Appendix 1. Findings Literature Review of Tools and Methods for Quantification of Co-Benefits GSI

Heat Reduction

Source	Tool/Method	Relevant Parameters	Case Study	Key Findings
Tran et al., 2020	Green Infrastructure Space and Traits (GIST) model	**Location:** Areas with high land surface temperature are prioritized for GI placement to mitigate the urban heat island effect (Locke et al., 2011; Meerow & Newell, 2017). **Plant trait-benefits**: • **Plant Height:** Taller plants can provide more shade and cool the surrounding area through evapotranspiration (Lundholm et al., 2015). • **Leaf Size Traits**: Larger leaves can enhance cooling through increased shade and higher rates of evapotranspiration (Lundholm et al., 2015; Blanuša et al., 2013). • **Species Richness**: A diverse mix of species can improve overall ecosystem function and resilience, leading to more effective heat reduction (Maestre et al., 2012; Lundholm, 2015).	Philadelphia, PA	The study found that Philadelphia's current GI system has high potential for multifunctionality, but the actual benefits have not been fully realized due to suboptimal placement and plant species selection. The model suggested that to improve heat reduction, **GI should be placed in areas with high land surface temperatures and use plant species with traits like tall height and large leaves.**
Meerow & Newell, 2017	Green Infrastructure Spatial Planning (GISP) method (GIS-based, multi-criteria spatial planning model)	**Land surface temperature** (LST) data is used to prioritize areas for GI placement where reducing heat is critical. **Impervious Surfaces:** Areas with high impervious surface cover are prioritized because they tend to retain heat and exacerbate urban heat island (UHI) effects.	Detroit, MI	Trees and green roofs help mitigate UHI by shading buildings and increasing evapotranspiration, leading to cooler temperatures. The Detroit case study reveals that while there are several ongoing GI projects (e.g., rain gardens, green streets), they are not always located in the most effective areas for multiple ecosystem services. The GISP model showed that many projects were not situated in "hotspot" areas where social vulnerability and UHI mitigation were greatest concerns. Areas with high potential for reducing stormwater runoff and UHI often overlapped, but GI projects were not always placed in these areas, suggesting missed opportunities for maximizing benefits
Makido et al., 2019	ENVI-met® microclimate modelling	**Percent of Canopy:** Trees and vegetation providing shade and cooling through evapotranspiration. **Vegetation:** Types, density (overall green cover), and distribution of vegetation, which provide shading and transpiration cooling effects. **Sum of Biomass Density:** Amount of living plant material affecting transpiration rates. **Building Materials:** Thermal properties of building materials, influencing heat storage and release. **Building Height Standard Deviation:** Variation in building heights affecting shading and wind patterns. **Surface Materials:** Differences in albedo (reflectivity) and heat retention between asphalt, concrete, and vegetated surfaces. **Water Bodies:** Presence and extent of water features, contributing to evaporative cooling. **Wind Patterns:** Local wind flow and turbulence, which affect the dispersion of heat and pollutants. **Soil Moisture:** Level of soil moisture, affecting evaporative cooling potential.	Portland, OR	Green infrastructure could significantly lower temperatures at the city-block scale, but the effectiveness varied depending on the specific landscape and built environment characteristics. This suggests that targeted, context-specific green infrastructure solutions are needed to achieve optimal heat reduction in urban areas. The study utilized ENVI-met to evaluate how different configurations of green infrastructure impact localized temperatures. For instance, adding trees and grass (AddGreen scenario), increasing roof albedo (reflectivity), and combining various cooling interventions were modeled across six different urban clusters in Portland. The model was calibrated using data from weather stations to ensure accuracy in simulated air temperatures. The study focused on six cluster types: High-Canopy Neighborhood, Urban Districts and Corridors, Medium-Canopy Neighborhood, Hardscaped Industrial, Vegetated Urban, and Semi-Rural. No site was selected for the Hillside Forest cluster. Each cluster was modeled with varying development patterns to assess the impact on air temperature. Results showed that adding vegetation in predominantly hardscaped industrial areas had minimal cooling effects when done in a linear pattern. However, a combination of adding green spaces, increasing roof albedo, and increasing road albedo demonstrated the most significant temperature reductions, particularly in built-up areas with minimal existing vegetation. In the "AddGreen" scenario, which involved adding trees along sidewalks and parking lots, as well as grass and trees in exposed soil areas, the model showed specific temperature reductions. For example, in the Hardscaped Industrial cluster, the combination of adding green spaces and increasing albedo resulted in notable cooling effects.

Epelde et al., 2019	ENVI-met ® microclimate modelling	Same as above.	Donostia-San Sebastian City, Spain	**<u>Vegetation:</u>** Planting woody species and installing green roofs demonstrated significant cooling effects. "Planting woody species and installing light-colored permeable pavements and water fountains reduced the mean radiant temperature by 26.5 K and the air temperature by 0.5 and 2.5 K, respectively, in specific places". **<u>Light-Colored Permeable Pavements:</u>** These surfaces reduce heat absorption, contributing to lower surface and air temperatures. **<u>Water Features:</u>** The installation of water fountains led to localized cooling effects through evaporative cooling. "The feasibility design led to a 0.5 K reduction in mean radiant temperature, while the ideal design showed a reduction of up to 2.5 K" **<u>Green Roofs and Soil:</u>** Extensive green roofs on public buildings and soil with herbaceous vegetation in courtyards helped to moderate temperatures and improve thermal comfort. "Soil with herbaceous vegetation provided substantial cooling benefits".
Spahr et al., 2020	GSI inventory ecosystem service trackers	**Vegetation Cover:** Increased vegetation, as measured by NDVI, correlates with reduced urban heat island effects and enhanced biodiversity. **Stormwater Control Measures (SCMs):** Different types of SCMs contribute to varying degrees of greenness. Vegetated SCMs, such as rain gardens and green roofs, provide more significant environmental co-benefits compared to non-vegetated SCMs. **Spatial Distribution:** The arrangement and density of vegetated SCMs affect their overall impact on urban greenness and ecosystem services.		
Ronchi & Salata, 2022	HQ Model	**<u>Vegetation Density and Type</u>**: Different plants have varying capacities for evapotranspiration and shading, which impact heat reduction. **<u>Surface Albedo:</u>** The reflectivity of surfaces affects heat absorption. Vegetated areas typically have higher albedo than concrete. **<u>Proximity to Heat Sources:</u>** Areas closer to heat sources (e.g., roads, buildings) benefit more from increased vegetation.	Settimo Torinese, Italy	**<u>Vegetation Cover:</u>** The extent and type of vegetation play a crucial role in cooling urban areas through evapotranspiration and providing shade. **<u>Green Roofs and Walls:</u>** These features help in reducing ambient temperatures by absorbing less heat compared to conventional building materials. **<u>Urban Trees:</u>** Trees help in lowering surface and air temperatures through shade and evapotranspiration. In the case study, the integration of the HQ model with heat mapping data revealed several key areas where GSI could mitigate urban heat islands. The study highlighted that increasing tree cover in specific neighborhoods could lower local temperatures by several degrees, improving thermal comfort and reducing energy consumption for cooling. "The strategic placement of vegetated NBS in urban heat islands has been shown to effectively reduce local temperatures, creating cooler microclimates that enhance urban livability."
Locke et al., 2011	Three Ps Framework for increasing urban tree canopy	Maximum Average Surface Temperature: Tree planting is prioritized **in areas with high average summer surface temperatures**, as trees reduce the urban heat island effect by **providing shade and evapotranspiration**	New York, NY	The case study of NYC demonstrated the effectiveness of this prioritization method. The city used the spatial data to target tree planting in areas with the greatest need for cooling and air quality improvements, as well as in ecological corridors to enhance biodiversity. The analysis showed that neighborhoods with higher summer surface temperatures were ideal for tree planting to reduce heat. For instance, data from Landsat identified areas that were significantly hotter in the summer, and these areas were prioritized for tree planting. The method identifies areas with high surface temperatures, which could be priority zones for GSI. Planting trees and other vegetation in these areas would lower temperatures through shading and evapotranspiration, thereby mitigating urban heat island effects
Hysa, 2021	Transversal Connectivity Index	**<u>Patch Area (PA)</u>**: Larger patches can support more diverse species and provide **more extensive cooling through evapotranspiration.**	Berlin, Germany	The TCI can be applied to model and quantify the biodiversity enhancement and heat reduction benefits of green (stormwater) infrastructure by assessing the connectivity and quality of landscape patches.

		<u>Patch Compactness Index (PCI):</u> Indicates the shape complexity of patches, influencing **edge effects** and habitat suitability. **<u>Transport Fragmentation Buffer (Buff):</u>** Quantifies the fragmentation caused by transportation networks, which can hinder connectivity and reduce ecological and **cooling functions.**		
Lundholm et al., 2015; Lundholm, 2015	Ecosystem Multifunctionality	**<u>Canopy Density</u>**: A denser canopy leads to lower substrate temperatures, reducing heat flux into buildings. This was positively correlated with plant height and SLA. **<u>Albedo</u>**: Reflectivity of plant surfaces was measured, showing that plants with higher albedo reduced substrate heating more effectively. **<u>Water Loss and Transpiration</u>**: Tall species with higher SLA, like graminoids and forbs, had greater water loss rates, contributing to cooling through evapotranspiration.		**Optimizing Plant Selection:** Just as plant traits were used to predict green roof performance, they can be applied to GSI elements like bioswales or rain gardens to select species that maximize both heat reduction and biodiversity benefits. **Substrate Cooling:** Plants like Poa compressa and Sedum acre reduced substrate temperatures by up to 26% compared to control modules. This demonstrates how vegetation can significantly lower urban temperatures
Rainey et al., 2022	i-Tree model	**<u>Tree Canopy Size:</u>** Larger canopies provide more shade, reducing ambient temperatures and energy use for cooling. **<u>Evapotranspiration:</u>** Trees release water vapor into the atmosphere, which cools the surrounding air. **<u>Proximity to Buildings:</u>** Trees located near buildings reduce the need for air conditioning through shading	Baltimore, Denver, New York City, Philadelphia, and Portland	The model calculates, next to carbon storage and sequestration and air pollution removal, the cooling and UV reduction: Effects are measured based on tree canopy size, shade provided, and water evaporation through transpiration. **<u>Species Selection</u>:** Identifying tree species that provide both **cooling** and habitat for local wildlife. For instance, in **New York City** and **Philadelphia**, Honeylocust (Gleditsia triacanthos) was commonly planted due to its ability to provide significant cooling and support biodiversity. Being an arid city, Denver's trees provided **lower co-benefits per tree for cooling** and air quality, but large-scale SGI projects like detention basins helped offset this by using more trees. **Portland:** Had the most extensive use of trees in SGI programs, leading to higher total municipal-level co-benefits from cooling, carbon sequestration, and air pollution removal

Biodiversity Enhancement

Source	Tool/Method	Relevant Parameters	Case Study	Key Findings
Tran et al., 2020	Green Infrastructure Space and Traits (GIST) model	**<u>Location:</u>** Areas with large habitat patches or those lacking habitat to increase connectivity are prioritized for enhancing biodiversity (Meerow & Newell, 2017) **<u>Plant traits-benefits:</u>** •**Colourfulness**: Plants with colorful flowers can attract a variety of pollinators and support diverse wildlife (Bernardello et al., 2001). •**Flower Size, Floral Reward, Flower Abundance and Bloom Time Length**: These traits can attract pollinators and provide necessary resources, supporting a diverse ecosystem (Bosch et al., 1997). •**Height Range and Species Richness:** A variety of plant heights and a rich mix of species can create different habitats and niches, enhancing overall biodiversity (Evans et al., 2009).	Philadelphia, PA	For biodiversity enhancement, the model recommended placing GI in areas that either lack habitat to increase connectivity or where large habitat patches can be expanded. It also emphasized using plant species with traits like colourfulness, flower size, and species richness to attract and support diverse wildlife.

Meerow & Newell, 2017	Green Infrastructure Spatial Planning (GISP) method (GIS-based, multi-criteria spatial planning model)	**Landscape Connectivity:** **The Patch Cohesion Index (PCI)** from *Fragstats software* is used to assess the structural connectivity of existing green spaces. GI is prioritized in areas where it can connect fragmented habitats, improving biodiversity by facilitating species movement **Vegetation and Habitat Creation**: GI projects such as tree planting and rain gardens enhance urban biodiversity by providing new habitats. Vegetation clusters close to existing green spaces are particularly valuable for biodiversity	Detroit, MI	Although landscape connectivity was a lower priority for stakeholders, the model identified synergies between improving connectivity and other benefits like air quality and stormwater management
Jessup et al., 2021	Biodiversity analysis	**Land Cover Types:** Different land cover types (e.g., Tree Canopy, Grass/Shrubs) play a crucial role in determining biodiversity levels and temperature regulation. **Convertible Lands:** Areas identified as Convertible Lands (Other Paved plus Bare Soil) represent opportunities for habitat creation and expansion. **Proximity to Existing Vegetation:** The context of siting (whether adding new vegetation in isolation or expanding existing vegetated areas) affects the ecological benefits	Los Angeles, CA	Vegetation is strongly correlated with ecosystem services such as habitat enhancement and bird species richness. The study emphasizes the importance of siting context for maximizing these benefits. For instance, adding habitat in isolated patches can support pollinators and other small animals, while expanding existing habitats can support larger animal populations and additional species. The findings can be applied to model and quantify biodiversity enhancement benefits of Green Stormwater Infrastructure through: 1) Using GIS-based tools to map and analyze land cover types and identify Convertible Lands for habitat creation. 2) Prioritizing sites for green stormwater infrastructure (GSI) based on potential biodiversity benefits, social and public health benefits, and water quality improvements. The study's methodology helps answer where to prioritize vegetated GSI for maximum benefits. 3) Employing NDVI and other remote sensing data to track greenness trends and evaluate the impact of GSI programs on urban greenness and associated ecosystem services. This approach helps in assessing the co-benefits of GSI installations and incorporating them into planning and decision-making processes
Ronchi & Salata, 2022	HQ Model	**Assessing Baseline Conditions:** Using existing data on land cover, vegetation types, and human impacts to establish a baseline for habitat quality. **Simulating GSI Implementation:** Modelling the addition of GSI features, such as green roofs, rain gardens, and urban forests, to predict changes in habitat quality and biodiversity. **Measuring Connectivity:** Evaluating how new green spaces connect with existing habitats and the potential for creating wildlife corridors. **Monitoring Changes:** Continuously monitoring the impact of GSI on biodiversity by tracking changes in species richness and abundance over time.	Settimo Torinese, Italy	**Habitat Connectivity**: Ensuring that new green spaces are connected to existing habitats to facilitate species movement and genetic exchange. **Diverse Plant Species:** Planting a variety of native species to support a wide range of wildlife, including pollinators and other beneficial insects. **Habitat Size and Quality:** Larger and higher quality habitats support more species and larger populations of wildlife. **Human Disturbance Levels:** Lower human impact areas provide better conditions for species diversity. In the case study of the Italian city analyzed in the paper, the HQ model was applied to identify potential sites for GSI that would enhance biodiversity. The HQ model can be applied to identify areas within urban landscapes where green stormwater infrastructure (GSI) can be most effective in enhancing biodiversity. By mapping current vegetation, human disturbance, and existing habitats, planners can prioritize areas for GSI implementation that will maximize biodiversity benefits. For example, adding green roofs, urban forests, or rain gardens in strategic locations can create new habitats or enhance existing ones
Locke et al., 2011	Three Ps Framework for increasing urban tree canopy	**Ecological Corridor Density and Existing Habitat Density:** The method prioritizes planting in areas near ecological corridors and existing habitats to enhance landscape connectivity, thereby improving the movement of wildlife and supporting biodiversity	New York, NY	Areas near existing ecological corridors were targeted for planting to improve biodiversity by increasing habitat connectivity (the degree to which the landscape permits movement from patch to patch). "Planting trees in, around, and in between ecological corridors helps increase landscape connectivity, improving the ability for urban wildlife like birds to move throughout the otherwise harsh urban matrix". Planting more trees in and near areas of existing habitat (Natural Areas, Preserves, DEC Freshwater Wetlands) may improve the quality of the habitats and better integrate them intro the surrounding landscape. The framework's emphasis on planting trees near ecological corridors and existing habitats can be extended to GSI. By creating connected green spaces through vegetated rain gardens, bioswales, and green roofs, GSI can improve habitat connectivity and enhance biodiversity
Hysa, 2021	Transversal Connectivity Index	**Patch Area (PA):** Larger patches can support more diverse species and provide more extensive cooling through evapotranspiration.	Berlin, Germany	The TCI can be applied to model and quantify the biodiversity enhancement and heat reduction benefits of green (stormwater) infrastructure by assessing the connectivity and quality of landscape patches. Specifically, the method can:

		Patch Compactness Index (PCI): Indicates the shape complexity of patches, influencing edge effects and habitat suitability.		**Identify Key Patches and Corridors:** Determine which patches and corridors are most critical for maintaining connectivity and enhancing biodiversity. For example, in Berlin, the study found that despite abundant green spaces, only 50% had direct access to freshwater surfaces.
		Patch Ecological Indicator (PEI): Assesses the ecological quality of patches.		**Assess Impact of Fragmentation:** Evaluate how transportation and urban infrastructure fragment natural landscapes and reduce connectivity, thereby informing urban planning to minimize these impacts.
		Band Level (BL): Represents the connectivity level of patches within a specific band.		**Guide Policy and Management:** Provide quantitative data to support urban management agendas like the City Biodiversity Index, the concept of Sponge City, and Sustainable Development Goals .
		Shared Border Ratio (SBR): Measures the extent of shared boundaries between patches, indicating potential connectivity and habitat corridors.		
		Transport Fragmentation Buffer (Buff): Quantifies the fragmentation caused by transportation networks, which can hinder connectivity and reduce ecological and cooling functions.		
Lundholm et al., 2015; Lundholm, 2015	Ecosystem Multifunctionality	**Species Diversity:** Greater species diversity enhances multiple ecosystem functions. In particular, the combination of tall and short species, or species with different SLA values, improved resource use efficiency and habitat availability for wildlife.		**Optimizing Plant Selection:** Just as plant traits were used to predict green roof performance, they can be applied to GSI elements like bioswales or rain gardens to select species that maximize both heat reduction and biodiversity benefits.
		Habitat Provisioning: Denser canopies provide better habitats, especially for invertebrates and birds, contributing to urban biodiversity. Species with higher growth rates also accumulated more biomass, which aids in creating habitats.		**Scaling for Landscape Connectivity**: Green roofs that incorporate diverse species can be designed as part of a larger network of urban green spaces, creating corridors that enhance biodiversity across cities.
		Functional Traits: The articles suggest that mixing species with complementary traits (e.g., a tall species with high SLA like Carex nigra and a low, drought-tolerant species like Sedum acre) can optimize both cooling and habitat provisioning (Lundholm et al., 2015)		**Stormwater Management and Habitat:** Vegetated GSI can be optimized to capture stormwater while simultaneously providing habitats for urban wildlife. As seen in the studies, species like Sedum were less effective at capturing water but provided cooling benefits, suggesting that mixed-species plantings could enhance multifunctionality
Rainey et al., 2022	i-Tree model	**Tree Species Diversity:** Planting a variety of tree species creates habitats for different wildlife species, supporting greater biodiversity.	Baltimore, Denver, New York City, Philadelphia, and Portland	**Species Selection**: Identifying tree species that provide both cooling and **habitat for local wildlife.** For instance, in New York City and Philadelphia, Honeylocust (Gleditsia triacanthos) was commonly planted due to its ability to provide significant cooling and **support biodiversity**
		Tree Age and Size: Larger, older trees provide better habitat structures for birds and other wildlife.		**Habitat Creation:** The model's ability to predict carbon storage benefits helps prioritize tree species that simultaneously sequester carbon and **enhance biodiversity by creating diverse urban habitats**
		Landscape Connectivity: Trees planted in SGI projects help connect fragmented urban habitats, improving biodiversity and ecological resilience		**Integrating GSI into Urban Planning**: The i-Tree model allows planners to predict how SGI projects can enhance connectivity between green spaces, promoting **urban wildlife corridors**

Other Co-Benefits

Source	Tool/Method	Relevant Parameters	Case Study	Key Findings
Meerow & Newell, 2017	Green Infrastructure Spatial Planning (GISP) method (GIS-based, multi-criteria	**Social vulnerability reduction** **Access to green space** **Air quality improvement** **Landscape connectivity**	Detroit, MI	
Locke et al., 2011	Three Ps Framework for increasing urban tree canopy	**Air Quality:** Areas near major roads with higher vehicular pollution are prioritized for tree planting, as trees can improve air quality by removing pollutants.	New York, NY	

Lundholm et al., 2015; Lundholm, 2015	Ecosystem Multifunctionality	**Nutrient Retention:** Taller plants with higher canopy growth rates were associated with better **nitrate and phosphate uptake**, reducing nutrient runoff from green roofs. **Substrate Winter Temperature Increase:** Specific Leaf area and Leaf Dry Matter Content have an impact on Snow Depth, and togehter with Albedo, which is influenced by Canopy Density, these have an impact on winter temperatures, potentially reducing costs for heating in winter.	
Rainey et al., 2022	i-Tree model	**Carbon storage and sequestration:** By using allometric equations to model tree growth. **Air pollution removal:** Trees' ability to remove pollutants such as PM2.5, O3, and CO2.	**Carbon Sequestration:** The model's ability to predict carbon storage benefits helps prioritize tree species that simultaneously sequester carbon and enhance biodiversity by creating diverse urban habitats

Appendix II. Interview Guide and findings Interviews

Part 1. Interview Guide

General or City Studies

- Q1. General: Do you know of any studies that demonstrate/justify (ideally quantitatively) that GSI/GRI tools can contribute to urban heat reduction and biodiversity enhancement (or other co-benefits)?
- Q2. Cooling analysis from 2023:
  - Q2.a. How does [City] measure the benefits of GRI for urban heat reduction Are there tools, metrics, or studies you can share?
  - Q2.b. Could you share any recent updates on how rain gardens and vegetated trench pits (or other forms of GSI) contribute to localized cooling effects? and biodiversity enhancement?
- Q3. Have there been any enhancements in mapping or tracking GSI impacts on urban heat and biodiversity?
- Q4. General: Does GSI/GRI play a role (e.g. is it identified) in any of your organization's strategies that advance climate adaptation objectives (e.g. urban heat reduction, biodiversity enhancement, other)
  - Q4.a. If so, what kind of GSI/GRI and what role does it play?
  - Q4.b. What policy or programmatic frameworks support widespread implementation, particularly on private property?
  - Q4.c. Any supporting tools (such as enhanced GSI/GRI design standards)?

Adaptive Management

- Definition: Adaptive management may be described as a means to measure and assess the ongoing effectiveness of an approach, and then self-corrects that approach to achieve better results.
- Q6. General: Does your organization use an adaptive management approach for GSI/GRI? If so, can you describe any adaptive management initiatives undertaken by your organization? We are primarily interested in initiatives related to GSI/GRI, but list others if related.
  - Examples: monitoring, reporting, new or revised bylaws, supporting programs, funding, tools such as online maps, other key lessons learned.
- Q7. Are there any differences in approach between **public** (Parks, streets, boulevards) and **private lands**?

In addition to these questions, specific questions regarding studies or programs in the cities were added.

Part 2. Findings interviews

GI Leadership Exchange

The interview with representatives from the GI Leadership Exchange (GILE) and The Nature Conservancy highlighted key insights regarding the promotion and implementation of GSI across local governments and water agencies in the United States and Canada.

Tools and Resources for GSI Implementation: The GI Leadership Exchange provides several valuable resources, including a Climate Resilience Resources Guide and access to incentive programs aimed at stormwater management. Notably, RainPlan, a U.S.-based organization, offers an interactive platform where users can search for local stormwater management incentives by inputting their address or zip code. The GILE is also collaborating with The Nature Conservancy and One Water ECON to develop the **GSI Impact Calculator**, a tool that evaluates the impacts of different GSI practices. The GILE is working on a guide to help users select the best tools for their specific needs, especially at the block-level, which is a common scale for many local GSI projects.

GSI Benefits and Impact: The interview highlighted the significant potential of GSI to mitigate urban heat. For instance, GSI practices can reduce temperatures by 0.5 to 1.8°F, with trees offering even greater cooling effects, up to 9°F in tree groves, as reported by the EPA. These cooling effects, when scaled across urban areas, can have substantial benefits for mitigating heat islands and improving urban livability.

- **The State of Public Sector GSI (2023 Study):** A pivotal study by GILE, titled "State of Public Sector GSI," identified three key factors essential for effective GSI programs:
- **People**: Gaining buy-in from elected officials, stormwater managers, and community groups is fundamental. Without this, GSI projects struggle to gain traction.
- **Policy**: Having the right policies in place, such as stormwater management incentives and fees, is critical to the success of GSI initiatives.
- **Emerging Practices**: Advancements in asset management and workforce development are also crucial but must follow after securing people and policy support. This study, released in 2023, emphasizes the importance of collaboration and securing political support for GSI.

Challenges and Funding: The interview shed light on challenges faced in the U.S., particularly regarding regulatory frameworks and funding. Many stormwater management programs focus solely on compliance with stormwater regulations due to limited financial resources. In some cities like Chicago, the Water Reclamation District focuses on GSI for stormwater management but lacks a dedicated funding mechanism, while tree planting for heat mitigation is managed separately by the city. This disconnect illustrates the need for integrated approaches to address both stormwater management and urban heat island effects.

Case Studies and Innovative Approaches: The interview touched on several cities with notable GSI initiatives:

- **Kansas City**: Known for its green roof development, which has been supported through incentives and programs.
- **Boston**: The Housing Department in Boston has taken a proactive approach to GSI by hiring a dedicated green infrastructure expert, highlighting the importance of local leadership and institutional support.
- **Chicago**: Chicago's StormStore program is an innovative water credit trading system that incentivizes GSI projects in underserved areas, particularly on private properties. This program is still evolving but offers a promising model for cost-benefit analysis in GSI implementation.
- In **Philadelphia**, despite having one of the most advanced GSI programs, challenges persist. While the city's green roof incentives are important, they are not sufficient to drive large-scale adoption of green roofs. Additionally, interdepartmental collaboration remains a hurdle, with key stakeholders still working to address the gaps in funding and coordination. A **neighbourhood-scale approach** that incorporates community-driven greening projects and public-private partnerships is helping to overcome these challenges, but the need for comprehensive, cross-sector collaboration remains evident.

Toronto

GSI programs and co-benefits

In the context of Green Infrastructure with specific co-benefits, we talked with civil servants from the City of Toronto about the PollinateTO incentive program and the Eco-Roof incentive program.

The **PollinateTO program** provides up to $5,000 in funding to community groups for the creation of pollinator habitats, including rain gardens. It also engages residents through initiatives such as plant giveaways. For example, over 2,000 native wildflower seedlings were distributed to TTC riders at stations during the past growing season. The program aims to reach underserved communities by meeting them in everyday spaces and promoting conversations around habitat creation, biodiversity, and sustainable landscaping.

The program focuses on creating pollinator gardens, which must include at least 95% native plant species. Grantees participate in a seven-week training program covering pollinator stewardship, urban biodiversity, and habitat creation.

Since its inception in 2019, PollinateTO has established over 25,500 square meters of pollinator habitat, with an increasing emphasis on rain gardens. Many pollinator gardens also serve as rain gardens, supporting both biodiversity and stormwater management. The program provides annual reports to city councillors detailing grant activities, such as habitat creation, school involvement, and community participation.

While PollinateTO is **open to applicants on private property, the projects must be highly visible to the public.** Many private property projects involve multiple homeowners, creating a community impact through collaborative efforts. The program focuses **primarily on public spaces**, including parks, boulevards, school grounds, and community centres. Projects may also include pollinator pathways to encourage community-led biodiverse landscaping.

Connectivity is a key focus, with projects like Business Improvement Areas (BIAs) converting long stretches of plantings to native species, creating biodiversity corridors. While there are no formal, long-term biodiversity targets, the program takes an incremental approach, focusing on expanding existing initiatives. Many of the projects also address stormwater management, often through bioswales or similar features, with a biodiversity component.

An interactive map is available, allowing users to explore project locations and filter by property type, such as schools or boulevards.

The **Eco-Roof Incentive Program** has been active for 15 years, supporting the installation of green roofs and cool roofs on both existing and new buildings. The program offers funding of $100 per square meter for green roofs and $2–5 per square meter for cool roofs. Recently, the city has developed methodologies to assess the urban heat island mitigation, stormwater management, and energy cost savings provided by these roofs, though these calculations are still being finalized.

Biodiversity is a priority in both the city's **Biodiversity Strategy** and **Green Roof Strategy**, and efforts are being made to incorporate this focus into the Eco-Roof Incentive Program. However, biodiverse green roofs tend to be more expensive due to the deeper growing medium required. As part of this effort, the program is moving away from the use of sedum green roofs, which are common but less beneficial for pollinators. Some newer installations even use lightweight wool substrates instead of traditional soil. The goal is to more meaningfully integrate biodiversity across all green roof projects and related programs.

In addition to the incentive program, Toronto has a **Green Roof Bylaw**, which mandates green roofs on buildings above a certain size. Developers who are exempt from the bylaw pay a fee that sustains the Eco-Roof Incentive Program, making it self-funded rather than reliant on taxpayer dollars.

The Eco-Roof Incentive Program primarily focuses on **public spaces**, with most projects located on boulevards and other public areas. The program, however, **also supports private**

property projects, though typically not residential buildings. The city is currently conducting a program review to assess its impact and identify strategies to further incentivize high-performing green roofs.

Despite their benefits, green roofs are not yet fully integrated into Toronto's broader climate resilience and sustainability strategies, such as the TransformTO Net Zero Strategy, which aims for net-zero emissions by 2040. While **TransformTO** includes actions to increase tree canopy cover and ensure equitable tree distribution, green roofs are not prominently featured. However, as part of an ongoing update to TransformTO, there is growing consideration for integrating nature-based solutions, including green roofs and Indigenous perspectives, into the city's climate action plans.

Insights for GSI Design practices

Consideration of Plant Selection for Green Roofs: In Toronto's green roof initiatives, the choice of plants plays a crucial role in achieving desired benefits such as heat mitigation and biodiversity. While sedums are commonly used due to their resilience and ease of maintenance, they may not provide sufficient microclimate regulation due to their smooth surface. This limits their effectiveness in mitigating urban heat. It is recommended to explore a diverse range of species that can contribute to a more functional green roof. Additionally, ensuring adequate soil volume is essential for plant health and performance. For tailored plant selection advice, consulting with specialists in horticulture and biodiversity can provide valuable insights to improve outcomes.

Sedums are often the default choice for green roofs because they are perceived as an easy option. However, their effectiveness in addressing broader environmental goals may be limited. As the focus shifts towards more sustainable, high-performance GSI, relying on sedums may no longer be the best approach. It is important to prioritize plant diversity and consider the unique ecological needs of each project rather than opting for the most straightforward solution.

Collaboration on Biodiversity Guidelines: City planning and green roof teams are actively working on updating guidelines for greener solutions, with a particular focus on biodiversity. While existing documents for biodiverse green roofs are useful, they are becoming outdated. A revision is planned for 2025, with input from researchers to reflect recent findings in biodiversity studies. For instance, it is now understood that pollinators like bees travel up to six floors, and studies in the U.S. have documented monarch butterflies at much higher altitudes. This underscores the importance of designing green roofs and facades that facilitate pollinator movement across multiple levels. Simply placing a green roof on top of a building may not be sufficient to support biodiversity if the necessary pathways for wildlife are not considered.

Food-Producing Green Roofs: The city has developed a guide for food-producing green roofs, which aligns with local bylaws. These roofs can fulfil bylaw requirements as long as a cover crop is planted in the winter to prevent wind uplift and erosion. The guide addresses key considerations for growing food on rooftops, such as avoiding damage to the membrane, determining optimal soil depths for different crops, and identifying suitable building conditions. Although initially detailed, the guide has been condensed into a more accessible format, making it applicable across various cities. While local microclimates and plant choices may vary, rooftop farming principles remain broadly transferable, offering useful insights for cities like Vancouver.

Cool and Blue Roofs: While green roofs are a valuable tool for urban climate resilience, cool and blue roofs also play a significant role in managing urban heat islands. In certain cases, such as industrial buildings, the structural reinforcement required for green roofs may not be feasible due to cost or environmental impact. Cool roofs, which reflect sunlight and reduce building temperatures, can offer substantial benefits in such instances. While cool roofs may have a marginally increased heating demand in winter due to reflected heat, the summer cooling savings typically outweigh the additional heating costs. Research from experts like Hashem Akbari from Concordia University has helped to validate the net positive impact of cool roofs in mitigating urban heat. Blue roofs, designed to capture and store rainwater, also serve an important function in urban water management.

Trees and Their Cooling Benefits: Trees are often the most effective for cooling and stormwater management, thanks to their extensive surface area. Trees provide shade and contribute to cooling through evapotranspiration, while their canopy can help mitigate stormwater runoff. Toronto's forestry division is an integral partner in these efforts, with the urban forest recently valued at $7 billion. While this report focuses on green roofs, it is important to note that trees, as part of a broader green infrastructure strategy, can offer unparalleled environmental benefits, especially in terms of cooling and stormwater regulation.

Integration of Green Roofs within Larger Urban Landscape: The role of green roofs within the larger urban landscape is expanding beyond simple green spaces to include multifunctional design elements like urban forests and recreational spaces. Recent presentations, such as those at *CitiesAlive*, demonstrated how rooftops can be categorized and designed based on their potential uses, from green roofs to urban forests or temporary installations. These concepts encourage thinking beyond traditional green roofs to create dynamic, adaptable urban environments that respond to both ecological and social needs. As green infrastructure continues to evolve, integrating these varied uses into a cohesive urban fabric will be key to meeting sustainability and livability goals.

Quantification of co-benefits, a difficult extensive progress

The City of Toronto has been working with the private sector consultant AutoCase to assess the co-benefits of green infrastructure, with a particular focus on the Eco-Roof Incentive Program. A comprehensive report was commissioned to evaluate 20–30 co-benefits, such as stormwater management, energy savings, greenhouse gas reductions, and urban heat island mitigation. The city is also refining stormwater management equations, currently under peer review, to ensure accuracy. These efforts reflect the city's commitment to quantifying the multi-faceted benefits of green infrastructure, although challenges persist in ensuring the reliability of these calculations.

- **Challenges with Using Consultant-Developed Equations:** Calculating the benefits of green infrastructure involves complex equations that are based on numerous assumptions, such as irrigation needs, roof types, and environmental conditions. These assumptions require constant scrutiny, particularly when applying them to evolving projects. Consultants provide initial estimates using these equations, but the process remains challenging due to the high level of uncertainty. Toronto's team has found it difficult to rely solely on external tools, such as AutoCase, given that much of the data comes from different climates (like the U.S.) and may not fully account for local conditions, making precise calculations of ecosystem services a continual challenge.

- **Control Over Equation Development:** While AutoCase offers valuable insights, Toronto opted not to proceed with their system due to a desire for greater control over the equations and calculations. The city's preference is to develop equations in-house, ensuring transparency in the calculations and the ability to adapt the models to fit local conditions. This hands-on approach is seen as necessary for accurate, long-term monitoring of green infrastructure impacts. However, the complexity of this process means that the equations are still in draft form, with coefficients that require local verification—such as adjusting for Toronto's unique climate, energy costs, and urban landscape.
- **Equations and Metrics in Development:** Toronto has developed equations for about 50 different metrics, covering various co-benefits such as energy savings from building heating and cooling, urban heat island mitigation, stormwater management, and GHG sequestration. These equations aim to capture both environmental and social impacts, such as reduced mortality from heat and job creation. However, the challenge lies in the granularity of these metrics. For instance, accurately estimating the heat mitigation benefits requires factors like building age, insulation, and window type, which can significantly vary across different building types. This complexity makes the process more intricate than initially anticipated.
- **Need for Updated Tools:** A major gap in the industry is the lack of verified tools for calculating the benefits of green roofs and other green infrastructure. Toronto's consultations with stakeholders, including green roof professionals, homeowners, and property owners, revealed a strong demand for a tool that allows users to input specific parameters—such as roof size, green roof type, and stormwater impacts—to calculate the associated benefits. An outdated tool, the Portland State University green roof energy calculator, no longer meets the industry's needs, highlighting the demand for a more sophisticated and locally verified solution.
- **Building Type and Impact Variability:** The impact of green infrastructure, particularly cool roofs, varies depending on building type. Smaller, taller buildings may see minimal direct benefits from a green roof, as only the top floor receives cooling effects. In contrast, larger, low-rise buildings like warehouses can experience substantial benefits, as seen with Amazon's use of cool roofs. The reflective effect on these buildings, particularly those without air conditioning, results in significant energy savings. This variation underscores the need for tailored calculations based on building characteristics, further complicating the task of quantifying the co-benefits of green infrastructure in a consistent way.

While the City of Toronto's efforts to refine calculations and develop locally-specific equations are a step forward, the complexities involved in accounting for various variables make this a continuously evolving task. There remains a need for updated, region-specific tools that can reliably quantify green infrastructure's multifaceted contributions to urban sustainability.

Adaptive management

The **PollinateTO program** follows an adaptive management approach by requiring impact reports from grant recipients, who have two years to complete their projects and submit these reports. A 10% withholding of the grant funds serves as an incentive for timely submission. The reports include estimates of the number of plants planted, people engaged, and sometimes species-specific data, such as for keystone plants like goldenrod and milkweed. The program also tracks the size of project sites, which may differ from their original proposals.In addition, some groups collaborate with graduate students or citizen science initiatives to conduct additional monitoring, like bee counts, and share these findings, providing a more nuanced understanding of the project impacts. There are differences in how success is assessed in public versus private spaces. For private properties, applicants are asked about their plans for maintaining the site, though challenges can arise if homeowners sell their property, and the new owners remove the plants. For schools or institutional spaces, the property owners (e.g., school boards) are involved in the review process to ensure long-term viability. Similarly, for city-owned land, the program coordinates with relevant divisions, such as Parks or Transportation Services, to get approvals for proposed sites.

Since its establishment, the **EcoRoof Incentive Program** has integrated a methodology into its application portal, which calculates metrics like greenhouse gas emissions reduced and stormwater managed. This data is available on the program's website under "program impacts." However, the methodology is outdated, and there are plans to update it. Currently, the program tracks indicators such as the number of applications received, the square footage of eco-roofs installed, and the results of site visits to ensure the roofs are performing as intended. For voluntary installations, these site visits also serve as maintenance checks to encourage upkeep. The program has observed a decline in applications, which is attributed to stagnant incentive levels while installation costs have risen. To address this, the City has recently engaged consultants to help reassess the program. Success is currently measured by the number of applications, square meters of eco-roofs installed, and site visits. Additionally, a map is available for the EcoRoof Incentive Program, and all green roofs installed since 2009 are tracked through a permitting process, with their locations publicly available on the City of Toronto's open data website. A student study conducted a few years ago verified some of these records, finding that some green roofs have been removed after inspections, particularly those installed under the mandatory green roof bylaw.

The green roof bylaw differs from the incentive program as it mandates installations of green roofs, and site visits are conducted to ensure compliance. These visits focus more on qualitative assessments, rather than quantitative measurements. The city is considering potential updates to the bylaw.

Additional resources:

- Page 77 is the Natural Systems section of TransformTO and there are only two actions associated with this. Transform To Net Zero Strtegy - A Climate Action Pathway to 2030 and Beyond (toronto.ca)
- Toronto Resilience Strategy UHI& Flooding,
- Policy Resources — Green Roofs for Healthy Cities
- Pollinate TO: https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives/pollinateto-community-grants/pollinateto-project-sites-map/
- POLLINATOR PROTECTION STRATEGY https://www.toronto.ca/wp-content/uploads/2018/05/9676-A1802734_pollinator-protection-strategy-booklet.pdf
- BIODIVERSITY STRATEGY https://www.toronto.ca/legdocs/mmis/2019/ie/bgrd/backgroundfile-136906.pdf
- About — Our Mission — Climate Positive Design
- Hashem Akbari researches cool roofs at Concordia University: https://www.tandfonline.com/doi/full/10.1080/17512549.2014.890541

Detroit

Detroit has implemented several green infrastructure (GSI) programs, with a particular focus on managing stormwater runoff. The **Detroit Water and Sewage Department (DWSD)** offers an **incentive program** for **private property owners** to manage their stormwater through GSI solutions. This program allows property owners to receive **credits on their water bills** for implementing stormwater management strategies, such as **detention and retention systems**. Developers are mandated by regulation to manage stormwater on properties of a certain size, and GSI is a key part of these requirements. For example, private developers can earn up to **40% credit** for detention and retention measures, and an additional **20% fixed credit** based on the type of infrastructure they install (e.g., green roofs, infiltration systems) as detailed in the city's **drainage charge guide**. This encourages private developers to manage stormwater on-site rather than simply relying on detention tanks. In addition to this, the city mandates that developers of properties **over five acres** must manage stormwater through retention or detention measures, making green infrastructure a key requirement for large-scale developments.

For **public sector projects**, the city also undertakes GSI installations, focusing on parks and large-scale neighbourhood projects, parks, and **green streets.** These are administered by the **Department of Public Works (DPW)** for street-level interventions, while the Water Department handles larger infrastructure like parks and vacant lot improvements.

Quantifying Co-benefits:

Detroit's focus is on quantifying the benefits of GSI in terms of stormwater management, tracking acres of stormwater **pre- and post-installation modeling**, and **sewer flow data** to assess the effectiveness of their projects. While the primary focus has been on stormwater management, the city is beginning to explore the **social and environmental co-benefits** of GSI, such as **urban heat island mitigation, biodiversity enhancement.**

GSI Practice	Water Quantity and Quality Benefits	Habitat and Wildlife Benefits	Community Benefits	Educational Benefits	Economic Benefits
Bioretention and Rain Gardens	💧	💧	💧	💧	💧
Cisterns	💧			💧	💧
Green Roofs	💧	💧	💧	💧	💧
Permeable Pavements	💧			💧	💧
Trees and Green Space	💧	💧	💧	💧	💧
Remove Impervious Cover	💧				💧

Figure 1. Benefits of Green Stormwater Infrastructure. From Detroit Water and Sewerage Department. https://detroitmi.gov/sites/detroitmi.localhost/files/2018-05/GSI Starter Guide - Benefits of GSI.pdf

The city's use of **native plants** in GSI projects ensures that ecological benefits, such as **pollinator habitat** and **bird nesting**, are integrated into designs. The city is also working to assess the **social benefits** of green infrastructure, using post-installation surveys to gather feedback from the community on how these measures impact local quality of life. However, there are challenges in linking all these co-benefits to specific funding or incentive structures, particularly as they relate to biodiversity and climate resilience.

Wider climate adaptation planning:

GSI plays an important role in Detroit's **climate adaptation and resilience efforts**. As part of the **Detroit Office of Sustainability's resilience plan**, GSI is integrated into the city's response to **bigger storms** and **more intense rainfall**. This is reflected in updated **design standards** for stormwater management. While there is a broad recognition of the importance of GSI in supporting resilience to climate impacts, especially related to stormwater and flooding, there are challenges with **inter-departmental collaboration**. For example, the Office of Sustainability and the Department of Public Works must work together in the context of GSI, but each department's goals and priorities can sometimes be siloed, hindering integrated implementation.

Adaptive Management and Tracking Progress:

Detroit is developing an **adaptive management** approach to track the performance of GSI projects over time. The city monitors **how much stormwater is being managed**, both publicly and privately, and is using **pre- and post-installation modelling** to assess the impacts of GSI systems. Additionally, the installation of **sewer meters** will help provide more accurate data on stormwater runoff and the effectiveness of interventions. The city has made significant progress with **vacant lot projects**, showing good performance in terms of stormwater management. However, there are challenges with **data collection** and ensuring that monitoring is comprehensive across both public and private sector installations.

The **annual reporting** to the state provides an overview of GSI progress, and resources like the **Detroit Stormwater website** offer information to the public about the city's stormwater management initiatives. This platform helps track the city's climate and public development activities related to GSI.

Challenges to GSI Implementation: Detroit faces several **challenges** in implementing green infrastructure, primarily related to:

- **Siloed departments**: There is a need for better coordination between departments, such as the Office of Sustainability, DWSD, and DPW, each of which has different roles in implementing GSI solutions. This can lead to fragmented efforts and delays.
- **Private sector adoption**: While there is a well-defined incentive structure for private developers, there is variability in how interested developers are in maximizing their GSI credits. Some developers may opt for the minimum requirements, which limits the full potential of green infrastructure on private properties.
- **Technical and structural limitations**: Retrofitting existing buildings, particularly those not designed for green roofs, presents challenges. While the city supports the use of **green roofs** and **blue roofs** (which manage rainwater runoff), the **structural capacity** of older buildings often limits the installation of such infrastructure.
- **Monitoring and data gaps**: Although the city has made strides in monitoring stormwater management, accurately tracking all co-benefits (such as heat reduction and biodiversity) remains a work in progress. The need for more **local data** on the effectiveness of green infrastructure in Detroit's unique environment is ongoing.

Differences public and private sector:

- **Public sector**: The city mandates stormwater management for large developments and installs GSI in public spaces (e.g., parks, vacant lots). The public sector is also responsible for tracking and reporting progress on GSI implementation.
- **Private sector**: Developers are incentivized to implement GSI through credits for stormwater detention and retention. Property owners also have the option to install GSI voluntarily, with guidance provided through the city's design manual and drainage charge guide. However, private developers may not always prioritize the full potential of GSI unless incentivized to do so.

Additional resources:

- Haapaniemi S, Doran P, Strassberg V, Isely E, Nordman E, Isely P, Glupker C, Viars S, Dierks S, Giese S, Noye L. (2023) Making Detroit's Green Stormwater Infrastructure Count: A Report. https://www.nature.org/content/dam/tnc/nature/en/documents/MI_MakingDetroitsGSICount.pdf

- Sanchez, L., & Reames, T. G. (2019). Cooling Detroit: A socio-spatial analysis of equity in green roofs as an urban heat island mitigation strategy. *Urban Forestry & Urban Greening*, *44*, 126331.

Philadelphia

GSI Programs and Incentive Programs in Philadelphia

- **Public GSI Programs**: Philadelphia has been implementing GSI for over a decade, primarily on public land and right-of-way areas like parks and streets. Their Green Stormwater Infrastructure (GSI) program includes vegetated systems such as rain gardens, tree trenches, and vegetated swales, which aim to manage stormwater runoff while also providing additional benefits like urban heat island (UHI) reduction and increased biodiversity.
- **Private Property Incentive Programs**:
    - The city has a grant program for private property owners to implement GSI on their land. However, these are limited, and the program primarily funds projects on private properties that incorporate some form of stormwater management.
    - Philadelphia also has **stormwater regulations** that mandate developments exceeding a certain threshold (15,000 square feet of disturbance, or 5,000 square feet in certain areas) to meet stormwater management requirements through GSI measures.
    - There are ongoing efforts to increase green components in private developments, which often lean toward less green, more gravel-based systems like large gravel boxes. The city is exploring how to steer these projects toward more sustainable, greener solutions.

Philadelphia's **Rain Check Program** incentivizes green infrastructure installation on private property, including rain gardens and downspout planters, by sharing costs between the city and property owners. This program allows for significant expansion of GI to manage rainwater but also introduces challenges around **maintenance and effectiveness**. One of the interviewees noted that while they personally installed a downspout planter, it failed during a major storm, underscoring potential vulnerabilities even in well-meaning projects.

The prioritization of **tree planting efforts** within neighbourhoods, based on environmental health and demographic indicators (e.g., heat exposure, asthma rates), plays a key role in how the City engages with **underserved communities**.

While the **Philly Tree Plan** is an essential tool for prioritizing tree planting efforts in high-need areas, operationally, the system is still mostly **first-come, first-served**, and **equity in resource allocation** remains a challenge.

However, there remains a gap in **adaptive management** or long-term monitoring of effectiveness—particularly in underserved neighbourhoods where resources are limited.

Co-benefits Quantification:

- Philadelphia acknowledges the potential co-benefits of GSI, such as urban heat island reduction, biodiversity enhancement, and public health improvement, but has not yet fully quantified these benefits.
- The city is in the early stages of trying to quantify co-benefits like heat reduction and biodiversity using tools such as the **GSI impacts calculator**, which is still in development. These tools aim to assess GSI's contributions to urban cooling and biodiversity, though they are not yet fully operational.

Tracking and Measurement:

- Currently, Philadelphia tracks key components such as the **species, size, and location** of trees planted as part of GSI systems, as well as the area of vegetated space added. This data will enable future assessments of biodiversity impacts.
- The **cooling analysis** and pilot programs, like the "cool roof" project in North Philadelphia, aim to assess how GSI contributes to urban heat reduction. These efforts are in the data collection phase, and the results are yet to be fully analyzed.

Challenges in Quantification:

- There is a lack of **dedicated expertise** on heat and biodiversity tracking, particularly within the **Water Department**. While there is significant interest from the **Office of Sustainability**, the absence of clear leadership on these issues makes it difficult to track or prioritize the co-benefits of GSI.
- A more structured, citywide approach to tracking heat and biodiversity specifically linked to GSI has not been developed yet.

Role of GSI in Climate Adaptation and Resilience Plans

- **Climate Resilience Plans**:
    - GSI is identified as a **key tool** in Philadelphia's climate resilience and climate adaptation strategies. For example, GSI is highlighted as a mechanism for cooling in **high heat stress areas**.
    - While the city does not have specific, measurable targets for co-benefits in its climate action plan, GSI is embedded in the city's **climate action playbook** (2021), which is currently being updated. GSI's role is presented as an **aspirational goal**, focusing on the broader environmental, economic, and social benefits of implementing green infrastructure.
- **Strategic Planning**:
    - Philadelphia's **strategic planning for climate resilience** includes efforts to maximize GSI in neighbourhoods most impacted by heat stress. This includes incorporating trees and other vegetative elements into GSI systems to maximize cooling benefits. However, this planning work takes **several years** to go from

design to implementation, so early-stage efforts are just beginning to see the light of day.

- **Collaborations**:
  - Coordination with other departments and organizations like **Parks and Rec** and the **Pennsylvania Horticultural Society** (PHS) is ongoing to ensure that GSI projects and tree planting efforts are complementary and not duplicative.
  - The city also integrates GSI efforts with its **Tree Plan**, which is focused on increasing tree canopy in high-heat areas. GSI projects are prioritized in neighbourhoods identified as most vulnerable to urban heat island effects.

Philadelphia's experience, as shared by the City Forester, highlights the importance of integrating trees into broader green infrastructure strategies to combat urban heat. While the Parks Department primarily focuses on tree canopy and arboriculture, green stormwater infrastructure (GSI) like rain gardens and vegetated tree pits are managed by other city departments like the Philadelphia Water Department. However, trees are an essential part of the GSI equation. Philadelphia's **Philly Tree Plan** prioritizes planting in areas with high heat exposure and poor tree canopy cover, recognizing the role of trees in reducing urban heat. While heat wasn't a primary messaging focus for the Parks Department, it was a key criterion in the Tree Plan's prioritization, underscoring the city's recognition of heat as a critical urban climate challenge.

- **Key Insights:**
  - **Urban Tree Canopy as a Cost-Effective Cooling Measure:** Trees are seen as a more affordable option compared to green roofs, with the added benefit of being able to generate even greater cooling benefits as they mature.
  - **GIS Modeling for Heat:** The U.S. Forest Service's i-Tree software suite is a tool used to measure tree benefits, but modeling changes in air temperature due to urban tree canopy expansion can be complex. One of the interviewees stressed that accurately predicting the cooling benefits of trees involves detailed data on species, growth, and environmental conditions.
  - The City Forester's work emphasizes managing **species diversity** in street trees, with a goal of preventing the over-planting of common, non-native species like maples and cherries. Additionally, their urban forestry efforts are connected to biodiversity goals, though more detailed biodiversity tracking (e.g., beyond tree species) is often handled by other partners like the **Academy of Natural Sciences**. However, **collaborative projects**, such as the restoration of **meadow habitats** in partnership with the **National Audubon Society**, help track **bird diversity** in targeted areas.

Adaptive Management and Tracking Progress

- **Progress Tracking**:
  - While Philadelphia has made efforts to track progress, especially in terms of **tree planting** and the area of **vegetated space** added, there is no comprehensive

system in place to track the impacts of GSI on **heat reduction** or **biodiversity** at the citywide level.
    - The **GSI impacts calculator** and ongoing research into heat island reduction are expected to help with these efforts, but comprehensive, citywide tracking is still in development.
- **Adaptive Management**:
    - Philadelphia is working to improve its adaptive management practices by collecting more data and refining its metrics. For example, ongoing studies (e.g., **cool pavement** and **cool roofs**) are gathering data on surface and ambient temperatures in pilot areas.
    - There is also interest in modeling future impacts of GSI at the **neighborhood scale**, including looking at how **green roofs** and **urban tree canopies** can reduce heat island effects over time.
    - The city is exploring the creation of a **digital twin of Philadelphia**, a project in its early stages that could help in tracking and forecasting the long-term impacts of GSI interventions across the city.

Tree Canopy Targets and Assessments:

The goal for **urban tree canopy** in Philadelphia has been set at **30%** after reassessing the originally recommended **40% target** (cited from an American Forests report that has since been retracted). T**ree canopy assessments** are carried out every **decade**, with data-driven decisions about canopy coverage made based on characteristics like **heat exposure** and community health metrics. However, **annual assessments** for canopy change might not provide significant insights due to the slow growth of trees and the time it takes for urban canopy management to show measurable progress. Instead, larger-scale, **longer-term evaluations** (e.g., 10-year assessments) are more effective for measuring progress.

Broader biodiversity assessments, including metrics for **wildlife and plant diversity**, are not routinely conducted in urban forestry. The **Parks Department**'s focus is mainly on the stewardship of tree canopy, with a concerted effort to phase out **invasive species** in natural areas, but not much beyond that. For more expansive biodiversity studies, the department coordinates with external experts and partners.

Adaptive Management and Long-Term Monitoring:

The Parks Department does not have a systematic **adaptive management** approach for urban forestry. **Success** is primarily measured by **work orders** (e.g., tree planting and service requests) rather than the achievement of long-term goals or effectiveness of interventions. This reactive, rather than proactive, approach is especially noticeable in terms of **sustainable canopy growth** and addressing the **slow-paced changes** in urban tree cover.

Challenges to Implementation

- **Siloed Departments and Lack of Dedicated Resources**:

    - A key challenge is the lack of a **centralized or dedicated program** for tracking and coordinating heat and biodiversity impacts, which are primarily the responsibility of the **Sustainability Office** rather than the **Water Department**. This siloed approach has made it difficult to focus on quantifying GSI co-benefits.
    - The absence of a dedicated **heat expert** and the limited tracking of biodiversity make it harder to make the case for GSI's broader impacts, particularly its contributions to urban cooling and biodiversity.
- **Private Property Implementation**:
    - Implementing GSI on **private properties** presents challenges, as private landowners are not always incentivized to prioritize greening. Many projects proposed on private land involve stormwater solutions that prioritize detention rather than green infrastructure.
    - The city is working on finding ways to incentivize more **green** stormwater solutions on private properties, but this is an ongoing process. The availability of **grant funding** and revisions to the **stormwater regulations** may help increase the adoption of more sustainable solutions on private land.

Additional resources:

Philly tree plan: **https://www.phila.gov/media/20230223005617/Philly-Tree-Plan.pdf**

Advocacy - Sustainable Business Network of Greater Philadelphia - See the Research and & Publications page.

https://www.phila.gov/media/20230912155935/GSI-Cooling-Analysis-Report-202309.pdf

Climate action playbook (2021) we're basically doing an update of that right now.
Green infrastructure is called out as an approach we want to use but it is a high-level aspirational report. https://www.phila.gov/media/20210113125627/Philadelphia-Climate-Action-Playbook.pdf
PWD also has a very small ecological restoration team. Not sure if you would consider their work green stormwater infrastructure, but it is green infrastructure.
https://water.phila.gov/projects/type/ecological-restoration/
This is the research we are trying to build on to develop a model that could help us understand how these interventions could impact heat islands: https://xiaojianggis.github.io/pedheat/

NOAA GFDL is also working on a heat model with us: https://www.gfdl.noaa.gov/heat-and-health-downscaling/

Sustainable Funding and Financing:
https://arch.umd.edu/sites/default/files/docs/publications/PA_Green%20City%20Clean%20Waters_FINAL.pdf