SUMMARY

HEAT REDUCTION BENEFITS of Green Stormwater Infrastructure

GSI Impact Hub

WHAT YOU NEED TO KNOW

- The cooling effect of GSI can:
  - + reduce heat-related illness and death
  - + reduce building energy demands for cooling
  - + improve air and water quality
  - + lengthen the lifespan of infrastructure
  - + promote climate change resilience
- GSI can help to address heat-related equity concerns
- The siting, scale, and design of GSI can influence its ability to reduce urban temperatures
- Funding opportunities related to reducing the effects of urban heat island can help fund GSI projects

This is a summary of a full guide produced as part of the GSI Impact Hub, a larger project that provides resources and support related to specific GSI co-benefits. Please visit the GSI Impact Hub website to explore these resources including:

- Compendium of GSI Co-benefits Valuation Resources
- GSI Impact Calculator, a block-level tool for quantifying and monetizing co-benefits
- Full-length guides related to flood risk reduction, green jobs and economic development, heat risk reduction, habitat and biodiversity, and transportation.

The GSI Impact Hub is a collaboration between The Nature Conservancy, Green Infrastructure Leadership Exchange, One Water Econ, government agencies and technical partners.

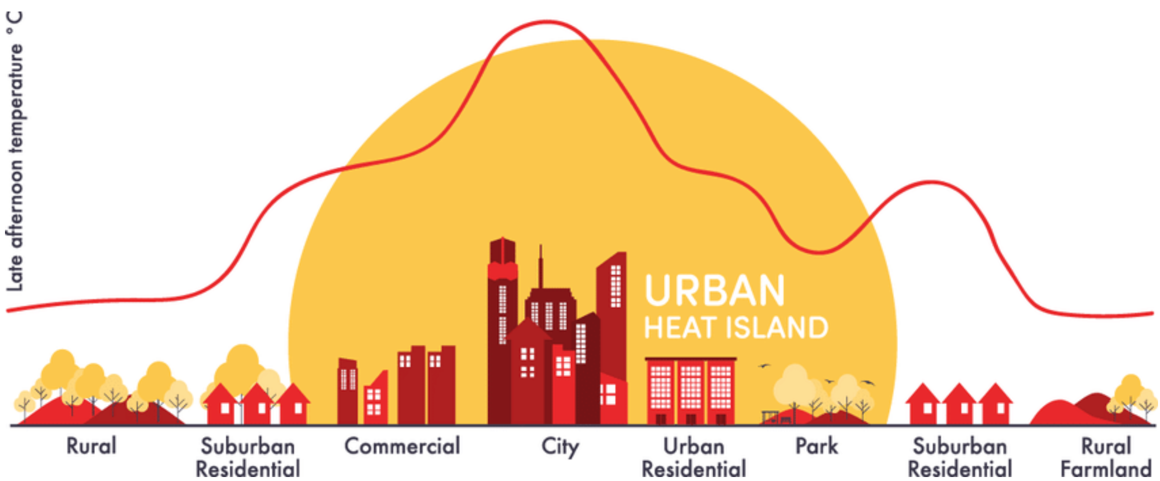
Please see the full guide to "Understanding and Quantifying the Heat Reduction Benefits of Green Stormwater Infrastructure" for citations to the sources referenced in this summary.

Urban Heat Island : What Is It and How Does GSI Help?

Urban heat islands (UHIs) are the elevated temperatures that arise in heavily paved and developed areas compared to more rural surroundings. UHIs are caused by the prevalence of dark, impermeable surfaces that become hotter in the sunlight than natural and more reflective landscapes, a relative lack of vegetation that keeps temperatures lower by providing evaporative cooling and shade, and concentrated human activities which generate heat (e.g., air conditioning exhaust, vehicles, industrial processes).

Dark surfaces, like asphalt streets and parking lots, can become dangerously hot during high heat events, creating threats to people and wildlife. These surfaces also heat the surrounding air, raising overall temperatures across neighborhoods or entire urban areas. In contrast, lighter colored areas (those with a “high albedo”) reflect heat. They stay cooler and contribute less to the UHI effect.

Large scale “greening” projects (i.e., parkway tree plantings, conversion of impervious areas to tree canopy, expansion of parks, etc.) are more likely to result in a meaningful decrease in ambient temperatures; smaller distributed GSI projects also can make meaningful contributions to larger, citywide cooling efforts.



Source: World Meteorological Organization (n.d.)

Green stormwater infrastructure (GSI) practices including green roofs, trees, bioretention areas, and permeable pavement, create shade, reduce heat absorbing surfaces, and emit water vapor, all of which cool hot air and reduce the urban heat island (UHI) effect. Studies have shown that at sufficient scale, GSI practices can decrease ambient air temperatures by 0.5 to 1.8°F. Direct shade from trees reduces temperatures even more. Even a 0.5°F decrease in urban temperatures can significantly reduce heat-related impacts, including illnesses and deaths caused by extreme heat events. Thus, GSI can be a cost effective way to combat the effects of urban heat.[1]

According to the U.S. EPA, tree groves can reduce urban air temperatures up to 9°F as compared to surrounding areas.

Adverse impacts of UHIs and associated costs/outcomes.

Impacts	$ Costs
Increased energy use and associated emissions due to increased air conditioning	• Higher energy costs • Damages caused by CO2 • Adverse public health effects
Increased ozone formation	Tree health and crop damage
Increased heat-related illnesses and mortalities	Increased health care costs, pain and suffering, lives lost, missed work/school
Thermal impacts to local streams and rivers	Avoided water treatment costs/values for aquatic habitat
Reduced infrastructure efficiency/lifecycle	Increased lifecycle costs

A wide range of GSI practices have been demonstrated to measurably reduce urban temperatures.

Decreases in temperature from different GSI practices

GSI Practice	Scale of Implementation	Temperature Reduction	Notes
Overall	City-wide	1.93°F	The average decrease in land surface temperature from 601 European cities in a model-based study of the temperature in baseline vs. no-vegetation scenarios.
	100%	0.1-0.7°F	City-wide simulation of mitigation scenarios if 100% of available area is redeveloped.
	10% increase in GSI	0.13-0.5°F	Decrease in average temperatures across 9 U.S. cities
Trees	10-20% increase	0.5-1.8°F	A review of 146 studies of numerical models found a 10% increase in canopy cover results in 0.3°C decrease in air temperatures and a review of 55 scenarios from 29 cities around the globe found a 20% increase in GSI results in 0.3°C decrease in air temperatures. Modeling of the temperature difference of 601 cities across Europe found that a minimum of a 16% increase in tree cover was required for a 1°C decrease in urban temperatures.
Green roofs	100%	5°F	Modeled changes in roof temperatures in Chicago, IL
Albedo	10% increase	0.36-1.08°F	Lighter color surfaces reduce local air temperatures.

UNDERSTANDING KEY BENEFITS

GSI has direct or indirect cooling benefits for buildings, air quality, avoided heat-related illnesses or fatalities, water quality, and infrastructure. For further information on any topic, see the section in the corresponding full guide identified in the "refer to section" column.

Reduced energy use

Almost half of the energy consumed by buildings in the U.S. comes from heating and cooling. As temperatures increase, so does the use of air conditioning. Trees and green roofs provide shade and insulation, reducing building energy demands.

GSI Practice	Cost / Metric / Baseline Conditions	GSI-Related Benefit	Design Considerations	Refer to Section
Trees	A 1.8°F increase in temperature increases a building's peak electricity load by up to 4.6% and electricity demands by 0.5% - 8.5%	Buildings with surrounding trees use between 2.3% to 90% less energy for cooling	Local climate conditions, building characteristics, and design parameters (e.g., the orientation, size, and distance from a building)	2.1
Green roofs		Buildings with green roofs use 7% more to 90% less energy for cooling	Local climate conditions, and building and roof characteristics (poorly insulated buildings and intensive green roofs have greater savings potential)	2.1

Improved air quality

The energy used to cool buildings results in emissions of air pollutants, including sulfur dioxide (SO_2), nitrous oxides (NO_x), and particulate matter 2.5 ($PM_{2.5}$). NOx and ozone react in hot temperatures to create smog. Air pollution and smog are linked to respiratory illness, cardiovascular effects, and premature deaths, and can limit crop yields and forest growth. GSI can increase vegetation and increase the albedo of urban surfaces, which generally reduce ozone concentrations.

Cost / Metric / Baseline Conditions	GSI-Related Benefit	Design Considerations	Refer to Section
In L.A., smog increases by 5% for every 1.8°F the temperature rises above 71.6°F.	A ton of ozone reduction results in $3,636 in avoided health care costs	Most effective if implemented at a large scale	2.2

Avoided heat-related illnesses and fatalities

Heat is the leading weather-related killer in the U.S. and causes other health problems and illnesses including respiratory difficulties, heat exhaustion, cardiovascular stress, and organ failure. When implemented at sufficient scale, GSI can help reduce the UHI effect, which reduces heat-related illness and mortality during extreme heat events.

Cost / Metric / Baseline Conditions	GSI-Related Benefit	Design Considerations	Refer to Section
In the U.S., heat is responsible for more than 1,300 premature fatalities, 67,500 emergency department visits, and 9,200 hospitalizations each year.	A 10% increase in vegetated area reduces heat-related mortality by up to 30.5%, and ambulance calls and hospital admissions by up to 70%	Wide-scale implementation of GSI will make a noticeable impact	2.3

Improved water quality

Water temperatures increase with rising ambient air temperatures and as a result of stormwater runoff flowing over hot impervious surfaces before it reaches urban waterways. Elevated water temperatures reduce water quality and increase the rate of evapotranspiration. In addition to reducing peak flows and pollutant flows associated with stormwater runoff, GSI practices help control water temperatures.

Cost / Metric / Baseline Conditions	GSI-Related Benefit	Design Considerations	Refer to Section
Warmer water temperatures reduce water quality, affecting drinking water and aquatic habitats	GSI can reduce downstream heat loads by 62%.	Deeper bioretention practices are more likely to prevent elevated runoff temperatures than shallow wet ponds or stormwater basins that can be more easily influenced by solar radiation	2.4

Increased lifecycle and efficiency of infrastructure

Increased temperatures can impact the operations, maintenance, and lifespan of public infrastructure and impede system efficiencies. As a result, more money must be spent to maintain and repair infrastructure. GSI practices can help avoid infrastructure maintenance and replacement costs by shading infrastructure, increasing surface albedo, and reducing damages from the effects of freeze/thaw cycles.

Cost / Metric / Baseline Conditions	GSI-Related Benefit	Design Considerations	Refer to Section
Rising temperatures impact and stress infrastructure and impede system efficiencies.	Shading streets with trees saved $1 per square foot and reduced repaving costs by 58% over a 30-year lifecycle. Porous pavement and permeable pavers have a lifecycle 15 years longer than traditional asphalt parking lots.	Targeting GSI can maximize its efficacy, such as reducing temperatures around air conditioner intakes.	2.5

MAXIMIZING UHI REDUCTION BENEFITS

To maximize UHI reduction benefits of GSI, create a comprehensive plan that targets optimal locations, practices, and GSI design elements.

Location matters

Highly-developed "intra-urban" areas with few trees and green areas can be 15-20°F hotter than other areas within the city. These are areas where GSI can be particularly effective. To identify vulnerable populations within intra-urban areas, combine publicly-available local temperature data with land use and socioeconomic data. Add in water quality, localized flooding, sewer system capacity, or other stormwater management data to create a comprehensive picture of where to target GSI. See sections 3.1 and 3.2 of the full guide for additional details.

Consider scale, GSI practice type, and other factors

The cooling effects of GSI are influenced by several factors:

- Baseline conditions of a city, neighborhood, or site – GSI projects are likely to be less effective in areas with high levels of existing vegetation. The extent to which a city's population has already adapted to urban heat can affect the level of benefits achieved.
- Scale of implementation within a study area – converting between 6% to 31% of a study area will result in GSI-related cooling benefits
- Type of GSI installation and other design elements – in some situations, increasing the albedo of surfaces within a study area may be more effective at reducing temperatures than vegetative surfaces. Trees and green roofs may also have greater cooling benefits than ground-level vegetated practices.

Additional factors that can influence the efficacy of GSI include local climate, maintenance of GSI, and a city's population. The siting of GSI can also influence its ability to reduce temperatures. For example, trees and vegetative cover between tall buildings are less effective than in more open areas. Table 1 has additional design consideration for GSI practices; for further information see Section 3.3.1 in the full guide.

Surface Temperature and Impervious Cover Data in Philadelphia

The map shows Landsat surface temperature grid data by Census block group (CBG). CBGs with blue boundaries fall within the 85th percentile for surface temperatures and impervious cover. Averaging the Landsat and NLCD grid data by CBG or Census tract allows for a direct comparison of socioeconomic variables from the U.S. Census that have been found to be correlated to increased heat vulnerability.

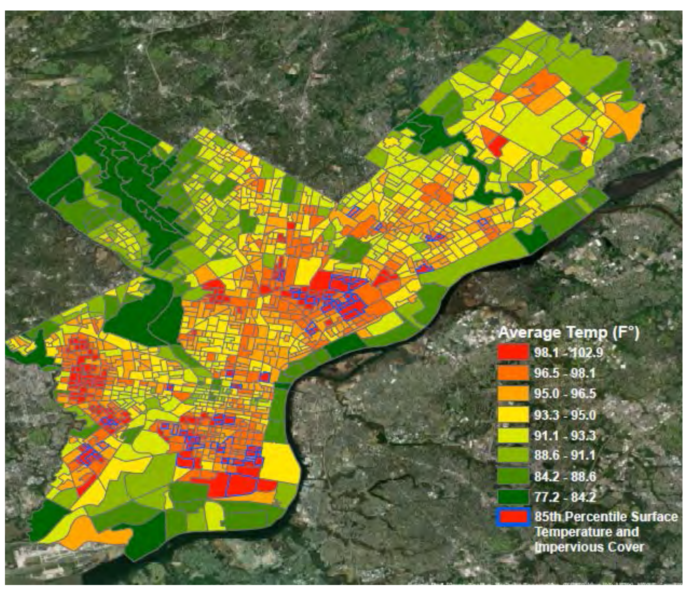


Table 1. Design elements and considerations by GSI practice type

GSI Practice Type	Key Findings
Trees	Trees are the most effective GSI practice for heat stress reduction, although the type of tree species and location can influence its efficacy. Canopy covers provide different amounts of shade. Certain species are more likely to survive in more difficult conditions. Planting trees on east-west oriented streets has a greater cooling effect. Trees can negatively affect traffic safety sight lines.
Bioretention, green space, and parks	Ground-level vegetation cools ambient temperatures, although parks are more efficient at reducing heat when combined with trees. In some cases, open park spaces (<30% tree canopy) allow higher wind speeds and increase evapotranspiration for nighttime cooling.
Green roofs and green walls	Green roofs and walls are most suitable for urban areas where large spaces for GSI are limited. For one- or two-story buildings, green roofs can effectively contribute to building cooling, while green walls provide better cooling benefits on multistory buildings. These savings vary depending on location and the plant palette used.
Permeable pavement	Water infiltration though permeable pavements can aid heat loss. The water held in these pavements can provide post-rain event evapotranspiration, with a greater degree of cooling benefit with more accumulated moisture. Because permeable pavement materials do not absorb as much heat, these surfaces more readily cool off at night.

QUANTIFYING AND MONETIZING UHI REDUCTION BENEFITS

The GSI Impact Calculator at the GSI Impact Hub is a simplified interactive web-based calculator tool that can quantify and monetize GSI co-benefits at the block level and across various practices. It uses existing resources to calculate benefits for each co-benefit, summarized in Table 2. See Section 4 of the full guide for additional information.

Table 2. Specific co-benefits of GSI on UHI

Benefit	Summary Findings	Savings Based On
Building energy savings from street trees	Depending on the location, street trees can save between $7 and $42 per tree on building cooling costs per year	Based on avoided energy expenditures for building climate control.
Building energy savings from green roofs	Green roofs (relative to black roofs) can save up to $4 per square foot of roof in average annual energy costs, depending on the climate zone.	Based on avoided energy expenditures for building climate control.
Reductions in energy-related emissions	The current estimate for the Social Cost of Carbon is $58 per ton of avoided carbon dioxide equivalent.	Based on future avoided heath impacts.
Heat-related health benefits	Studies in three sample cities reveal an estimated total public health value of$0.04 per square foot of GSI and $290 per tree	Based on reductions in illness and mortality associated with urban cooling.

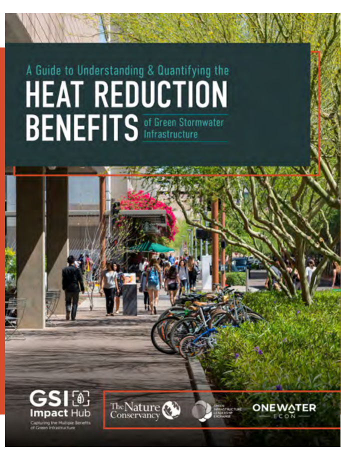
FUNDING GSI FOR UHI REDUCTION

Opportunities for funding for GSI projects that reduce UHI can come from the federal or state level; project funding and financing; or partnerships (Table 3). See Section 5 in the full guide for additional information.

Table 3. Example funding opportunities for implementing GSI that reduces UHI

Scale	Examples of Resources or Funding Opportunities	Sponsoring Entity
Comprehensive	Federal Funding Compendium for Urban Heat Adaptation	Georgetown Climate Center
	Nature-based Funding Solutions Database	NWF
Federal	Environmental Justice small grants program	EPA
	Urban Heat Island mapping program	NOAA
	Building Resilient Infrastructure and Communities grant	FEMA
	Safeguarding Tomorrow Revolving Loan Funds	FEMA
	Environmental and Climate Justice Block Grants	EPA
	Urban and Community Forestry Assistance	USFS
State	Community Development Block Grants (CDBG)	HUD
	Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Grants	DOT
	Urban Trees Grant Program	Chesapeake Bay Trust (MD)
	Community Challenge Grants	AZ Department of Forestry and Fire Management
	Environmental Justice Small Grants	California EPA
	Environmental Justice Community Impact Grants	NYS DEC
Project finance and partnership opportunities	Environmental Impact Bonds	Quantified Ventures
	Better Together Resilient Communities Grant Program	PG&E (CA)
	Urban Forest Climate Change Grants Program	CT Urban Forest Council

NFWF: National Fish & Wildlife Foundation; EPA: US Environmental Protection Agency; NOAA: National Oceanic and Atmospheric Administration; FEMA: Federal Emergency Management Agency; USFS: US Forest Service; HUD: Department of Housing and Urban Development; DOT: state Departments of Transportation; NYS DEC: New York State Department of Environmental Conservation; PG&E: Pacific Gas & Electric.



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For more information visit:
gsiimpacthub.org

Please see the full guide to "Understanding and Quantifying the Heat Reduction Benefits of Green Stormwater Infrastructure" for citations to the sources referenced in this summary.

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