices.[xxxvi] Table 11 presents national average values included in BenMAP-CE (per incident) for mortalities, hospital admissions, and emergency room visits.

Table 11. BenMAP-CE Values for One Case of Each Health Effect.

Health Effect	Value per Case (2023 USD)
Premature mortality (VSL)	$11,179,000
Hospital admission	$40,300
Emergency room visit	$595

Source: U.S. EPA 2018a

Recreation

GSI implementation can result in increased recreational opportunities and enjoyment of green space in several ways:

- Substantial increases in vegetated acreage, tree canopy, and enhanced urban aesthetics can increase enjoyment and participation in neighborhood activities such as walking, biking or jogging on sidewalks, bench sitting, and/or other general outdoor recreation.
- Some GSI projects are specifically designed to include recreational amenities. For example, several cities across the U.S. have created "stormwater parks," while others have integrated small parks or "pocket parks" into neighborhood-scale retrofit projects. In some cities, large infiltration areas, such as wetlands, provide active and passive recreation opportunities.
- Projects that make substantial improvements to water quality may also increase opportunities for water-based recreation.

Individuals value outdoor recreation for several reasons, including for physical activity and associated health benefits, improved mental health, and for building social capital. Because recreational activities associated with GSI projects are not traded in the market (i.e., there is no fee for participation), it can be difficult to establish the values associated with them. However, many researchers have conducted WTP surveys to estimate the value of a recreational experience across a range of activities. These studies yield what economists refer to as *direct use values*. Direct use values reflect the amount that individuals would be willing to spend to participate in a recreational activity if they had to pay for it. Total recreational benefits associated with GSI are a function of direct use values and the additional recreational trips (often referred to as "user days") taken as a result of the GSI improvements.

Additional recreational trips: The Calculator asks the user whether the GSI Scenario they are analyzing will include creation of the following types of green space or park areas:

- Small recreation areas or pocket parks (if the user checks yes, they are asked to enter the number of pocket parks)
- Neighborhood parks or larger community open space areas (if the user checks yes, they are asked to input the total area of the park / open space area in acres)
- Wetland areas that support recreation

- General neighborhood greening that supports recreation (e.g., green streets, improvements to pedestrian corridors)

If recreational sites are included in the user's GSI scenario, the Calculator relies on estimates from the literature and reasonable assumptions to estimate the level of use that these areas will experience.

The Calculator estimates usage for small park areas or pocket parks using the National Recreation and Parks Association (NRPA) design standards for pocket parks.[xxxvii] Specifically, the Calculator methodology assumes that these areas average one-quarter acre in size and serve residents within a one-quarter to one-half-mile radius, depending on population density. NRPA recommends that pocket parks should serve 500 to 1,000 residents on average.

Based on findings from relevant studies[xxxviii] and a 2015 NRPA survey on park use, the Calculator methodology assumes that 22% of residents would use the pocket park once per week, 30% of nearby residents would never use the parks, and the remaining 48% would use them occasionally. For estimation purposes, occasionally means six times per year, on average. For a population of 1,000 residents, these assumptions would yield a total of 11,460 visits per year, or an average of 11.5 trips per resident per year (on average, including those that never visit). The Calculator assumes that each pocket park services 1,000 residents.

To calculate visitation to larger neighborhood parks or community spaces, the Calculator relies on a regression model developed by Cohen et al. that estimates annual park visits based on various inputs.[xxxix] Although the nature of the parks included in the Cohen study may vary some from the types of recreational sites included in the GSI scenario being analyzed, the model provides a reasonable estimate of average weekly use for parks ranging in size from 2 to 20 acres. The regression begins with an estimate of 1,022 visits per park per week and adjusts this number based on local factors related to park size, local poverty rate, and population within a one-mile radius of the park. The Calculator uses park size data entered by the user, the poverty rate for the U.S., and average population density for U.S. urban areas to as inputs into the regression model.

To estimate recreational use associated with general neighborhood greening (i.e., non-park improvements), the Calculator assumes a usage equal to the population density of the area affected by general urban greening and assumes a relatively modest additional number of new recreational trips of three times per year per resident.

Monetizing additional recreational visits: Except for wetland-related recreation (see below), the Calculator applies the Unit Day Value Method developed by the US Army Corps of Engineers (USACE) to monetize the value of additional recreational trips. The Unit Day Value Method estimates direct use values based on a series of questions related to the recreational site and the activities it supports. As shown in Table 12, the answers to these questions yield point values across five criteria:

- Recreation Experience: the number and type of recreational activities that a site or recreational area supports (0 – 30 points)
- Availability of Opportunity: the availability of similar recreational opportunities located nearby (0 – 18 points)

- Carrying Capacity: the degree to which a site provides adequate services to support recreation (0 - 14 points)
- Accessibility: the degree to which the area is readily accessible (0 – 18 points)
- Environmental Quality: the aesthetic qualities of the area including water and vegetation, air and water quality, scenery, and climate (0 – 20 points)

Table 12. Recreational Value Point Assignment, Army Corps of Engineers Unit Day Value Method

Category/Questions	Answers	Rating/Available Points
Recreation Experience		0 – 30 pts
Will the project provide capacity for hunting or fishing?	Yes/No	Note, if the project will support hunting, fishing, or specialized activities, the user will need to answer questions related to the percentage of total recreational activities they expect specialized activities to account for.
If yes, does this facility have the capacity for specialized fishing and/or hunting (e.g., big game)? While this answer will likely be no in most cases, some stream restoration activities might support specialized fishing, e.g., fishing for salmon or steelhead.	Yes/No	
Does the facility support other types of specialized recreation? Examples may include white water rafting, community gardening, or other non-general park uses.	Yes/No	
How many general recreation activities of normal quality will be provided by the project? General activities include picnicking, walking, bench-sitting, playground activity, bike riding, and other general activities of normal quality	Low (5) Moderate (15) High (30)	0 - 30 pts
Opportunity availability. What is the availability of similar recreational opportunities located nearby?	None (18) A few (10) Many (5)	0 to 18 points
Carrying Capacity: the degree to which a site provides adequate services to support recreation	Default is 7	0 to 14 points
Accessibility. How accessible is the facility? Accessibility: the degree to which the area is readily accessible	Default is 14	0 to 18 points
Quality. How are the aesthetic qualities of the area including water and vegetation, air and water quality, scenery, and climate? (0 – 20 points)	Low aesthetic quality (2) Average (10) Above average (20)	0 to 20 points

Source: Adapted from USACOE 2018[xl]

Table 13 shows how the point values and activities supported by the site are used to estimate direct use values. As shown, values range from $4.93 per person per day or recreational trip for general recreation activities to $58.63 per person for specialized activities, including fishing, hunting, and other unique activities (e.g., backpacking, white water boating). The Calculator assumes direct use values for general recreational activities of $4.93 for neighborhood greening, $9.26 for pocket park visits, and $11.42 for visits to larger neighborhood parks and community open spaces (as highlighted in the table below).

Table 13. U.S. Army Corps of Engineers Unit Day Values for Recreational Activities, FY 2023.

Point values	General recreation values ($)	General fishing and hunting values ($)	Specialized fishing and hunting values ($)	Specialized recreation values other than fishing and hunting ($)
0	$4.93	$7.09	$34.56	$20.06
10	$5.86	$8.02	$35.48	$21.29
20	$6.48	$8.64	$36.10	$22.84
30	$7.40	$9.57	$37.03	$24.68
40	$9.26	$10.49	$37.96	$26.23
50	$10.49	$11.42	$41.65	$29.63
60	$11.42	$12.66	$45.36	$32.70
70	$12.04	$13.27	$48.14	$39.50
80	$13.27	$14.19	$51.84	$45.98
90	$14.19	$14.50	$55.54	$52.46
100	$14.81	$14.81	$58.63	$58.63

Source: USACOE 2022[xli]

Note: Cells highlighted in blue show the direct use values the Calculator applies for general recreational activities: $4.93 for neighborhood greening, $9.26 for pocket park visits, and $11.42 for visits to larger neighborhood parks and community open spaces.

To value recreational benefits associated with wetlands, the Calculator relies on extensive research that provides a range of values reflecting WTP per acre for various services provided by wetlands, including recreation. These values reflect both use values (WTP by recreators), as well as non-use values (e.g., WTP by members of the public who may not recreate but value the existence or option value that wetlands provide for this purpose). Based on estimates from the literature, the Calculator applies a value of $8,150 per acre of wetland that provides recreational opportunities. For more background on wetland valuation literature, see the section below on habitat and biodiversity benefits associated with GSI.

Green jobs

The construction, operations, and maintenance of GSI projects have the potential to create entry-level job opportunities for low-skilled workers.[xlii] When paired with workforce development initiatives, GSI programs can provide participants with the technical skills necessary to enter the green workforce, earn a livable wage, and further professional development. In addition, when GSI jobs are targeted to individuals who are currently unemployed or underemployed, this creates a net social welfare gain that should be reflected in benefit-cost analysis.

Economists have developed various approaches for valuing job creation benefits associated with hiring individuals who would otherwise be unemployed. These approaches include the calculation and application of reservation and/or shadow wages (also known as the social opportunity cost of labor), as well as the estimation of avoided social costs that local, state, and federal governments would otherwise incur to support an individual who is not gainfully employed. The Calculator incorporates former approach to assess the job creation benefits associated with GSI.

Quantifying green jobs: The first step to quantifying the employment effects associated with a GSI Scenario is to estimate the construction and maintenance jobs that it will create:

- For construction jobs, the Calculator assumes a default value of 4.6 jobs per $1 million of construction spending across all GSI BMP types. This estimate reflects an approximate average from studies that produced low- to mid-range estimates.
- For maintenance jobs, the Calculator incorporates mid-range values from the WRF Whole Life Cycle Cost Tool (2009), which estimates maintenance jobs for BMP units of specific sizes.
- For maintenance jobs related to street trees, the Calculator draws on a study Davey Tree conducted for the City of Portland to estimate the maintenance requirements associated with the City's 218,602 street trees.[xliii] The study does not directly report maintenance jobs per tree or per million dollars; however, the project team reviewed costs and information provided in the report (total maintenance costs, hourly rates, etc.) and applied reasonable assumptions (e.g., percentage of maintenance costs that labor accounts for) to develop a ballpark estimate of 0.00014 FTEs per tree per year.

The next step is to determine the percentage of jobs that will be filled by unemployed individuals. The Calculator assumes a value of 20% for GSI construction workers and 30% for maintenance workers.

Monetary value of green job creation: Benefit-cost analysis does not typically include the employment effects associated with a policy or program; some economists posit that this is because traditional benefit cost analysis adopts the simplifying assumption that labor markets "clear", meaning that the demand for labor is equal to supply and that there is no involuntary unemployment or other market distortions.[xliv] When labor markets clear, the job creation benefits of a policy or program represent a transfer of benefits rather than a net gain in jobs.

An obvious problem with this assumption is that there is rarely no involuntary unemployment in an economy (particularly in urban areas where a GSI program has the potential to result in substantial job creation benefits). As such, economists have developed various approaches and assumptions for incorporating employment effects into benefit cost analysis, with a focus on benefits gained from employing individuals who are not currently employed (or are underemployed). The "textbook approach" to including jobs in benefit-cost analysis assumes that the benefit of reduced unemployment is equal to the market wage associated with the new job minus the unemployed persons reservation wages ($w - r_w$), where:

- w is equal to the market wage for the newly created job.
- r_w is equal to the unemployed individual's reservation wage. In labor economics, the reservation wage is the lowest wage rate at which a worker would be willing to accept a specific job.

To obtain an aggregate benefit, the analyst can multiply this difference by the number of unemployed individuals expected to find work through the program being analyzed.[xlv]

For the reservation wage approach, the Tool assumes a market wage of $22 per hour for construction and maintenance workers ($40,000 per year) and a reservation wage that amounts to 55% of the market wage. The 55% assumption is based on the average amount that individuals typically receive in unemployment insurance. This is often used as a starting point for reservation wages in labor economics models. These inputs are used to calculate total job creation benefits.

Habitat/biodiversity

Urban and suburban areas generally consist of a network of green spaces – including parks, yards, street plantings, greenways, urban streams, commercial landscaping, and vacant lots - that provide important ecosystem and biodiversity benefits. These areas:

- Provide food and refuge for birds, amphibians, bees, butterflies, and other species.[xlvi]
- Promote functional groups of insects that enhance pollination and bird communities, which in turn enhance seed dispersal.[xlvii]
- Provide landscape connectivity and encouraging the movement of mobile organisms between habitat patches.[xlviii]

Many GSI practices, including rain gardens, bioretention facilities, trees, retention ponds, and wetlands, can contribute to the network of green spaces that support terrestrial ecosystems and biodiversity in urban and suburban settings. This is particularly true in areas where development and impervious cover have degraded habitat for native species and/or where green spaces are isolated within the built environment. However, urban and suburban ecosystems are complex; the extent to which GSI benefits terrestrial ecosystems depends on several factors, including proximity to other natural areas, design and management of the surrounding built environment, local environmental conditions, and the characteristics of individual GSI projects (e.g., type and diversity of vegetation).

The Calculator applies the same approach as the WRF GSI TBL Tool to estimate habitat/biodiversity benefit values associated with GSI BMPs. The GSI TBL Tool relies on a meta-analysis of stated preference studies that estimate willingness-to-pay (WTP) for wetland habitat that provide specific services. This approach is intended to help users develop a ballpark estimate of the potential biodiversity and ecosystem benefits associated with GSI.

As a starting point, the Calculator uses the total area of GSI practices that have the potential to provide habitat value using design parameters assumed in the GSI scenario (for trees, the tool uses crown area). This results in an estimate of total habitat area by practice type. Based on the research conducted by Clements et al. 2021 for the GSI TBL Tool, it is evident that not all GSI practices are considered equal in terms of ecosystem and biodiversity value. For example, wetlands seem to have greater richness and abundance of flora and fauna compared to many other GSI practices. Green roofs generally provide fewer benefits compared to ground-level practices, while some practices can be designed to support specific species of interest (e.g., to enhance pollination).

To account for these differences, the WRF GSI TBL Tool assigned a relative ranking to the suite of GSI practices that provide ecosystem and biodiversity benefits (based on qualitative research) using a 5-point scale, with wetlands earning a 5-point ranking and other GSI BMPs scoring lower. The Tool assigns a value of $5,850 per acre per year of wetland habitat. This value was calculated using a meta-regression function developed by Ghermandi et al..[xlix] The meta-regression estimates the marginal habitat value of constructed wetlands designed to provide habitat and biodiversity benefits, faces medium to high anthropogenic pressure, and is adjusted to the average population density and GDP per capita for all U.S. metropolitan statistical areas.

The wetland values are then scaled to other GSI BMPs based on their relative ecosystem/ biodiversity ranking. Table 14 shows the relative rankings and associated ecosystem/biodiversity values for the GSI BMPs included in the Calculator.

Table 14. Relative Ecosystem/Biodiversity Rankings and Values for GSI BMPs (2023 USD)

GSI Practice	Relative Ecosystem / Biodiversity Ranking	Monetary Value ($ Per Acre Per Year)
Wetlands	5	$ 5,850
Wet ponds and trees	3	$ 3,500
Rain gardens and bioretention areas	2	$ 2,340
Green roofs	0.5 to 1.5 (extensive/intensive)	$ 1,170 (average)

Carbon reduction

Carbon dioxide (CO_2) contributes to rising atmospheric temperatures and associated climate change. Vegetation removes CO_2 from the atmosphere when it photosynthesizes and acts as a sink by storing carbon in the form of biomass.[l] Thus, most GSI practices that involve vegetation remove CO_2 from the air (for every pound of carbon stored or sequestered, 3.67 pounds of CO_2 are removed from the atmosphere). In addition, as described previously, GSI practices can save energy by providing shade and insulation to buildings and reducing pumping and treatment requirements. This in turn reduces energy-related CO_2 emissions.

Carbon sequestration from trees: The Calculator relies on data from the WRF GSI TBL Tool to estimate the carbon sequestration benefits of trees. This data was developed using tools from the USFS that allow practitioners to inventory and assess the benefits and costs of trees in various settings – the Urban Tree Database[li] and the National Tree Benefit Calculator (NTBC).[lii]

The WRF GSI TBL Tool relies on tree growth equations from the Urban Tree Database to estimate the diameter at breast height (dbh, a common size measurement for trees) over time for the 15 to 20 most common street tree species in each of 16 U.S. climate zones.[liii] Dbh is a key input into the

NTBC, a web application that integrates i-Tree Streets data[4] into an accessible online tool, allowing users to estimate the per-tree energy savings (and other benefits) associated with street trees based on tree size (dbh), tree species, region, and type of adjacent structures (e.g., residential, commercial, industrial).[5]

Table 15 shows the average dbh (at 30-years) and associated carbon sequestration benefits for street trees in each region. To estimate these benefits over time, the Calculator applies a tree growth model that correlates tree growth to annual carbon sequestration benefits.

Table 15. Average Annual Carbon Sequestered (CO2 reduction) for Common Street Tree Species at Year 30, by Climate Zone[a]

Tree Climate Zones	Average dbh at 30 years (inches)[a]	Carbon sequestration benefit (lbs of CO_2 removed)
Central Florida	23.7	570
Coastal Plain	17.9	280
Inland Empire	16.1	145
Inland Valleys	15.4	108
Interior West	15.7	113
Lower Midwest	15.9	187
Midwest	21.3	627
North	16.1	213
Northern California Coast	14.6	200
Northeast	13.4	186
Pacific Northwest	19.3	341
South	22.4	536
Southern California Coast	14.1	113
Southwest Desert	16.1	164
Temperate Interior West	16.0	188
Tropical	14.5	140

a. Calculated using NTBC; b. Average dbh calculated using equations from McPherson et al.[liv]

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[4] I-Tree Streets is now a legacy i-Tree package that is no longer supported by USFS.

[5] NTBC was first developed in 2009 by Casey Trees and Davey Tree, in partnership with the USFS. NTBC has not been updated with more recent research that the USFS has conducted related to the carbon sequestration of trees. However, the project team compared the estimates from the NTBC to more recent studies on carbon sequestration rates in different states and regions (e.g., as published in Nowak et al. 2013) and did not find significant differences.

Carbon sequestration from green roofs and other GSI practices: Carbon sequestration estimates for green roofs vary significantly in the literature. The Calculator applies a value of 2.04 kg CO_{2eq} per m2. This estimate represents the average annual sequestration rate from several peer reviewed studies.[lv] In addition, we know that roofs continue to sequester carbon for at least three years.[lvi] Based on findings from the WRF GSI TBL Tool, the Calculator assumes that green roof systems will reach equilibrium after four years.[lvii] No carbon sequestration benefits are counted after this time.

For bioretention, rain gardens, and wetlands, the Calculator incorporates average sequestration rates based on the range of estimates reported in the literature, as follows:

- Wetlands: 0.41 kg CO_{2eq}/m^2 [lviii]
- Bioretention, rain gardens, and bioswales: 1.01 kg CO2 eq/m^2 [lix].

Avoided GHG emissions from reduced energy use: The Calculator estimates avoided CO_{2e} emissions from GSI-related energy savings using emissions rates published in the 2022 U.S. EPA eGrid database (Table 16).[lx] Specifically, the Calculator multiplies the avoided energy use calculated in a previous step (see section on Energy Savings) by the relevant non-baseload emissions rate for their eGrid subregion, while accounting for grid transmission losses.

Table 16. 2022 eGrid CO2e non-baseload output emission rates and transmission loss percentage, by eGrid Subregion.

eGRID subregion acronym	eGRID subregion name	CO_2e emission rate (lb/MWh)	Grid Gross Loss (%)
AKGD	ASCC Alaska Grid	1,057.8	5.00%
AKMS	ASCC Miscellaneous	497.6	5.10%
AZNM	WECC Southwest	779.4	5.10%
CAMX	WECC California	499.3	5.10%
ERCT	ERCOT All	774.3	5.10%
FRCC	FRCC All	816.9	5.10%
HIMS	HICC Miscellaneous	1,163.1	5.10%
HIOA	HICC Oahu	1,586.9	5.40%
MROE	MRO East	1,488.7	5.10%
MROW	MRO West	943.4	5.10%
NEWE	NPCC New England	540.5	5.10%
NWPP	WECC Northwest	605.9	5.10%

NYCW	NPCC NYC/Westchester	886.6	5.10%
NYLI	NPCC Long Island	1,209.3	5.10%
NYUP	NPCC Upstate NY	275.4	5.10%
PRMS	Puerto Rico Miscellaneous	1,599.9	5.10%
RFCE	RFC East	660.3	5.10%
RFCM	RFC Michigan	1,224.2	5.10%
RFCW	RFC West	1,005.9	5.10%
RMPA	WECC Rockies	1,131.7	5.10%
SPNO	SPP North	959.4	5.10%
SPSO	SPP South	975.3	5.10%
SRMV	SERC Mississippi Valley	803.7	5.10%
SRMW	SERC Midwest	1,380.2	5.10%
SRSO	SERC South	897.7	5.10%
SRTV	SERC Tennessee Valley	938.6	5.10%

Source: U.S. EPA 2024

Monetary value of carbon reduction benefits: Economists value the benefits of CO_{2e} reductions using the "social cost of carbon" (SCC), which represents the aggregate net economic value of damages from climate change across the globe. These damages "include but are not limited to, the impact on agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change."[lxi]

In 2024, the U.S. EPA issued updated guidance on recommended SCC values (per ton of CO_2) for regulatory benefit-cost analysis. Table 17 shows SCC estimates in ten-year increments (2020 to 2080) at different discount rates. EPA's SCC values are calculated in 2020 dollars; the values increase over time because there is a greater accumulation of CO_2 in the atmosphere over time, and higher future levels of population, global output, and emissions. This leads to a higher total willingness to pay to avoid climate change-related damages. This rate of increase should be considered a "real" escalation rate, which shows increases in values above the general rate of inflation.

Table 17. Social cost of carbon estimates, 2020 USD ($/MT CO2e)

	Discount rate		
Year	**2.5%**	**2.0%**	**1.5%**
2020	120	190	340
2030	140	230	380
2040	170	270	430
2050	200	310	480
2060	230	350	530
2070	260	380	570
2080	280	410	600

Source: U.S. EPA 2024.

The Calculator applies the 2.0% discount rate values for SCC, interpolating values for interim years. The SCC values are updated to 2023 USD using the Consumer Price Index (CPI).

Evaluate Benefits

This page presents the co-benefits associated with the user's GSI Scenario, including monetized present value benefits over the user's analysis period, as well as annual averages. Total present value benefits are calculated using the discount rate entered by the user.

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

The "time value of money" captures a social preference for a dollar today over an inflation-adjusted dollar available in the future. The annual rate at which present values are preferred to deferred values is known as the discount rate (which is like an interest rate). The greater the preference for immediate benefits (time preference), or the greater the expected rate of return on other investments today, the greater the discount rate.[lxii]

To compare streams of value over time from different projects, the stream of values for each project is discounted to "present value" using the discount rate. If both benefits and costs are involved, the present value of the costs is subtracted from the present value of the benefits to get the net present value (NPV) of the project.

In general, federal agency guidance currently (2024) recommends applying discount rates in benefit cost analysis ranging from 2 to 3.1%, as follows:

- **Office of Management and Budget (OMB) Risk-Free Social Discount Rate: 2.0%**
  Circular No. A-94 reflects OMB's guidance to Federal agencies for conducting benefit-cost analysis. Per this guidance (Appendix D), OMB approximates the risk-free discount rate as the average real (inflation-adjusted) rate of return on long-term U.S. government debt over the last 30 years. This currently produces a real 10-year rate of 1.7%, to which a 0.3% rate is added to reflect inflation. The risk-free real social discount rate is therefore 2.0%. The real (inflation-adjusted) rate of return on long-term U.S. government debt provides a fair approximation of the social rate of time preference.
- **Federal Emergency Management Agency: 3.1%**
  FEMA currently uses a 3.1% social discount rate, which reflects the 2% Social Discount Rate (above), plus a risk premium of 1.1%.
- **Federal Water Resources Development Act: 2.75%**
  The Water Resources Planning Act of 1965 and the Water Resources Development Act of 1974 require an annual determination of a discount rate for Federal water resources planning. The discount rate for fiscal year 2024 is 2.75%. This rate is calculated annually based on the average yield of U.S. Treasury securities with 15 or more years to maturity.

For projects that do not increase risk or have little or no incidence on capital (e.g., such as GSI) the magnitudes of costs falling on capital and benefits falling on capital are the same in every period. In such cases, you can simply discount at the social rate of time preference. Thus, we recommend the use of OMB's risk-free discount rate, which is currently 2.0%.

Review Costs

The Calculator provides high-level cost estimates by GSI BMP type, including capital, annual maintenance, and rehabilitation costs over the project's lifecycle. More accurate cost estimates can be entered manually by the user in this step.

WRF's CLASIC Tool is the source of the BMP cost estimates, with the exception of costs for trees, which are not included in CLASIC. For each BMP type, the Calculator uses the average CLASIC cost estimate (average across various design parameters) for the "medium" size CLASIC BMP, unless otherwise noted. Costs are updated from 2020 USD (dollar year used in the CLASIC tool) to 2023 USD. Table 18 shows the unit cost assumptions built into the Calculator.

Table 18. Calculator life cycle cost assumptions, based on WRF CLASIC Tool (2023 USD)

BMP type (unit)	Capital costs	Annual maintenance costs	Rehabilitation costs	Years to rehabilitation	Notes
Rain gardens (sq. ft.)	$68.32	$1.41	$29.97	25	Reflect average CLASIC costs for medium size rain garden
Bioretention (sq. ft.)	$62.43	$1.02	$26.64	25	Reflect average CLASIC costs for large rain garden (10,000 sq. ft.).
Wet ponds/ wetland (top area, sq. ft.)	$5.30	$0.35	$3.59	35	CLASIC does not include separate costs for constructed wetlands.
Permeable pavement (sq. ft.)	$17.05	$0.05	$3.27	24	Average CLASIC costs for permeable concrete, pavers, and asphalt
Green roofs (sq. ft.)	$38.49	$0.52	$40.13	40	
Rain barrels (gal. of capacity)	$9.32	$0.49	$9.27	20	Assumes average CLASIC costs for small BMP size, plastic
Cisterns (gal. of capacity)	$6.45	$0.21	$6.44	20	Assumes average CLASIC costs for medium BMP size, plastic
Disconnection/biofiltration (sq. ft.)	$2.53	$0.07	$2.42	20	Assumes average cost across all disconnection types, excluding downspouts
Trees (per tree)	$400	$40	$400	30	Source: Clements et al. 2021

Endnotes

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[i] The Water Research Foundation. 2021. Community-Enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC). Available: https://www.waterrf.org/CLASIC

[ii] U.S. Climate Normals Data, National Centers for Environmental Information, National Oceanic and Atmospheric Administration. Accessed at: https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals

[iii] Clements et al., (2020) Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure, WRF Research Project 4852. Available https://www.waterrf.org/research/projects/economic-framework-and-tools-quantifying-and-monetizing-triple-bottom-line.

[iv] Wise, S. J. Braden, D. Ghalayini, J. Grant, C. Kloss, E. MacMullan, S. Morse, F. Montalto, D. Nees, D. Nowak, S. Peck, S. Shikh, and C. Yu. Undated. Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits. Center for Neighborhood Technology Publication.

[v] City of Elkhart. 2007. Combined Sewer Overflow Long Term Control Plan Update: Basis for Cost Estimates. Prepared by Greeley and Hansen.

[vi] Clements, J. et al., 2021.

[vii] McPherson, E.G., Natalie S. van Doorn, and Paula J. Peper. 2016. Urban Tree Database and Allometric Equations. PSW-GTR-253. Pacific Southwest Research Station, U.S. Department of Agriculture Forest Service. Albany, CA. Available: https://www.fs.fed.us/psw/publications/documents/psw_gtr253/psw_gtr_253.pdf

[viii] National Tree Benefit Calculator. Available http://www.treebenefits.com/calculator/.

[ix] McPherson et al. 2016

[x] EPRI. (2013). "Electricity Use and Management in the Municipal Water Supply and Wastewater Industries." Water Research Foundation. 3002001433. Available: http://www.waterrf.org/PublicReportLibrary/4454.pdf. Accessed 2/15/2019.

[xi] Based on Capodaglio, A. and G. Olsson. 2020. "Energy Issues in Sustainable Urban Wastewater Management: Use, Demand Reduction and Recovery in the Urban Water Cycle." Sustainability, 12(266). Available: https://www.researchgate.net/publication/338240650_Energy_Issues_in_Sustainable_Urban_Wastewater_Management_Use_Demand_Reduction_and_Recovery_in_the_Urban_Water_Cycle.

[xii] U.S. EPA. Undated. Benefits of Green Infrastructure. Available: https://www.epa.gov/green-infrastructure/benefits-green-infrastructure#waterquality.

[xiii] NAS (National Academies of Sciences). 2016. Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits. National Academies Press. Available: https://www.nap.edu/catalog/21866/using-graywater-and-stormwater-to-enhance-local-water-supplies-an.

[xiv] Litofsky, A.L.E. and A.A. Jennings. 2014. Evaluating Rain Barrel Storm Water Management Effectiveness across Climatography Zones of the United States. Journal of Environmental Engineering, American Society of Civil Engineers, 140(4): 04014009.

[xv] NAS 2016

[xvi] Dorfman, M. and A. Haren. 2014. Testing the Waters: A Guide to Water Quality At Vacation Beaches. Natural Resources Defense Council. Available: https://www.nrdc.org/sites/default/files/ttw2014.pdf. Accessed 5/14/2021.

[xvii] Tetra Tech. 2016 Estimating Monetized Benefits of Groundwater Recharge from Stormwater Retention Practices. Prepared for United States Environmental Protection Agency Nonpoint Source Control Branch (4503T), Washington, DC.

[xviii] U.S. EPA. 2018a. Environmental Benefits Mapping and Analysis Program – Community Edition: User's Manual. Updated for BenMAP-CE Version 1.4.8. Available: https://www.epa.gov/sites/production/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf.

[xix] Clements, J., C. Wagner, and S. VanHaren. 2016. Triple Bottom Line Analysis of Toronto's Proposed Standards for Planting Street Trees in Hard Boulevard Surfaces: Final Report. Prepared for: City of Toronto Planning Division and Toronto Water. Prepared by Stratus Consulting and MMM Group Limited; U.S. EPA. 2002. Overview of the Human Health and Environmental Effets of Power Generation: Focus on Sulfur Dioxide (SO2), Nitrogen Oxides (NOx) and Mercury (Hg). Available: https://archive.epa.gov/clearskies/web/pdf/overview.pdf; Massetti, E, M. Brown, M. Lapsa, I. Sharma, J. Bradbury, C. Cunliff, and Y. Li. 2017. Environmental Quality and the U.S. Power Sector: Air Quality, Water Quality, Land Use and Environmental Justice. Oakridge National Laboratory, U.S. Department of Energy. ORNL/SPR-2016/772.

[xx] Rothschild, E.H. and A. Diem. 2009. Total, Non-baseload, eGRID Subregion, State? Guidance on the Use of eGRID Output Emission Rates. Prepared for U.S. EPA. Available: https://www3.epa.gov/ttnchie1/conference/ei18/session5/rothschild.pdf

[xxi] U.S. EPA. 2023. EPA's AVoided Emissions and geneRation Tool (AVERT) . Available https://www.epa.gov/avert.

[xxii] USFS, data developed for Nowak et al. 2014

[xxiii] Ratio from Nowak, David J.; Crane, Daniel E.; Stevens, Jack C.; Ibarra, Myriam. 2002.Brooklyn's urban forest. General Technical Report NE-290. 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

[xxiv] 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.

[xxv] Clements et al. 2021

[xxvi] NOAA (National Oceanic and Atmospheric Administration). (2023). *Weather related fatality and injury statistics*. Retrieved August 15, 2024, from www.weather.gov/hazstat

[xxvii] U.S. EPA. 2017. Expanding the Benefits of Seattle's Green Stormwater Infrastructure Examining Values Previously Unmeasured from Past and Potential Future Efforts in Seattle, Washington. EPA 832-R-16-011. Available: https://www.epa.gov/sites/production/files/2017-03/documents/seattle_technical_assistance_010517_combined_508.pdf.

[xxviii] Medina-Ramon M, Schwartz J (2007) Temperature, temperature extremes, and mortality: a study of acclimatization and effect modification in 50 US cities. Occup Environ Med 64:827–833.; Mills, D., J. Schwartz, M. Lee, M. Sarofim, R. Jones, M. Lawson, M. Duckworth, and L. Deck. 2015. Climate change impacts on extreme temperature mortality in select metropolitan areas in the United States. Climatic Change. 131: 83 – 95.

[xxix] Moriyama, M. and M. Matsumoto, M. 1988. Control of urban night temperature in semitropical regions during summer. Energy and Buildings, 11(1-3): 213-219, as cited by The Trust for Public Land. 2016. The benefits of green infrastructure for heat mitigation and emissions reductions in cities: A review of the literature. Executive Report. Written by the Urban Climate Lab at the Georgia Institute of Technology. Available: https://www.tpl.org/benefits-green-infrastructure-heat-mitigation-and-emissions-reductions-cities#sm.00001xwjoo8wocd6uuxfmc5su97zb.

[xxx] U.S. EPA. 2008. Reducing Urban Heat Islands: Compendium of Strategies. US Environmental Protection Agency. Available: http://www.epa.gov/heat-islands/heat-island-compendium

[xxxi] Clements et al. (2021)

[xxxii] U.S. EPA. 2017. Multi-model framework for quantitative sectoral impacts analysis: A technical report for the Fourth National Climate Assessment. Climate Change Impacts and Risks Analysis. Available: https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=OAP&dirEntryId=335095.

[xxxiii] Sailor, D.J. 2003. Streamlined Mesoscale Modeling of Air Temperature Impacts of Heat Island Mitigation Strategies. May 12. Final Project Report. US EPA Assistance ID No. 82806701.

[xxxiv] Sailor, D.J. and N. Dietsch. 2007. The urban heat island Mitigation Impact Screening Tool (MIST). Environmental Modeling & Software, 22:1529-1541.

[xxxv] U.S. EPA. 2019. Mortality Risk Valuation. Available: https://www.epa.gov/environmental-economics/mortality-risk-valuation.

[xxxvi] U.S. EPA. 2018. Environmental Benefits Mapping and Analysis Program – Community Edition: User's Manual. Updated for BenMAP-CE Version 1.4.8. Available: https://www.epa.gov/sites/production/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf

[xxxvii] National Recreation and Parks Association. 2015. Americans' Use and Perceptions of Local Recreation and Park Services: A Nationwide Reassessment. Available https://www.nrpa.org/uploadedFiles/nrpa.org/Publications_and_Research/Research/Park-Perception-Study-NRPA-Full-Report.pdf.

[xxxviii] E.g., Cohen, D., A. Sehgal, S. Williamson, R. Sturm, T. McKenzie, R. Lara, and N. Lurie. 2006. Park Use and Physical Activity in a Sample of Public Parks in the City of Los Angeles. Santa Monica, California: RAND Corporation.

[xxxix] Cohen et al. 2006

[xl] U.S. Army Corps of Engineers. 2018. Economic Guidance Memorandum, 18-03, Unit Day Values for Recreation for Fiscal Year 2018.

[xli] U.S. Army Corps of Engineers. 2018. Economic Guidance Memorandum, 18-03, Unit Day Values for Recreation for Fiscal Year 2018.

[xlii] Jobs for the Future. 2017. Exploring the Green Infrastructure Workforce: A NatureWorks Issue Brief. Available: https://www.jff.org/resources/exploring-green-infrastructure-workforce/

[xliii] Davey Resource Group. 2019. Managing Street Trees as Green Infrastructure: 2019 Cost Assessment, Draft Version 1.0. Prepared for City of Portland. Available: https://www.portlandoregon.gov/parks/article/747180.

[xliv] Masur, J. and E. Posner. 2012. Regulation, Unemployment, and Cost-Benefit Analysis. 98 Virginia Law Review 579.

[xlv] Bartik, T. 2012. Including Jobs in Benefit-Cost Analysis. Annual Review of Resource Economics, 4: 55-73.

[xlvi] Melles, S. and G. K. Martin. 2003. Urban bird diversity and landscape complexity: species-environment associations along a multiscale habitat gradient. Conservation Ecology, 7; Muller, N., P. Werner, J.G. Kelcey. 2010. Urban Biodiversity and Design. Wiley-Blackwell.

Oertli, B. and K.M. Parris. 2019. Review: Toward management of urban ponds for freshwater biodiversity. Ecosphere 10(7).

[xlvii] Andersson, E. S. Barthel, and K. Ahrne. 2007. Measuring social-ecological dynamics behind the generation of ecosystem services. Ecological Applications, 17:1267-1278.

[xlviii] Elmqvist, T., C. Alfsen, and J. Colding. 2008. Urban Systems. Encyclopedia of Ecology. Academic Press: 3665-3672.

[xlix] Ghermandi, A., J.C.J.M. van den Bergh, L.M. Brander, H.L.F. de Groot, and P.A.L.D. Nunes. 2010. Values of natural and human-made wetlands: A meta-analysis. Water Resources Research, 46 (W12516).

[l] Nowak et al., 2013

[li] McPherson et al. 2016

[lii] Available http://www.treebenefits.com/calculator/.

[liii] McPherson et al. 2016

[liv] McPherson et al. 2016

[lv] Getter, K., Rowe, D., Robertson, G., Cregg, B., and J. Andresen. 2009. "Carbon sequestration potential of extensive green roofs." Environmental Science & Technology. 43(19): 7564-7570.

IPCC. 2007. Summary for policymakers. In Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.). Cambridge University Press, Cambridge, UK, pp. 7-22;

Kuronuma, T., H. Watanabe, T. Ishihara, D. Kou, K. Toushima, M. Ando, and S. Shindo. 2018. CO2 Payoff of Extensive Green Roofs with Different Vegetation Species. Sustainability. 10, 2256; 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.

[lvi] Based on 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.

[lvii] Clements et al. (2021)

[lviii] Tan Z, Liu S, Sohl TL, Wu Y, Young CJ. Ecosystem carbon stocks and sequestration potential of federal lands across the conterminous United States. *Proc Natl Acad Sci U S A*. 2015;112(41):12723–12728. doi:10.1073/pnas.1512542112

[lix] Based on an average from Kavehei, E., G. Jenkins, M. Adame, and C. Lemckert, 2018. "Carbon sequestration potential for mitigating the carbon footprint of green stormwater infrastructure." *Renewable and Sustainable Energy Reviews*. 94: 1179–1191; Flynn, K. and R. Traver, 2013. "Green infrastructure life cycle assessment: A bio-infiltration case study." Ecological Engineering. 55: 9-22; Jo, H., and G. McPherson, 1995. "Carbon storage and flux in urban residential greenspace." *Journal of Environmental Management*. 45(2): 109-133; City of Calgary. 2019. Renfrew Integrated Stormwater Management Pilot Study.

[lx] U.S. EPA. 2022. Emissions & Generation Resource Integrated Database (eGRID). Available https://www.epa.gov/egrid.

[lxi] IWG, 2010. Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 - Interagency Working Group on Social Cost of Carbon, United States Government. February. https://www3.epa.gov/otaq/climate/regulations/scc-tsd.pdf.

[lxii] U.S. DOI BOR (U.S. Department of Interior, Bureau of Reclamation). 2023. Change in Discount Rate for Water Resources Planning.