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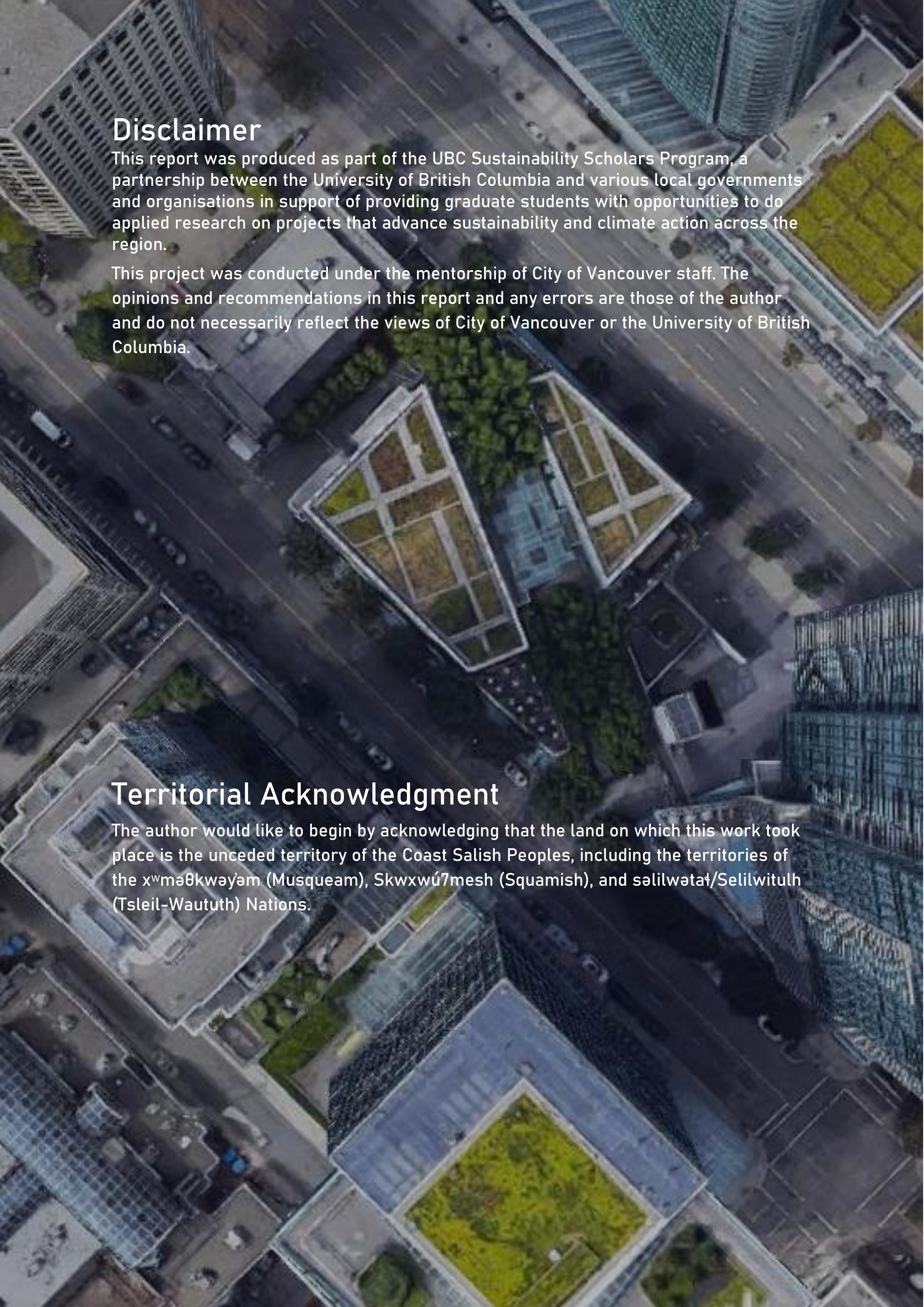
Addressing Urban Heat Reduction and Biodiversity Enhancement with Green Rainwater Infrastructure

Research on existing GRI models, initiatives, and adaptive management strategies, and associated recommendations, to advance GRI co-benefits for the City of Vancouver

Prepared by
Ana Polgar, Sustainability Scholar 2024
Doctoral Student in Planning at *University of British Columbia*
Prepared for
Gord Tycho
Senior Sustainability Planner at *City of Vancouver*



Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organisations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability and climate action across the region.

This project was conducted under the mentorship of City of Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of City of Vancouver or the University of British Columbia.

Territorial Acknowledgment

The author would like to begin by acknowledging that the land on which this work took place is the unceded territory of the Coast Salish Peoples, including the territories of the xʷməθkʷəy̓əm (Musqueam), Skwxwú7mesh (Squamish), and səlilwətaɬ/Selilwitulh (Tsleil-Waututh) Nations.

EXECUTIVE SUMMARY

This report presents a series of recommendations for the City of Vancouver (CoV) aimed at utilizing green rainwater infrastructure (GRI)[1] to address urban heat reduction, biodiversity enhancement, and rainwater management, informed by a systematic literature review and insights gathered from expert interviews with staff working in in Detroit, Toronto, Philadelphia and with the GI Leadership Exchange and The Nature Conservancy. The study, conducted as part of a three-month Sustainability Scholars project at the University of British Columbia, serves as a foundation for the City of Vancouver's Sustainability Department as it prepares for a proposed quantitative study exploring the connection between GRI and climate change adaptation.

The existing literature and interviews highlight the effectiveness of GRI in mitigating urban heat, enhancing biodiversity, and managing rainwater, with models like GIST, GISP, ENVI-met, and i-Tree demonstrating significant benefits. However, these models often require adjustment to fit Vancouver's unique climatic, topographical, and urban context. The following key insights emerged from the case studies and literature:

1. **Effectiveness of GRI**: The successful implementation of GRI in other cities has demonstrated its capacity to reduce local surface temperatures, enhance biodiversity, and manage stormwater. Vancouver's temperate rainforest climate and varied microclimates necessitate a tailored study to validate the impacts of different GRI types on heat reduction, air quality, and biodiversity.
2. **Challenges in Data Collection and Monitoring**: Effective tracking of GRI impacts is hindered by data gaps, outdated methodologies, and resource constraints. Vancouver should invest in modern, scalable systems for monitoring and data integration to bridge these gaps.
3. **Equity Considerations**: Ensuring that the benefits of GRI are equitably distributed across neighbourhoods, particularly in underserved areas, is critical. Prioritizing GRI projects in vulnerable neighbourhoods will help address disparities in access to green space and climate resilience.

Based on lessons learned from Toronto, Detroit, and Philadelphia, as well as the literature review, the following recommendations are made for Vancouver to enhance its climate adaptation efforts through GRI:

1. **City-Specific Modeling**: A localized Natural Asset Valuation Study, incorporating models such as ENVI-met and i-Tree, should be considered to assess GRI's effectiveness in Vancouver's specific context. This includes:
    a. Modeling the impacts of urban forests and green roofs.
    b. Addressing Vancouver's unique challenges such as urban densification, steep slopes and proximity to water bodies.
    c. Conducting an equity analysis to ensure benefits are spread across all socioeconomic groups.

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[1] Also known as Green Stormwater Infrastructure (GSI) and related terms Green-Blue (or Blue-Green) Infrastructure (G(B)I/BGI) and the more holistic umbrella term Nature-based Solutions (NBS)

2. **Create a Comprehensive, Citywide GRI Data Tracking System**: Vancouver should consider establishing a robust, scalable system to monitor GRI impacts across both public and private lands. This system should integrate data on heat reduction, biodiversity, and stormwater management, and include digital tools like GIS mapping and public-facing dashboards to ensure transparency and public engagement.
3. **Launch Community-Led and Private Property Incentive Programs**: Drawing inspiration from successful programs in other cities:
    a. **Community-Led Initiatives**: Consider establishing a funding program for community-driven GRI projects, focusing on biodiversity and public visibility.
    b. **Private Property Incentives**: Consider developing financial incentives for private property owners to install GRI features, such as green roofs and rain gardens, with a focus on quality and long-term environmental benefits.
4. **Establish Long-Term Monitoring and Maintenance Systems**: A critical challenge across cities was the sustainability of GRI initiatives. Vancouver should consider:
    a. Setting up a monitoring and maintenance program that tracks GRI performance and includes regular inspections.
    b. Creating a dedicated fund or exploring public-private partnerships to support the ongoing maintenance of GRI installations.
5. **Update Urban Design Standards**: Consider revising building codes and urban design standards to encourage GRI in new developments, including mandates for green roofs and permeable pavements. These updates should balance flexibility with measurable environmental outcomes.
6. **Proactive Adaptive Management**: Consider shifting from reactive to proactive management of GRI programs by:
    a. Setting clear, SMART goals for GRI initiatives.
    b. Regularly evaluating and adjusting strategies based on performance data.
    c. Involving communities in adaptive management through feedback mechanisms and participatory planning processes.
7. **Strengthen Inter-Departmental Collaboration**: Consider leveraging cross-departmental teams to integrate GRI across city planning, parks, water, and housing departments. This will ensure coherent strategies and effective resource allocation.
8. **Foster External Partnerships**: Consider leveraging external expertise from academic institutions, NGOs, and other stakeholders to support data collection, model calibration, and community engagement.

The recommendations are phased as follows:

- **Short-Term**: Consider developing and piloting data tracking systems and establish baseline models for Vancouver's specific context.
- **Medium-Term**: Subject to policy direction, consider developing potential incentive programs, updating urban design standards to encourage GRI in new developments, establishing long-term monitoring frameworks, and shifting to proactive adaptive management practices.
- **Long-Term**: Subject to policy direction, consider focusing on real-time monitoring tools, advanced data integration, and citywide scaling of GRI programs, ensuring ongoing community and stakeholder involvement.

CONTENTS

LIST OF ABBREVIATIONS

CCAS	City of Vancouver Climate Change Adaptation Strategy, 2024
CoV	City of Vancouver
CSO	combined sewer overflows
GRI	Green Rainwater Infrastructure
GSI	Green Stormwater Infrastructure
HWP	Healthy Waters Plan
IRMP	Integrated Rainwater Management Plan
IUWM	integrated urban water management
LST	land surface temperature
NDVI	Normalized Difference Vegetation Index
RCS	City of Vancouver Rain City Strategy, 2019
TCI	Transversal Connectivity Index
UFS	City of Vancouver Urban Forestry Strategy, 2018
UHI	urban heat island

1. INTRODUCTION

BACKGROUND, PROBLEM STATEMENT, PROJECT OBJECTIVES

The City of Vancouver is facing several challenges with respect to climate adaptation. Population growth, urban development practices, and climate change are increasing urban heat, reducing biodiversity, raising sea levels, and increasing the frequency and intensity of rainfall, which is straining the city's aging sewer system and leading to chronic water quality impacts on receiving waters such as False Creek and the Fraser River.

The Rain City Strategy (RCS, 2019), which was developed in response to the 2012 Climate Change Adaptation Strategy (CCAS, updated in 2024), calls for a shift to a more holistic and integrated approach for achieving the goals of improved water quality, increased resilience, and enhanced liveability. This ambitious approach treats rainwater as a valuable resource and mimics the natural hydrologic cycle by capturing and treating rainwater where it lands using green rainwater infrastructure (GRI), such as green roof systems and ground infiltration systems. GRI tools also exhibit multifunctionality and have been proven to deliver other climate adaptation benefits.

The purpose of this project is to better understand the role that GRI can play in addressing two specific adaptation challenges: **urban heat reduction and biodiversity enhancement**. Through best practices research, subject matter expert interviews, and case studies from other jurisdictions that currently use GRI to advance climate adaptation objectives in the areas of urban heat reduction, biodiversity enhancement, and rainwater management, this study provides recommendations for the City of Vancouver to better justify and utilize GRI in their own climate adaptation objectives.

The specific objectives for this project are listed below:

1. To help the Scholar understand the City of Vancouver context and begin creating the final report:
    a. Review and summarise the City of Vancouver's climate adaptation challenges, strategies and bylaws, with particular focus on urban heat and biodiversity, and;
    b. Literature review and brief summary of major types of GRI systems.
2. Literature review and case study research on a minimum of 2 jurisdictions and a summary of findings that:
    a. Demonstrate that GRI tools can contribute to urban heat reduction and biodiversity enhancement;
    b. Demonstrate the role of GRI within adaptation strategies aimed at addressing urban heat reduction and biodiversity enhancement (including supporting studies, design modifications, equity objectives advanced), and;
    c. Document adaptive management initiatives (including measurement of progress) and any other supporting programs or actions (bylaws, funding programs, tools, online maps, or other key lessons learned).
3. Based on the research provide a list of recommendations and actions the City can take to demonstrate:
    a. How GRI tools can be further justified to contribute to urban heat reduction and biodiversity enhancement;
    b. Improve implementation of GRI, and;
    c. Improve adaptive management of GRI, including monitoring and reporting on GRI initiatives. Recommendations may include, as example: Supporting studies, Bylaw changes, supporting tool development (online maps, etc.), other.

2. METHODOLOGY

This study was conducted in the context of a three-month Sustainability Scholars project. The author of this study is a PhD student at the School of Community and Regional Planning at the University of British Columbia. This study was borne out of the need to determine the rationale and scope for a potential quantitative study of the connection between GRI and both urban heat and biodiversity impacts in the context of climate change adaptation that may be conducted by the City of Vancouver's Sustainability Department.

The methodology of this study consists of three parts: 1) contextual understanding 2) academic literature review, and 3) case study research.

2.1 CONTEXTUAL UNDERSTANDING

The first part involves gaining a comprehensive understanding of the context in which the study is being conducted. It includes a grey literature analysis of key City of Vancouver documents and conversations with key individuals knowledgeable about Vancouver's climate adaptation challenges, strategies, and bylaws. The focus will be on urban heat and biodiversity. This part provides the necessary background and sets the stage for the subsequent parts of the study.

2.2 LITERATURE REVIEW

The second part involves a scoping review of academic literature on two main topics. A review of the published academic literature was performed to identify primary research on the major types of GRI and how GRI might contribute to urban heat reduction and biodiversity enhancement. Web of Science, and SCOPUS, were searched from their inception date to April 2024. The software Covidence was used to screen the academic literature identified through the search and decide to include or exclude them based on their relevance.

Academic literature review search strategy: ("green stormwater infrastructure" AND "urban heat" OR "biodiversity") on SCOPUS yielded 14 results. ("green stormwater infrastructure" AND "urban heat" OR "green stormwater infrastructure" AND "biodiversity") on Web of Science yielded 11 results. Additional records were found through hand search of related concepts, such as Green-Blue Infrastructure, Low Impact Development, Sustainable Urban Drainage Systems, and Nature-Based Solutions.

In addition to academic literature, grey literature sources were examined such as government agency websites and reports from other jurisdictions in North America.

The reviewed tools were categorised according to their applicability to urban heat reduction, biodiversity enhancement, and/or other co-benefits. Next, the relevant parameters for each category were described from each tool, noting the geography of their case study, the key findings and applicability to specific GRI.

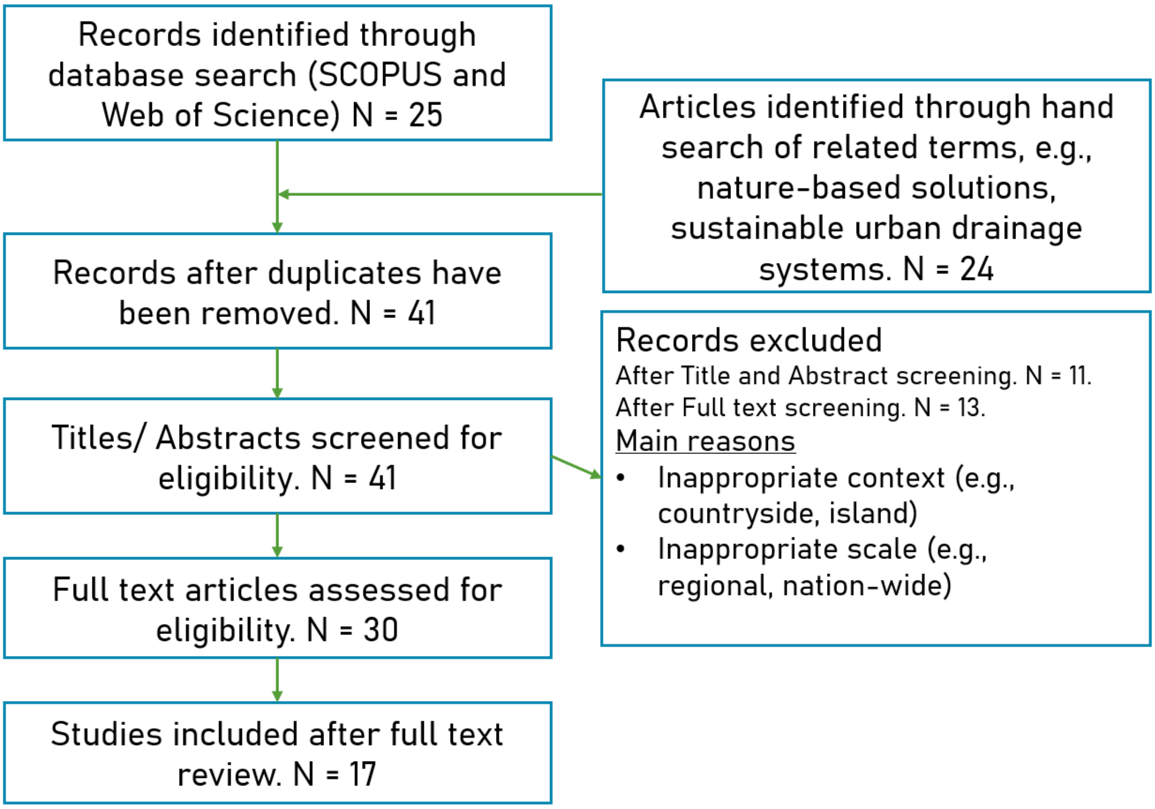


Figure 1. PRISMA Flow diagram displaying the systematic review process for academic literature.

2.3 CASE STUDY RESEARCH

This study employed a qualitative case study approach, conducting semi-structured interviews with subject matter experts to explore the role of GRI in urban heat reduction, biodiversity enhancement, and other co-benefits. A total of **7 semi-structured interviews** were conducted, involving **10 interviewees** from three cities—Detroit, Toronto, and Philadelphia—and two key knowledge organizations: the Green Infrastructure Leadership Exchange and The Nature Conservancy.

The interviewees were selected from a variety of municipal departments, including water, sustainability, and forestry, as well as from organizations directly involved in GRI initiatives. These interviews were conducted remotely via **Microsoft Teams** and lasted between **30 minutes to one hour** each. The interviews were audio-recorded to ensure an accurate transcription of responses and to minimize the risk of missing critical insights.

The interview questions were designed to explore three main themes:

1. **Awareness and Evidence of GRI Impact**: The first set of questions aimed to assess participants' knowledge of studies demonstrating the effectiveness of GRI in urban heat reduction and biodiversity enhancement.
2. **Integration of GRI in Local Contexts and Organizational Strategies**: The second set of questions focused on the integration of GRI measures within the interviewees' respective cities and organizations. This included inquiries about specific tools, strategies, and their role in larger climate change adaptation plans.

3. **Adaptive management and GRI:** The final set of questions seeks to explore the use of adaptive management in the context of GRI. Adaptive management is a dynamic process where actions are continuously monitored, evaluated, and adjusted based on their effectiveness to improve outcomes over time. This section is designed to assess how organizations or cities apply adaptive management principles to optimize GRI implementation.

The interview question framework is included in Appendix II.

3. CLIMATE CHANGE ADAPTATION IN THE CITY OF VANCOUVER

3.1 CHALLENGES: URBAN HEAT, BIODIVERSITY, RAINWATER MANAGEMENT

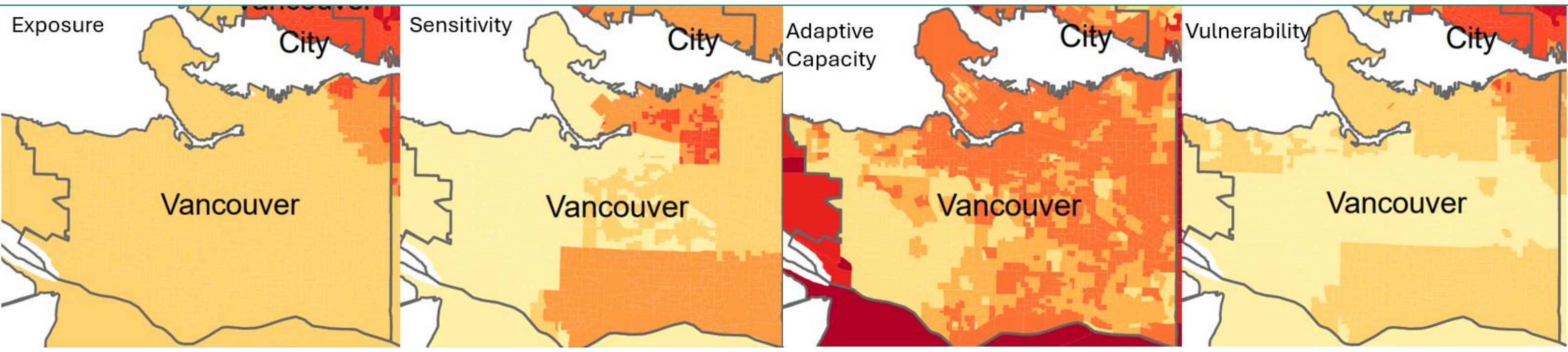
The climate change adaptation challenges of the City of Vancouver that fall in the scope of this study are 1) **increasing summer temperatures and the urban heat island effect**; 2) **the loss of biodiversity through the loss and fragmentation of habitats,** and; 3) **the increase in extreme rain events and pressure on existing drainage systems**.

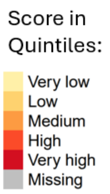
3.1.1 URBAN HEAT

The **Urban Heat Island** (UHI) effect refers to the elevated temperatures found in urban areas compared to surrounding rural areas. Buildings, roads, and other infrastructure absorb and re-emit more heat than natural landscapes like forests or water bodies. In cities, limited greenspace, minimized airflow, heat sources (e.g., air conditioning exhaust, vehicles, industrial processes), and an abundance of impervious surfaces—such as asphalt and concrete—trap heat. Internal heat challenges within buildings exacerbate these effects, as their structural characteristics—such as insufficient insulation, outdated cooling systems, and inadequate ventilation—fail to counteract the higher surface temperatures experienced outside. Consequently, maintaining comfortable interior temperatures becomes even more difficult, particularly during the warmer months, as the compounded heat from both the urban environment and within the buildings creates uncomfortable living conditions.

The Lower Mainland region, including Vancouver, is increasingly experiencing heat waves that vary in length and intensity across different areas (Henderson, et al. 2022; Stewart et al. 2017). This phenomenon is further complicated by the city's traditional housing designs, which prioritize heat retention for winter climates rather than facilitating heat dissipation in summer. Combined with the heat-retaining qualities of roads, buildings, sidewalks, and other infrastructure, these design choices exacerbate the impact of rising temperatures associated with climate change. This design is particularly problematic given the rising temperatures associated with climate change. Vancouver Coastal Health's assessment (Yu et al., 2020) highlights the vulnerability of certain neighbourhoods, especially in the eastern and southern parts of Vancouver (Figure 2). These areas have a higher sensitivity and lower adaptive capacity to extreme heat, making them more susceptible to its adverse effects. Populations such as older adults and individuals with pre-existing health conditions are particularly sensitive to extreme heat impacts, while living conditions often dictate the capacity to cope during heatwaves. Low-income residents frequently live in older housing without modern cooling systems and may lack the financial resources to install air conditioning or heat pumps. Renters face additional challenges in implementing cooling solutions due to restrictions imposed by leases and building policies.

Neighborhoods with more heat-absorbing surfaces and insufficient tree canopy and green space are more severely affected by the UHI effect. The areas south of **Marpole along the Fraser River, in the Downtown East side, and in the False Creek Flats in Strathcona** represent neighbourhoods impacted by four significant socio-ecological indicators: lower canopy cover, a lower score based on the local restorative nature index (based on deVisscher et al., 2022), lower-income households with less access to cooling measures, and less ability to address urban heat island with plantings due to poor soils and impervious surfaces. As noted, “Impermeability presents challenges for Vancouver’s urban forest by limiting i) space to plant new or replacement trees; ii) soil volume for existing and new trees; and iii) rainwater soil infiltration and storage” (UFS, 2018).





Exposure: Annual average of daily maximum temperature (>25 degrees Celsius); **Sensitivity:** the degree to which people can be harmed by exposure (based on age (<5, >65yrs), pre-existing health conditions); **Adaptive capacity:** the degree to which the community can mitigate the potential for harm (based on socioeconomic data, race/ethnicity, built environment, social cohesion, institutional capacity); **Vulnerability:** sum scores of each previous category.

Figure 2. Exposure, sensitivity, adaptive capacity and vulnerability to extreme heat in Vancouver (adapted from Yu et al., 2022).

3.1.2 BIODIVERSITY

Biodiversity refers to the variety of life across ecosystems, species, and genetic variation within species. It is essential for maintaining ecological balance, providing resilience against disturbances and climate change, as more species increase the likelihood that one will have traits that enable adaptation and survival in the face of such disturbances. Biodiversity also provides resources like food and clean water, and supports human well-being. It depends heavily on habitat availability and connectivity—allowing species to move freely between fragmented habitats via corridors. Without these connections, populations become isolated, leading to declines in biodiversity.

Vancouver’s urban landscape is home to a variety of habitats including forests, wetlands, streams, meadows, and marine environments, all of which host unique species and face differing levels of risk. Bald eagles and songbirds thrive in the forests of Stanley Park and Pacific Spirit, while wetlands sustain native frogs and young growing fish.

Yet, urban growth in the form of sprawl and infilling, coupled with the loss and fragmentation of green space and the channelization and piping of natural streams, has resulted in significant landscape and habitat transformations within city boundaries, negatively impacting biodiversity through habitat loss, fragmentation and degradation.

The *Vancouver Biodiversity Strategy* (2016) provides a snapshot of the current state, documenting key ecosystems and their challenges, but lacks normative targets for future habitat restoration or connectivity improvements.

Habitat Type	Dominant locations	Species	Risk Level	Risk Explanation
Forests	Stanley Park, Fraserview Golf Course, Everett Crowley Park, Musqueam Park, and Jericho Beach Park make up 66% of the urban forest.	Native squirrels, migrating songbirds, bald eagles, various forest-dependent birds, occasional historic strays of large native mammals (e.g., deer, elk, bear, wolf, cougar).	*Low to moderate*	Forests are relatively abundant, but some species of birds dependent on forests are declining. Large native mammals likely no longer occupy areas within the city. Any observed strays of large native mammals likely indicate potential habitat pressures on habitat areas outside the city boundary.
Wetlands	Lost Lagoon, Beaver Lake, Trout Lake, Jericho Ponds, Sanctuary Pond in Hastings Park	Native frogs (e.g., Pacific tree frogs, red-legged frogs), forage fish (e.g., Pacific herring, surf smelt, Pacific sand lance, eulachon), native bees (e.g., western bumblebee)	*High*	Rare due to urban development, impacting various species including native frogs and forage fish. Native bees are declining due to habitat loss and other factors. Species at risk include Johnson's hairstreak butterfly, Vancouver Island beggar ticks, western painted turtle.
Streams	Still, Musqueam, Vivian, Spanish Bank, Beaver Creeks	Salmon (coho, chum), trout (cutthroat), Pacific tree frogs	*High*	Remnant populations of salmon and trout exist, but they face threats such as habitat degradation and pollution. Some creeks support the only remaining populations of certain salmon species.
Meadows	Parks, roadsides, abandoned sites	Native bees, butterflies, grasses, wildflowers	*Uncommon*	Meadows are uncommon but important for birds and insects. Some species at risk occur in meadows.
Subtidal Habitats	Burrard Inlet, English Bay, Coal Harbour, First Narrows, Brockton Point	Forage fish (e.g., Pacific herring, surf smelt, Pacific sand lance, eulachon), whales, dolphins, and other marine species	*Moderate*	While subtidal habitats are mostly intact, some modifications to intertidal habitats have occurred. Forage fish populations are declining significantly, affecting the marine food web.
Intertidal Habitats	Stanley Park shoreline, Spanish Banks, Musqueam Marsh	Various marine species, shorebirds	*Moderate*	Intertidal habitats are stable but under threat from industrial development, oil spills, shoreline armouring, intensive recreation use, and sea level rise.
Ponds and ditches	Southlands and Jericho Beach Park	Pacific tree frogs, other amphibians	*Moderate*	Relatively abundant populations of Pacific tree frogs, but still vulnerable to habitat loss and degradation.
Urban parks and gardens	Stanley Park, Everett Crowley Park, Hastings Park, Jericho Beach Park, Musqueam Park	Various birds, native bees, occasional mammals	*Low to moderate*	Urban parks provide habitat for various bird species, some populations are declining. However, these parks also serve as refuges for urban wildlife. Native bees are declining due to habitat loss, pesticides, and disease.

Table 1. Overview of habitats of Vancouver and their associated locations, species and risks.

The absence of robust corridors exacerbates the impacts of habitat fragmentation, limiting species movement and reducing genetic diversity. Challenges to Vancouver's biodiversity include invasive species that outcompete native plants and animals, human-driven disturbances that replace natural processes, and pollution affecting air, soil, and water quality. Climate change adds further stress through rising sea levels, ocean acidification, and altered precipitation patterns.

Metro Vancouver's Sensitive Ecosystem Inventory displays ecologically significant and relatively unmodified sensitive ecosystems such as wetlands, older forests, and woodlands. It also includes some human-modified ecosystems with high ecological value such as old fields and young forests. The online map can be used to show park boundaries, protected areas as well as ecosystem losses and sensitive ecosystems. This is a valuable inventory for environmental planning, including GRI initiatives that aim to enhance biodiversity through improving habitat availability, quality and connectivity.

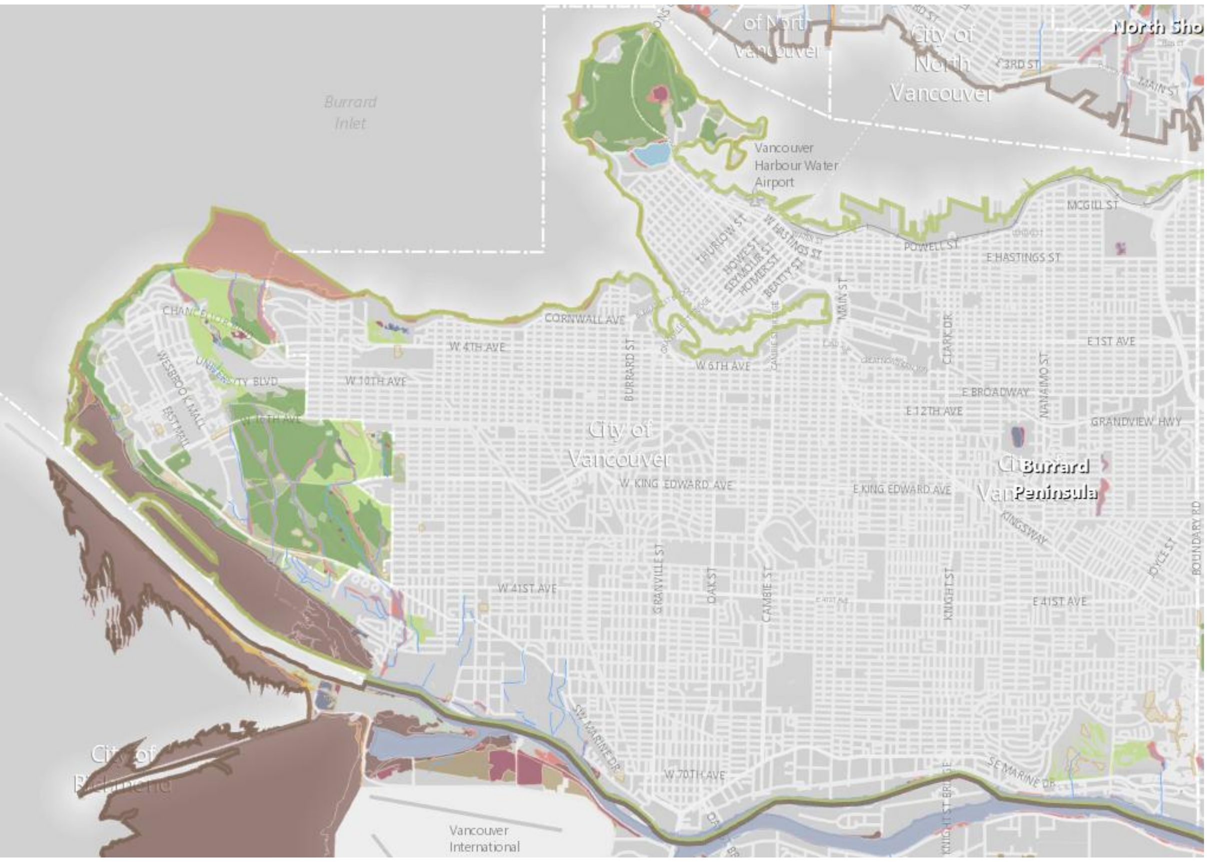


Figure 3. Sensitive Ecosystem Inventory (Metro Vancouver's Open Data Catalogue).

3.1.3 RAINWATER MANAGEMENT

Rainwater management refers to the planning and implementation of strategies to handle rainwater. It is important because different management approaches have different environmental, social, and economic consequences. Traditional approaches that replace natural streams and vegetation with impervious surfaces, pipes, and treatment plants tend to disrupt the natural water cycle. These approaches redirect rainwater overland instead of allowing it to infiltrate into the ground, leading to a faster and more concentrated runoff. This runoff picks up pollutants and can result in greater erosion and have a detrimental impact to receiving waters and aquatic ecosystems.

Vancouver faces several challenges in managing rainwater. The increase in urban development has led to more impermeable surfaces and a reduction in mature trees and plants, resulting in increased urban rainwater runoff. This issue is exacerbated by population growth and changes in density, which put additional strain on the combined sewer and drainage system. Unlike sewer back-ups, which occur when water flows back into buildings due to overwhelmed drainage systems, combined sewer overflows (CSOs) happen when excessive stormwater in the combined sewer system exceeds capacity, leading to untreated wastewater and stormwater being released directly into the environment because the sanitary sewer treatment plant cannot handle the volume. Despite efforts to address CSOs since the 1970s, this continues to be a challenge due to population growth, increasing precipitation, fiscal limitations, and the pace of implementation. Aging and deteriorating water infrastructure further compound these challenges, as renewal needs put pressure on repair and maintenance efforts (RCS, 2019).

Climate change has led to rising sea levels, more intense rainstorms and a shift from snow to rain in winter, leading to increased overland flooding and more frequent CSOs. These changes will heighten risks of:

- damage to buildings and infrastructure.
- mold-related health impacts and displacement of tenant and businesses at ground. and basement level.
- reduced public access to streets and outdoor recreation spaces.
- disrupted traffic patterns.
- landslides.
- compromised water quality in receiving water bodies.

Urban stormwater runoff, which picks up pollutants from roofs and roads, contaminates the aquatic environment, posing a threat to fish and other aquatic species. Changing precipitation patterns leading to an earlier freshet may cause additional stress to these species (CCAS, 2014). Vulnerable populations, including those experiencing homelessness, face heightened risks during extreme weather events.

The financial implications of upgrading rainwater management systems to meet urban growth, improve water quality, adapt to climate change, and address infrastructure renewal are substantial, with costs projected in the billions, making water-related infrastructure an increasingly important affordability issue in Vancouver (RCS, 2019). Given this context, quantifying the benefits of GRI assets for urban heat reduction and biodiversity enhancement is critical to fostering an increase in sustainable, multifunctional rainwater management solutions.

3.2 ADAPTATION GOALS AND SUPPORTING STRATEGIES, BYLAWS, POLICIES

The City of Vancouver is addressing these climate adaptation challenges by developing and implementing various strategies, policies, by-laws, and monitoring plans at citywide and local-level scales, on both public and private lands. The following section provides an overview of these policy tools. Each strategy addresses a particular aspect of adaptation, and where applicable, it is categorized based on whether it applies to public spaces, private properties, or citywide initiatives. It is not an exhaustive list.

3.2.1 STRATEGIES, BYLAWS, AND POLICIES FOR PUBLIC LANDS

OVERVIEW

The City of Vancouver has implemented a comprehensive array of strategies, bylaws, and policies specifically targeting public lands, including streets, boulevards, parks, and municipal buildings. Central to these efforts are the **Rain City Strategy (RCS)**, which emphasizes the adoption of GRI solutions to manage rainwater, enhance biodiversity, and mitigate flooding risks; the **Urban Forest Strategy (UFS)** which aims to expand the tree canopy, addressing heat impacts and improving air quality; **the Biodiversity Strategy** which focuses on strengthening natural ecosystems and urban biodiversity through park acquisition and ecological improvements; and the **Climate Change Adaptation Strategy (CCAS)** which promotes the integration of nature-based solutions in public spaces to tackle urban heat and extreme rainfall challenges.

RAIN CITY STRATEGY (RCS)

The ***Rain City Strategy (2019)*** is a key initiative that builds upon other citywide policies such as the **Integrated Rainwater Management Plan (IRMP, 2016)**, setting ambitious goals for rainwater management and broader GRI implementation. This strategy focuses on integrating GRI solutions across multiple urban sectors to reduce flood risks, enhance biodiversity, and promote water resilience. The implementation section of the RCS is divided into three areas: Buildings and Sites (private), Streets and Public Spaces (public), and Parks and Beaches (public). The latter two action plans address larger scale, public spaces. RCS targets for public property include:

- **Rainwater Capture and Treatment**: Capture, treat, and manage rainwater from at least 48 mm of rainfall per day through methods like infiltration, evapotranspiration, and reuse.
- **Restoration and Enhancement of Natural Areas**: Restoration or enhancement of 25 hectares of natural areas, including forests, to improve biodiversity and resilience, with 34 hectares successfully restored by 2021.

Additional actions under the RCS include:

- **New Capital Projects GRI Integration Program**: Focused on integrating GRI strategies in streets and public spaces.
- **Green Streets Program**: Promotes planting native plants and enhancing habitat connectivity as part of the Biodiversity Strategy.
- **Combined Sewer System Separation**: Reduces pollutants entering water bodies, enhancing overall water quality.

- As part of the ongoing work in the **Healthy Waters Plan (HWP)**, new rainwater management targets for private properties may be introduced, further integrating water resilience into the city's adaptation efforts.

URBAN FOREST STRATEGY

The **Urban Forest Strategy** focuses on expanding and managing the city's tree canopy to mitigate the impacts of heat, enhance biodiversity, and improve air quality. This includes actions across both public and private land:

- **Urban Tree Canopy Goal**: Increasing tree canopy coverage to 30% by 2050, with targeted efforts in neighbourhoods with below-average canopy coverage.
  - 8: Increase street tree planting in the Downtown Eastside, Marpole, False Creek Flats, and other priority neighbourhoods with below average urban forest cover.
  - 10: Partner with First Nations, the Vancouver School Board, and other groups to support tree planting on private and institutional lands.
  - 19: Increase canopy cover in conjunction with green infrastructure initiatives to improve rainfall interception and infiltration.
- **Tree Planting and Maintenance**: Installing 20-40 new tree pits annually, especially in low-canopy areas, with enhanced soil volume for optimal tree growth.
- **Park Stewards Program**: Engaging volunteers in the stewardship of urban forests, fostering community involvement in maintaining Vancouver's green spaces.
- **Monitoring**:
  - 25: Replace the VanTree inventory and work order management software with a GIS-based tree information system.
  - 34: Develop and share educational materials that highlight Vancouver's urban forest.
  - 42: Measure Vancouver's urban forest canopy every 5 years using LiDAR and i-Tree methods.
  - 43: Track trees planted and managed across the city on an annual basis.
  - 44. Map and assess the distribution and condition of native forests.
  - Following update to the Tree Bylaw, develop a monitoring approach to track changes to tree coverage on private land as a result of permitted tree removal.

The strategy also supports private landowners in planting and retaining trees, encouraging habitat connectivity across the city.

BIODIVERSITY STRATEGY

The **Biodiversity Strategy** is focused on enhancing Vancouver's natural ecosystems and improving urban biodiversity through park acquisition, tree planting, and creating ecological connections. Key actions include:

- Expanding the city's ecological network through park acquisition, tree planting, and development planning.
- Incorporating natural features such as pollinator meadows into new parks and redeveloping public lands.

- Developing a citywide biodiversity monitoring plan.
- Addressing invasive species through targeted management and control within city parks (Invasive Species Action Plan).

CLIMATE CHANGE ADAPTATION STRATEGY (CCAS)

The **Climate Change Adaptation Strategy (CCAS)** is a citywide initiative that includes both public and private sector actions aimed at mitigating the impacts of extreme heat, poor air quality, drought, extreme rainfall, and other climate change effects such as sea level rise. Key actions relevant to urban heat and rainwater management include:

Extreme Heat

- **H3.1**: Continuing to advance tree planting on public land to increase the urban forest canopy to 30% by 2050, with a focus on neighbourhoods with below-average canopy coverage. This action contributes to cooling urban spaces and mitigating heat island effects.
- **H3.5**: Following updates to the **Tree Bylaw**, developing a monitoring approach to track changes in tree coverage on private land due to permitted tree removals. This action helps ensure ongoing canopy protection and sustainable tree management.

For heat, the green buildings group is working on heat related issues for buildings on public and private property. The **CCAS** continues to evolve to incorporate emerging insights and new targets.

Extreme Rainfall

- **R2.3:** Incorporate GRI into three hectares of street area in City right-of-way reconstruction projects.
- **R2.4** Developing methods to quantify and communicate the service provision value of GRI for benefits such as improved drainage, enhanced liveability, and urban heat island mitigation. This approach will help stakeholders understand the broader value of GRI solutions in managing stormwater.
- **R3.1** Pilot coordination of Adopt a Catch Basin program with Resilient neighbourhoods Program to expand community participation and public awareness.

VANCOUVER PLAN

The **Vancouver Plan** emphasizes the integration of nature-based solutions and green infrastructure across the city. This includes:

- Building and site design that provides space for nature, and contributes to the capture, retention, and infiltration of rainwater.
- Developing a citywide network of blue-green systems, to be co-located with greenways[2] where possible.

[2] See location of greenways on Figure 5.

- 3.3.1 Climate Adaptation: advance natural climate solutions that buffer impacts of climate change, sequester carbon (capture, secure and store carbon from the atmosphere), and improve biodiversity.
- 4.4.3 Ensure the ecological network is equitably distributed.

3.2.2 STRATEGIES, BYLAWS AND POLICIES FOR PRIVATE LANDS

OVERVIEW

Regulatory requirements and advocacy efforts related to **rainwater management** for private properties are developed through various initiatives, including the **Buildings and Sites Action Plan** of the **Rain City Strategy** (see 3.2.1 Citywide Initiatives and Regulations for Public Spaces), transition of applicable rainwater policy to the **Vancouver Building Bylaw**, and ongoing advancement of large studies such as the **Healthy Waters Plan** and the **Groundwater Strategy**. The city's **Sustainable Large Sites Rezoning Policy** (updated in 2018) also requires developers to implement GRI solutions that prioritize water infiltration and on-site treatment.

VANCOUVER BUILDING BYLAW (VBBL)

The **Vancouver Building Bylaw (VBBL)** plays a key role in managing rainwater on private properties, with several components that contribute to climate resilience. Key policies and regulations include:

- **Rainwater Management**: The VBBL currently mandates a detention-based policy approach to rainwater management on private properties. This typically involves the installation of detention tanks that capture and release rainwater at a controlled rate, reducing peak flow pressure on the city's drainage system. Developers have the discretion to reduce the tank size by also incorporating other onsite GRI approaches such as green roofs and ground infiltration. This is distinct from the former retention-based policy approach previously found in the Zoning and Development Bylaw (Section 4), and as outlined in the **RCS**.
- **Water Conservation and Water Reuse Systems**: The VBBL requires low-flow toilets with a maximum flush volume of 4.8 liters per flush and includes standards for voluntary non-potable water systems. These systems facilitate the use of rainwater for non-potable purposes such as irrigation, helping to reduce pressure on the sanitary sewer system and support potable water conservation. Water reuse systems on private property must be registered citywide. This ensures that systems are monitored, maintained, and comply with operational standards.

Findings from the ongoing **HWP** may or may not result in changes to this policy.

CLIMATE CHANGE ADAPTATION STRATEGY (CCAS)

Several CCAS actions affect private lands and buildings, including:

- **Actions H1.1 through H1.8:** Improving thermal comfort and safety in private lands and buildings by supporting retrofits, incentivizing cooling measures, developing new building requirements, and advocating for policy changes to reduce heat-related health risks.

- **H3.4**: Exploring priority areas for tree planting and retention on private land. This aims to increase tree cover on private properties, contributing to climate resilience and supporting biodiversity.
- **H3.5** Following update to the Tree Bylaw, develop a monitoring approach to track changes in tree coverage on private land as a result of permitted tree removal.
- **R2.5:** Implement rainwater management requirements in the VBBL for Part 3 buildings and multiplexes.

VANCOUVER PLAN

- **4.3.6** Strengthen policies and regulations to protect and create natural assets on private property.
- **10.3** Manage stormwater and optimize drinking water use on private property; Develop land acquisition plans and design guidelines to create room for natural buffers, green rainwater infrastructure.

OTHER RELEVANT POLICIES INCLUDE:

- **Protection of Trees By-law 9958:** This bylaw requires a permit for the removal of trees with a diameter of 20 cm or greater at 1.4 meters above the ground on private property. This regulation supports the city's broader efforts in urban forest conservation and biodiversity protection.
- **Rezoning Policy for Large Sustainable Developments:** The policy encourages the restoration, creation, and connection of habitat on private lands. This reflects content in the **Biodiversity Strategy**, which aims to increase the ecological value of private properties through sustainable development practices.
- Additionally, the **Urban Forest Strategy** explores priority areas for tree planting and retention on private land. Initiatives such as the **Spring and Fall Tree Sales & Nursery Sales** program, with $20 rebates for residents, encourage property owners to plant trees and enhance the urban canopy.
- **Biodiversity Strategy**: Stewardship Programs: Educate and assist landowners in increasing biodiversity on private property.

4. GRI SYSTEMS, CHARACTERISTICS, CO-BENEFITS (ECOSYSTEM SERVICES)

Green Rainwater Infrastructure (GRI)[3] refers to a collection of nature-based solutions, land use practices, and engineered systems designed to manage rainwater, improve water quality, and restore natural ecosystems in urban environments. GRI encompasses engineered systems such as blue-green roofs, swales, rainwater tree trenches and rain gardens, that utilize natural components such as plants and soil with engineered elements such as soil cells and pipes to effectively manage rainwater.

GRI aims to mimic the natural water cycle by capturing rainwater where it falls, treating it using ecological processes, and allowing it to be absorbed back into the ground or harvested for reuse. There are various ways to categorize GRI, including the approach displayed in Figure 4.

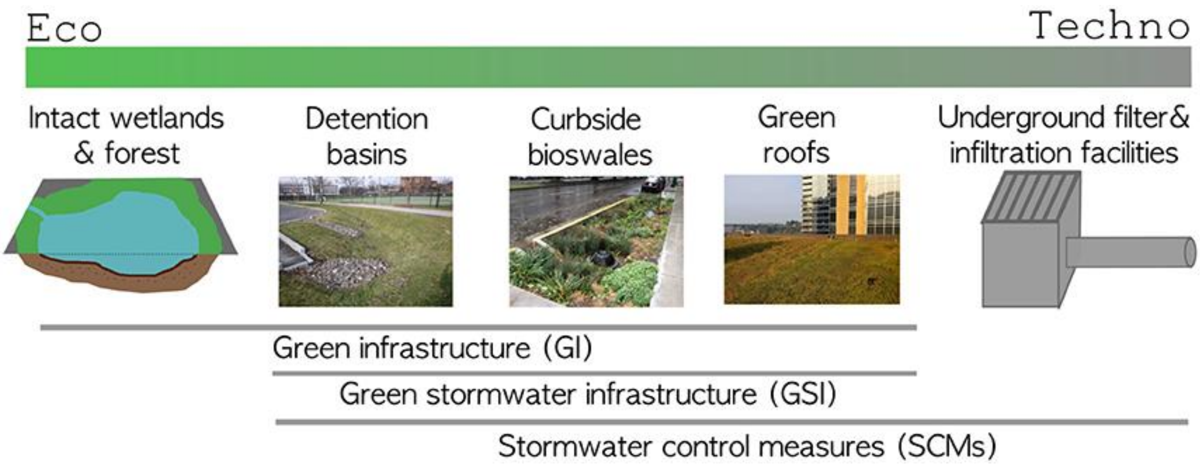


Figure 4. Eco-techno spectrum representing the range of different types of landscape features which play a role in urban stormwater management (McPhillips & Matsler, 2018).

Below is a summary of major types of GRI systems as they are classified in the context of Vancouver, their functionalities, their applications and the range of co-benefits/ ecosystem services they provide, including improving water quality, heat reduction, biodiversity and habitat, health and wellbeing through improved access to nature, recreation and amenities, and conservation of potable water.

Specific areas of interest for GRI in the future based on city strategies:

- Double the street tree density in **below-average blocks of the Downtown Eastside, Marpole, and other priority neighborhoods** by 2030 (Urban Forest Strategy).
- Use the *Urban Forest Strategy* to restore native forests **in Stanley, Jericho Beach, Musqueam, Everett Crowley, Renfrew Ravine and other large parks**. (as mentioned in Biodiversity Strategy).
- Improve the ecosystem health of **False Creek, Still Creek, and Musqueam Creek**. (Biodiversity Strategy).

[3] Note: The term Green Rainwater Infrastructure is unique to Vancouver. Elsewhere Green Stormwater Infrastructure is used to mean the same.

Placement:	Function:	Variations:	Potential Co-benefits					
			Water quality	Heat reduction	Biodiversity and habitat	Health and wellbeing	Recreation and amenities	Conservation potable water
Building-based 	**Resilient roofs:** Vegetated surfaces installed atop buildings to absorb and slow down rainwater runoff.	Intensive green roofs; extensive green roofs; blue roofs; blue-green roofs.						
	Non-potable systems: Rainwater Harvesting systems collect and store rainwater from rooftops for later use, such as irrigation or toilet flushing, thereby reducing stormwater runoff.	Water harvest, re-use, and treatment						
Ground-based 	**Bioretention practices:** Landscaped depressions or shallow basins that use soil, plants, and microorganisms to treat and store rainwater.	Bioswales, bioretention corner bulges, bioretention cells, bioretention planters, rain gardens						
	Rainwater Tree Trenches: Provide both storage for rainwater and support to street trees in dense urban environments.	Soil cells; structural soil						
	Permeable paving: Surfaces that allow water to percolate through, reducing runoff and increasing the amount of water that infiltrates into the ground.	Permeable concrete pavers, pervious concrete, porous asphalt, grass grid pavers/country lane, porous rubber, permeable epoxied gravel						
	Subsurface infiltration: Where rainwater runoff is collected by street gutter drains into the catch basin, a perforated pipe carries the rainwater runoff into the infiltration trench and the rainwater is filtered through a gravel layer into the native soils below.	Infiltration trenches, dry wells, soak-ways, chambers, arches and modular systems						
	Downspout disconnection: Redirecting rainwater from downspouts away from the sewer system to alternative rainwater management practices that absorb or utilize rainwater, thereby reducing the volume of rainwater entering local water bodies via the sewer system.	Can be combined with rain gardens and other types of bioretention, rainwater harvest and reuse, absorbent landscapes and subsurface infiltration						
Wider scale 	**Absorbent Landscapes:** Vegetated areas designed to absorb and retain larger amounts of rainfall than conventional compacted landscapes without ponding.	Evergreen trees intercepting rainwater in their upper branches; surface vegetation absorbing water, preventing erosion and improving evapotranspiration; and healthy soil offering permeability and water holding capacity						
	Large scale practices: Environmentally integrated solutions designed to manage stormwater on a broader scale intended to absorb, slow, and filter rainwater, reduce runoff, enhance biodiversity, and improve water quality.	Engineered wetlands, floodable spaces, designated floodplains stream daylighting						

Table 2. Categorisation of Green Rainwater Infrastructure Typologies

There are three "areas" in the City that are advancing GRI: **Private property** (comprised of both private and city-owned (REFM) property), **Streets and Boulevards (public),** and **Parks (public).** The maps below show the GRI assets in streets and boulevards, and parks in the public realm.

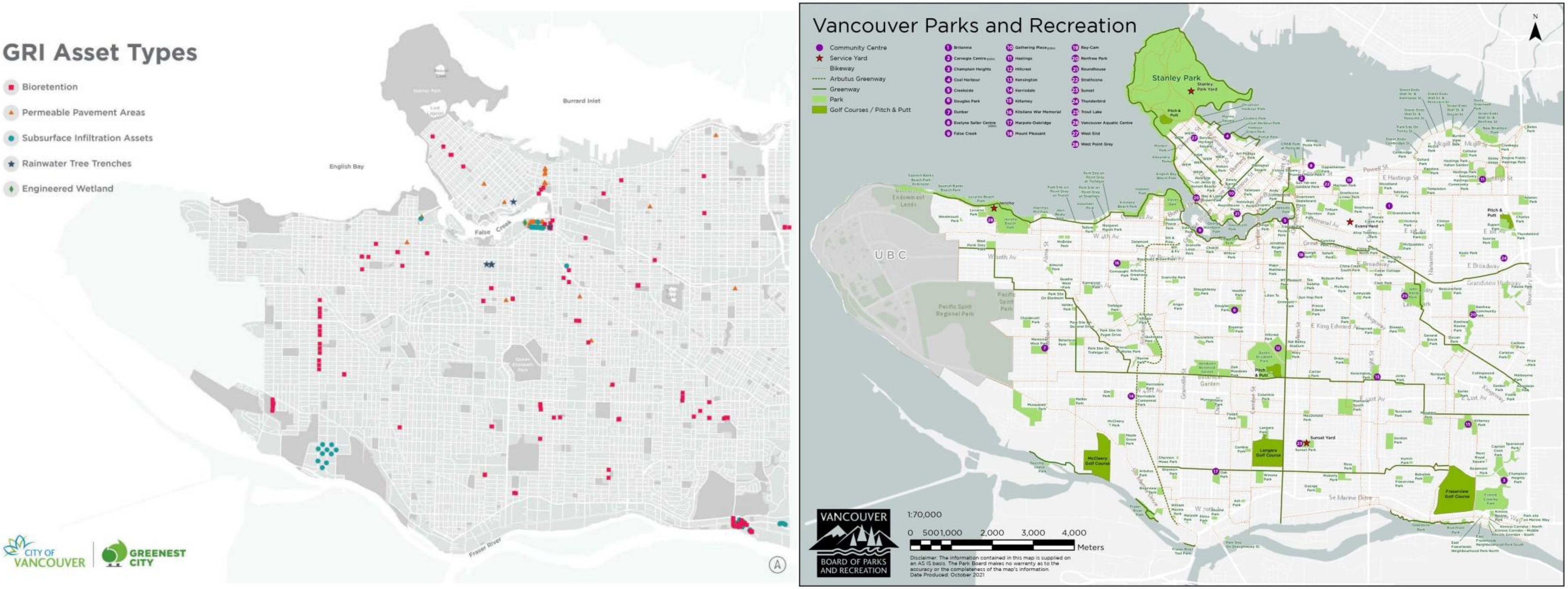


Figure 5. Vancouver's GRI Assets in Streets and Boulevards and Parks. Source: City of Vancouver and Vancouver Board of Parks and Recreation.

A GRI Assets Inventory for private sites was made by Rachel (Zurui) Gao in 2021 for the City of Vancouver, including sites based on XY coordinates of applications, and Hana Larson (2022) shows a methodology to find the existing green roofs based on satellite imagery. The combination of these two approaches can help to create an overview of existing GRI assets on private property.

5. FINDINGS

5.1 LITERATURE REVIEW

In this brief overview of the methods, I summarise 1) how each tool works 2) relevant parameters for measuring co-benefits or siting GRI to optimise them for heat reduction and/or biodiversity enhancement and 3) the application for GRI in practice, often demonstrated through a case study. An elaboration of the case studies can be found in an overview spreadsheet in Appendix I.

5.1.1 ASSESSMENT METHODS

GREEN INFRASTRUCTURE SPACE AND TRAITS (TRAN ET AL., 2020):

The Green Infrastructure Space and Traits (GIST) model is a planning tool designed to optimize the multifunctionality of GRI by integrating two critical components: spatial placement of GRI and the traits of the plant species used. The model aims to identify priority areas within a city for GRI placement and select plant species with traits that maximize various urban ecosystem benefits.

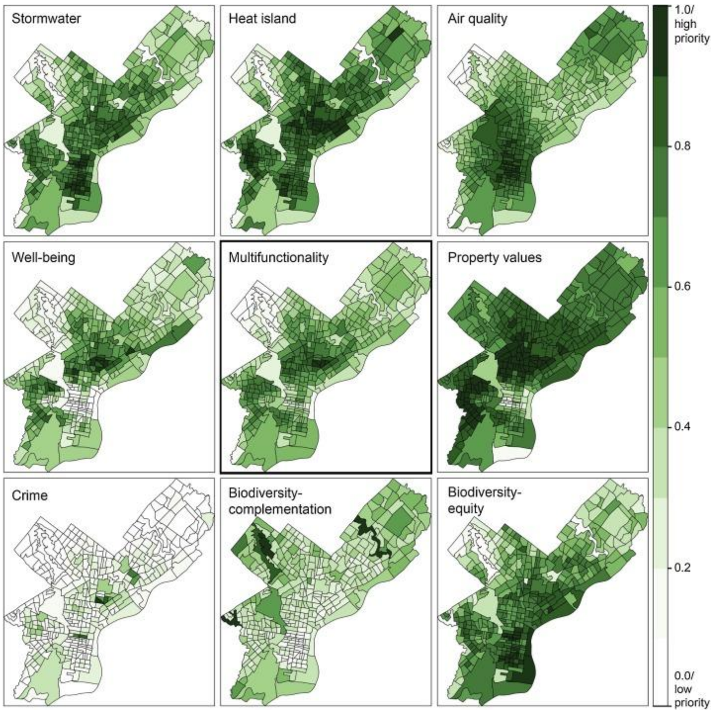


Figure 6. Priority scores of 384 census tracts for single benefits and multifunctionality (centre) for green infrastructure placement in Philadelphia.

GREEN INFRASTRUCTURE SPATIAL PLANNING (MEEROW & NEWELL 2017):

The Green Infrastructure Spatial Planning (GISP) method is a GIS-based, multi-criteria spatial planning model that integrates stakeholder input to identify areas where GRI can maximize ecosystem services. The GISP model evaluates six specific benefits:

1. Stormwater management.
2. Social vulnerability reduction.
3. Access to green space.
4. Urban heat island (UHI) amelioration.
5. Air quality improvement.
6. Landscape connectivity.

GISP allows stakeholders to weight these criteria based on local priorities, creating a composite map of "hotspots" where green infrastructure interventions are most needed. This process helps planners identify synergies and trade-offs between different ecosystem services and prioritize GRI placement based on maximum potential benefits.

The GISP model can be applied to quantify the biodiversity enhancement benefits of GRI in several ways:

- **Prioritizing GRI Placement**: By integrating landscape connectivity into the GISP model, planners can identify where GRI, such as bioswales or green roofs, will have the most impact in connecting fragmented green spaces. This supports urban biodiversity by creating continuous habitats.
- **Optimizing Multi-functionality**: GRI sites can be selected for their ability to enhance multiple benefits, including stormwater management and biodiversity. For example, areas with low vegetation cover but high connectivity potential can be targeted for tree planting to simultaneously address stormwater runoff and biodiversity enhancement.

ENVI-MET ® MICROCLIMATE MODELLING (MAKIDO ET AL., 2019; EPELDE ET AL., 2022):

ENVI-met is a computational fluid dynamics model designed to simulate the surface-plant-air interactions in urban environments. It operates on a fine spatial (0.5 to 10 meters) and temporal (seconds to hours) resolution, making it well-suited for detailed microclimate studies. It integrates various physical processes and parameters to simulate microclimatic conditions, including:

- **Solar and Thermal Radiation**: Calculation of direct, diffuse, and reflected solar radiation, as well as longwave radiation exchanges between surfaces.
- **Heat and Mass Exchange**: Simulation of heat fluxes between surfaces (e.g., buildings, soil, vegetation) and the atmosphere.
- **Vegetation Processes**: Representation of plant transpiration, shading, and thermal comfort effects.
- **Atmospheric Processes**: Inclusion of wind flow, turbulence, and humidity dynamics.

The model uses input data on physical and geometrical properties of the study area (such as building dimensions, vegetation types, and surface materials) to simulate the microclimatic impacts of various urban design scenarios. This tool is particularly valuable in assessing the cooling effects of GRI, including vegetation and water features.

ENVI-met requires two main input files: a **configuration file that sets initial values and timings**, and an **area input file that specifies the geometry of the model environment**. The model includes detailed handling of multilayer vegetation, soil moisture, and latent heat, enabling it to simulate complex urban structures and their microclimatic dynamics over a daily cycle.

In the context of heat reduction, ENVI-met can simulate various parameters such as air temperature, wind speed, and relative humidity. In Makido et al. (2019), air temperature was the primary parameter investigated. The initial climatic parameters were set based on real-world data from nearby weather stations.

GSI INVENTORY ECOSYSTEM SERVICE TRACKERS (SPAHR ET AL., 2020):

This "city-wide greenness tracking can provide insights into systems-level ecosystem services trends within a city and provide background information for [GRI] intervention planning at smaller scales." Spahr et al. (2020) utilize the Normalized Difference Vegetation Index (NDVI) to measure urban greenness and assess the impact of GRI programs. NDVI is calculated using satellite imagery to determine vegetation quality and quantity.

The methodology developed in this study can be applied to model and quantify the heat reduction and biodiversity enhancement benefits of GRI in the following ways:

- **Trend Analysis**: By analyzing NDVI trends over time, cities can track the effectiveness of GRI programs in increasing urban greenness and associated co-benefits.
- **High-Resolution Spatial Data**: Using high-resolution imagery and spatial data on GRI installations, cities can identify areas where vegetated stormwater control measures contribute significantly to ecosystem services. This can help in optimizing the placement of new GRI projects to maximize benefits.
- **Climate Adjustment**: Correcting for climate-related variations in NDVI allows for a more accurate assessment of the anthropogenic impacts of GRI on urban greenness.

BIODIVERSITY ANALYSIS (JESSUP ET AL., 2021):

The biodiversity analysis in Jessup et al. (2021) focuses on characterizing land cover types and identifying areas for potential habitat enhancement. The study area includes most of the urbanized portions of Los Angeles County. The analysis uses United States Census Blocks as the units and incorporates the Los Angeles Region Imagery Acquisition Consortium (LARIAC) dataset, categorizing lands into seven types: Tree Canopy, Tall Shrubs, Grass/Shrubs, Bare Soil, Roads/Railroads, Buildings, and Other Paved areas.

The biodiversity metrics used in the study are:

- **Opportunity to Add or Expand Habitat**: This metric evaluates the potential to convert "Convertible Lands" (Other Paved plus Bare Soil) into habitats. It can be calculated by the area of Convertible Lands within a block or by their proportion.
- **Benefit of Adding Habitat**: This metric considers both Convertible Lands and existing habitats. A high proportion of Convertible Lands and a low proportion of current habitat offer greater benefits for adding new habitats.
- **Benefit of Expanding Habitat**: This takes into account convertible Lands, existing habitats, and the inverse of non-habitat lands, indicating the benefits of enlarging current habitat patches.

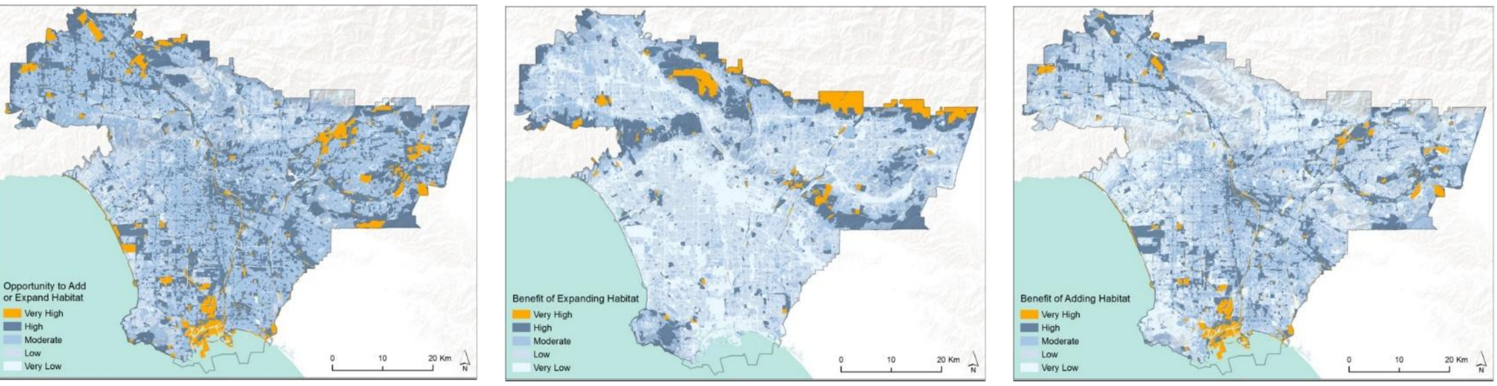


Figure 7. Opportunity to add or expand habitat (left) benefit of expanding habitat (centre) and benefit of adding habitat (right).

HQ MODEL (RONCHI & SALATA, 2022):

The HQ (Habitat Quality) model is used to assess the quality and functionality of habitats within a given area. This model helps to identify areas where habitat quality can be improved or where new habitats can be established. The model considers various factors, including land use, vegetation cover, and human impacts, to determine the overall health and sustainability of habitats.

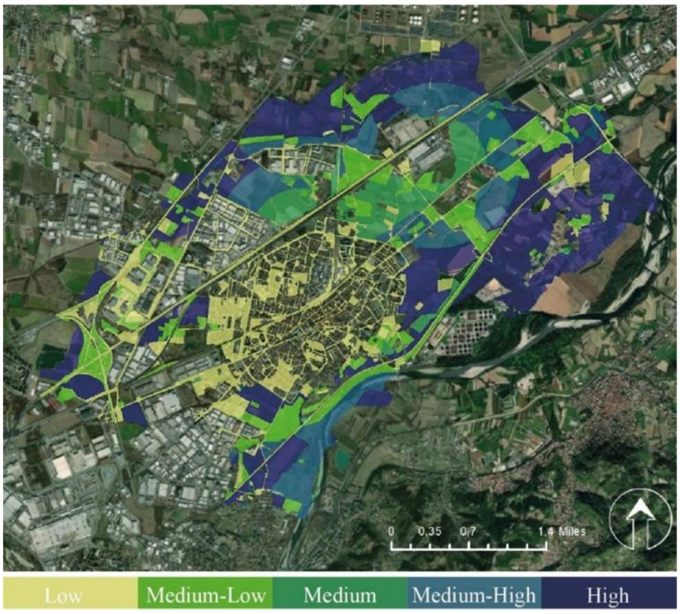


Figure 8. Classification of GRI HQ-based (NDVI-derived) accordingly with the vegetation management using NDVI.

PRIORITIZING LOCATIONS FOR INCREASING URBAN TREE CANOPY (LOCKE ET AL., 2011):

This method is built around the "Three Ps" framework introduced by Grove et al. (2006), which identifies *Possible*, *Preferable*, and *Potential* areas for tree planting:

- **Possible UTC**: Areas where trees can be physically planted, excluding roads, buildings, and water bodies.
- **Preferable UTC**: Areas where tree planting is socially desirable and can address specific community needs.
- **Potential UTC**: Focuses on the economic feasibility of tree planting.

This method integrates variables related to both need (i.e., whether trees can help address specific urban issues) and suitability (i.e., whether locations meet the biophysical constraints and goals of tree-planting organizations). Data collected from public health, air quality, urban heat islands, and socioeconomic factors were analyzed and mapped to show areas with the greatest need for tree canopy expansion.

The approach relies heavily on spatial data, combining neighbourhood-level need-based criteria (Tier 1) with parcel-level suitability criteria (Tier 2). This two-tiered analysis helps organizations target areas where trees will have the highest impact in terms of social, ecological, and programmatic goals.

TRANSVERSAL CONNECTIVITY INDEX (HYSA, 2021):

The Transversal Connectivity Index (TCI) is an ecological indicator designed to classify natural landscape patches by their effective transversal connectivity to water surfaces. The method emphasizes that the integration of GRI at the metropolitan scale is important because good connection between green spaces and water areas can help improve rainwater management, biodiversity habitat and decrease the impacts of climate change.

To calculate the TCI, we look at two main types of connections: **Connections within a patch:** This means examining how well parts of a green area work together, like how the shape and type of the area allow plants and animals to thrive. **Connections between patches:** This looks at how different green spaces link to each other. We consider factors like how close they are, how they border each other, and how easily wildlife can move between them.

The TCI for individual green spaces is calculated, and these scores are combined to see the overall connectivity for the entire city. This information can help us make better decisions about where to put new green spaces and how to protect existing ones.

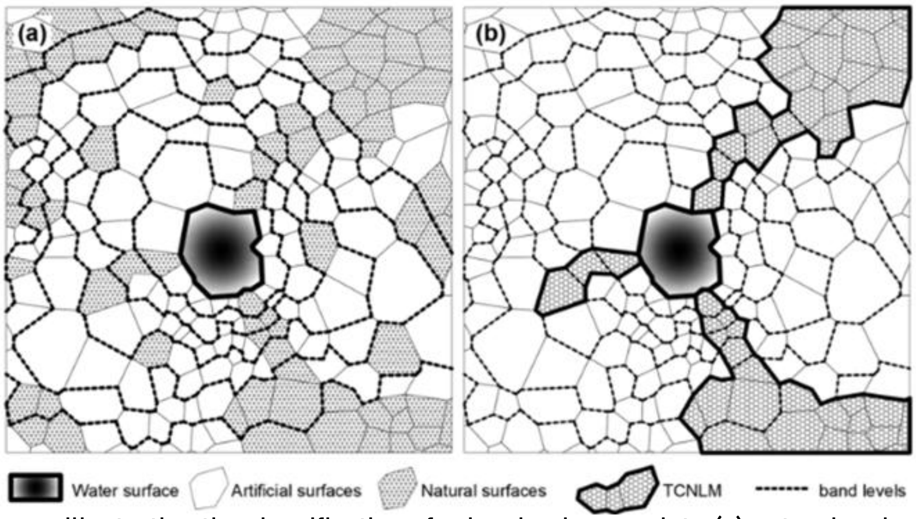


Figure 9. Diagrams illustrating the classification of urban landscapes into (a) natural and artificial surfaces and (b) the water oriented transversal connectivity area.

ECOSYSTEM MULTIFUNCTIONALITY OF GREEN ROOFS (LUNDHOLM ET AL., 2015; LUNDHOLM, 2015):

Ecosystem Multifunctionality is a concept used to assess how well an ecosystem performs across multiple services simultaneously. In the context of green roofs, multifunctionality is calculated by evaluating several ecosystem services such as heat reduction, stormwater retention, carbon sequestration, and biodiversity enhancement.

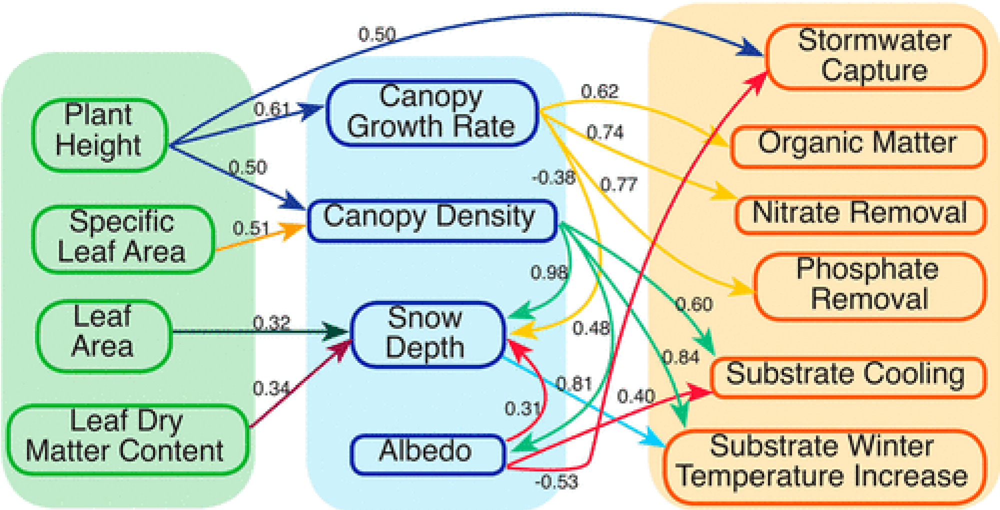


Figure 10. Relationships between plant traits (left), green roof ecosystem properties (center), and indicators of ecosystem services (right).

I-TREE MODEL (RAINEY ET AL., 2022):

The i-Tree model uses a combination of tree characteristics (e.g., diameter at breast height (DBH), crown width, tree height) and environmental factors (e.g., local climate, air quality) to estimate various co-benefits like carbon sequestration, air pollution removal, and cooling effects. The i-Tree Eco model also incorporates growth rates of specific tree species to calculate their environmental impact over time.

The model calculates:

- **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.
- **Cooling and UV reduction**: Effects are measured based on tree canopy size, shade provided, and water evaporation through transpiration.

GSI IMPACT CALCULATOR AND GUIDES

The GSI Impact Hub (A collaboration between GI Exchange, the Nature Conservancy and One Earth Water) has recently (October 2024) launched the GSI Impact calculator and published summary documents and in-depth guides as resources to help practitioners quantify the benefits of GRI:

- Flood Risk Reduction.
- Heat Reduction.
- Job Creation & Economic Development.
- Urban Habitat.
- Transportation.
- Compendium of GSI Co-Benefits Valuation Resources (to be published).

The overview of the parameters and key findings of each of these studies can be found in Appendix I.

5.1.2 ASSESSMENT METHODS OVERVIEW

Model	High-Level Pros	High-Level Cons	Suitability for CoV Context
Green Infrastructure Space and Traits (GIST)	- Identifies priority areas for GRI placement - Optimizes plant traits for multifunctionality	- Requires expertise in ecological planning - Localized information required	Suitable for identifying effective GRI locations in Vancouver, fostering biodiversity and maximizing ecosystem services.
Green Infrastructure Spatial Planning (GISP)	- Integrates stakeholder input - Identifies hotspots for GRI placement	- Complexity can deter non-experts - Data-intensive	Highly suitable for CoV, addressing social and environmental equity by prioritizing underserved areas for GRI, connecting fragmented green spaces and optimising multifunctionality.
ENVI-MET Microclimate Modelling	- High-resolution simulations of urban microclimate - Detailed analysis of cooling effects	- Requires technical knowledge to operate - Time-consuming data preparation	Useful for evaluating cooling strategies within urban design, critical for addressing heat impacts in CoV.
GSI Inventory Ecosystem Service Trackers	- Trends and insights on greenness	- Limited to remote sensing capabilities -May lack real-time data	Beneficial for monitoring GRI effectiveness, assisting in decision-making for future projects in CoV.

	- Utilizes widely available NDVI data		
Biodiversity Analysis	- Identifies habitat expansions - Quantifies potential benefits effectively	- Requires comprehensive datasets - May be site-specific	Valuable for CoV's planning processes, identifying areas for habitat enhancement and assessing biodiversity needs.
HQ Model	- Assesses habitat quality comprehensively - Identifies areas for improvement	- May require advanced ecological knowledge - Data-dependent	Can support CoV initiatives by focusing on enhancing local habitats and assessing ecological health.
Prioritizing Locations for Increasing Urban Tree Canopy	- Comprehensive framework for tree planting - Addresses both need and suitability	- May oversimplify complex urban issues - Requires extensive spatial data	Directly applicable to CoV's urban forestry goals, targeting high-need areas for tree canopy expansion.
Transversal Connectivity Index (TCI)	- Integrates multiple connectivity factors - Provides a holistic view of landscape connectivity	- Complex index may require expertise to interpret - Data-intensive	Supports CoV in enhancing ecological connectivity, important for biodiversity preservation in urban planning.
Ecosystem Multifunctionality of Green Roofs	- Assesses multiple services simultaneously -Highlights green roof benefits	- Requires robust data on various ecosystem services -Complexity can pose a challenge for non-experts	Relevant for CoV as a tool to justify green roofs' value in urban sustainability and heat management initiatives.
i-Tree Model	- Estimation of diverse environmental benefits - Supported by extensive research and resources	- Requires accurate input data; may not be user-friendly - Localized information required	Highly beneficial for CoV in quantifying tree benefits, informing urban forestry and public health initiatives.
GSI Impact Calculator and Guides	- Comprehensive overview of GRI benefits - Practical guides enhance user accessibility	- New tool may not have extensive case studies yet - This tool is more focused on the general benefits of GRI assets rather than localized quantification of benefits	Excellent fit for CoV in assessing and communicating GRI benefits to stakeholders and decision-makers.

Table 3. The relative pros and cons of the assessment methods from the reviewed literature.

- The **GISP** and **GIST** models appear most suitable for the CoV context, as they integrate stakeholder engagement and specific localized benefits, aligning with Vancouver's focus on community involvement and ecosystem health.
- **ENVI-MET** can be leveraged for specific heat reduction assessments while designing urban layouts, particularly where new GRI implementations are considered.
- The **i-Tree Model** provides essential data for asset valuation by illustrating tree benefits in terms of air quality and climate resilience, which resonates with CoV's environmental goals.
- Utilizing **GSI Impact Calculator and Guides** will enable practitioners in CoV to quantify and communicate the benefits of GRI effectively, encouraging wider adoption across public and private initiatives.

5.1.3 CONTRIBUTION OF GRI SYSTEMS TO URBAN HEAT REDUCTION

The outputs from the reviewed assessment methods consistently show that GRI are effective in mitigating urban heat, particularly through evapotranspiration, shading, and surface albedo effects. Assessment methods like the **GIST model** (Tran et al., 2020) and **GISP method** (Meerow & Newell, 2017) emphasize the strategic placement of vegetation in areas with high land surface temperatures (LST) or impervious surfaces. These assessment methods suggest that areas prone to UHI effects, such as densely built environments with minimal green cover, are ideal targets for GRI interventions. The **ENVI-met microclimate model** (Makido et al., 2019; Epelde et al., 2019) further demonstrates that vegetation, particularly trees and grass, significantly reduces localized temperatures by promoting shade and enhancing transpiration. Additionally, **i-Tree** (Rainey et al., 2022) highlights that tree canopy size and evapotranspiration are central to cooling, especially in urban environments.

In the **GSI Impact guide on Heat Reduction,** evidence for the direct cooling benefits is shown through a table that summarises selected research with 1) studies analysing change in temperatures associated with a city-scale implementation of vegetative cover, tree canopy, and/or surface reflectivity in urban landscapes; and 2) studies analysing change in temperatures associated with small scale implementation of GRI.

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.

Table 4. Temperature reduction benefits of various GRI types. Source: GSI Impact Guide

The guide elaborates air quality improvements, avoided heat-related illnesses and fatalities, water quality improvements and increased lifecycle/efficiency of infrastructure as a result of temperature reductions.

The traits of GRI systems that most effectively contribute to urban heat reduction can be divided into vegetation-related characteristics, surface properties, and water features:

- **Vegetation Traits**: Taller plants (Lundholm et al., 2015), larger leaves (Blanuša et al., 2013), and a diverse mix of species (Maestre et al., 2012) offer more shade and greater evapotranspiration capacity, leading to improved cooling. For example, **woody species** and **green roofs** have been found to provide significant cooling by increasing canopy density and transpiration (Epelde et al., 2019). Additionally, plant traits such as **leaf area index** (Lundholm et al., 2015) and **species richness** improve ecosystem function, thereby enhancing the overall cooling effect.
- **Surface Traits**: Albedo (surface reflectivity) plays a crucial role in heat reduction. **Light-coloured permeable pavements** (Epelde et al., 2019) and **green roofs** (Epelde et al., 2019; Ronchi & Salata, 2022) help reduce heat absorption, lowering surface and air temperatures. The **HQ Model** (Ronchi & Salata, 2022) underscores how areas with vegetated surfaces, which typically have higher albedo, can significantly mitigate heat compared to conventional concrete or asphalt.
- **Water Features**: Incorporating water elements like fountains or water bodies contributes to evaporative cooling. Studies by **Epelde et al. (2019)** and **Makido et al. (2019)** show that these features can lead to localized temperature reductions through evaporation, enhancing the overall cooling capacity of GRI.

Based on the traits of GRI systems contributing to urban heat reduction found in the literature and the design elements and considerations for heat reduction performance outlined in the GSI impact guide, GRI such as trees, rain gardens, green roofs and permeable pavements all demonstrate significant potential to mitigate heat in urban areas; however, their relative effectiveness is influenced by baseline conditions, placement, and design elements.

Trees with high canopy coverage on east-west oriented streets maximizes shade and cooling effects, by forming a dense canopy that blocks direct sunlight and reduces heat absorption. Selecting **taller plant species** with larger leaves and diverse mixes can enhance evapotranspiration and increase cooling through greater canopy density. **Bioretention areas and rain gardens** contribute to cooling through their evaporative processes, where water infiltration and storage support heat loss. **Vegetated GRI and parks** can be enriched with a variety of vegetation types to create open spaces that promote air circulation while optimizing their cooling potential. Incorporating **water features** like fountains or ponds can further contribute to evaporative cooling. In high-density areas, implementing **green roofs**, particularly on low-rise buildings, and **green walls** on mid- to high-rises provide a thermal break, reducing heat absorption from building materials. Utilizing **light-coloured permeable pavements** will not only improve surface cooling through enhanced evapotranspiration but also minimize heat retention at night.

The effectiveness and relative benefits of GRI systems in reducing urban heat is highly dependent on strategic design modifications and placements:

- **Strategic Placement**: The **GIST model** and **GISP method** suggest prioritising areas with high land surface temperature and impervious surfaces for the installation of GSI/GRI. These locations are more prone to urban heat islands, and strategically placing vegetated infrastructure in these areas maximizes cooling benefits. The **Three Ps Framework** (Locke et al., 2011) advocates for targeting tree planting in regions with the highest summer surface temperatures, which has been proven to reduce ambient temperatures and improve air quality in cities like New York City.
- **Vegetation Distribution**: The T**ransversal Connectivity Index (TCI)** (Hysa et al., 2021) indicates that larger, more continuous patches of vegetation provide more extensive cooling effects through evapotranspiration. Smaller, fragmented patches may offer limited cooling and

biodiversity benefits. Therefore, careful planning to avoid fragmentation—such as incorporating **green corridors** or expanding vegetated patches—is essential to enhance the cooling performance of GSI/GRI.

- **Urban Geometry**: Tools like **ENVI-met** (Makido et al., 2019) and the **HQ Model** (Ronchi & Salata, 2022) show that building height, surface materials, and the overall geometry of an urban area influence the effectiveness of GSI/GRI. For example, integrating GRI along roadways and sidewalks in **hardscaped industrial areas** with minimal vegetation can significantly reduce temperatures when combined with high albedo surfaces and water features. Additionally, placing vegetation near buildings (as suggested by **i-Tree** models) enhances shading and reduces energy consumption through lower air conditioning needs.
- **Incorporating Green Infrastructure in Design**: Integrating GRI in urban design—such as **rain gardens**, **bioswales**, and **green streets**—increases the cooling effects and can simultaneously provide stormwater management benefits. For example, the **GSI inventory ecosystem service trackers** (Spahr et al., 2020) demonstrate that vegetation cover (e.g., via **vegetated stormwater control measures**) can help reduce the urban heat island effect by cooling the air and providing habitat for urban wildlife.

The **GSI Impact guide** provides a summary of findings from existing research that documents key design elements and other considerations for GRI installations that impact urban temperatures, including:

- **Baseline conditions** of a city, neighbourhood, or site will affect the degree of heat stress reduction that can be achieved. The amount of dark and impermeable surfaces, existing levels of vegetation, local climate, building inventory characteristics, and other physical locational attributes impact the level of potential benefits provided by GRI projects.
- **Scale of implementation within study area.** Studies documenting the effects of GRI-related improvements on temperatures have found benefits associated with converting 6% to 31% of the study area (e.g., city block or entire city) to vegetation or more reflective surfaces. As a general rule, greater impacts are associated with larger conversion areas.
- **The type of GRI installation and other design elements** may matter as well. One study found that increasing the albedo of urban surfaces resulted in an approximately 44% greater temperature reduction compared to increasing vegetative cover by the same amount. This indicates there may be the potential for achieving greater benefits with **permeable pavement practices** when they can increase surface reflectivity relative to baseline conditions. **Trees and green roofs** also have been found to result in greater cooling benefits relative to other ground-level vegetated practices.
- **Design Considerations for GRI Practice Types:** The practice type chosen will often be influenced or determined by the available space for GRI: alleyways and parking lots may have room for permeable pavement and rain gardens, whereas areas of high-density building may only have space for green roofs. The width of rights-of-way along street corridors can determine the selection of tree and vegetation species. While green roofs can improve building cooling, they have been found to have limited impacts on direct ambient temperature reduction. In contrast, large tree covered areas and urban agriculture systems are highly effective cooling agents.

The GSI impact guide provides a sample estimate of the conversion of impervious areas to GRI types in Philadelphia, Tucson, and Atlanta, showing that **permeable pavements** exhibit the highest potential for **ambient temperature reduction** (Philadelphia: 0.55; Tucson: 0.44; Atlanta: 0.72), compared to other GRI tools such as green roofs, rain gardens/bioretention, and trees, which all score lower (Ph: 0.38; T: 0.30; A: 0.50 for all three). However, when evaluating **the impact on indoor**

heat, the analysis reveals that trees and green roofs play a critical role. Trees demonstrate a higher impact on electricity savings (Ph: 84.6 KWh/tree, T: 182 KWh/tree., A: 153 KWh/tree.), while **green roofs** offer lower energy savings (Ph: 0.5 KWh/sq.ft.; T: 0.7 KWh/sq.ft.; A: 0.6 KWh/sq.ft.), and their cooling effects largely benefit uppermost building floors. This makes **green walls** particularly beneficial for mid- to high-rise buildings, where they can help mitigate indoor temperatures effectively. The cost-saving implications of these cooling strategies vary across cities, influenced by local electricity and gas prices.

Because the Urban Heat Island effect can vary significantly across an urban area, understanding local temperature data and identifying heat vulnerable populations are critical to siting GRI for the greatest heat reduction benefits. **Equity** can be at the center of consideration when planning to use GRI to reduce urban heat stress. One example of a heat equity program is Cool Neighbourhoods NYC. The NYC Department of Health and Mental Hygiene, in partnership with Columbia University, developed a Heat Vulnerability Index that helped to identify New York City's most heat vulnerable neighbourhoods. This project informed Cool Neighbourhoods NYC, a citywide strategy to reduce extreme heat and target adaptation strategies in high-risk areas.

Lastly, the **GSI Impact guide** goes into how to quantify and monetize the UHI reduction benefits, with estimates of values associated with conversion of ten percent of impervious area to vegetated cover or light reflective permeable pavement, by region and practice type (trees, rain garden/bioretention, green roof, permeable pavement) and estimates of energy savings associated with reduced need for building climate control by region and practice type.

5.1.4 CONTRIBUTION OF GRI SYSTEMS TO BIODIVERSITY

GRI systems play a crucial role in enhancing urban biodiversity by **creating, improving, and connecting habitat areas** within cities. The reviewed studies (see Appendix I) show GRI can provide valuable ecological benefits, including the support of diverse species, improved habitat connectivity, and increased landscape resilience.

The GSI Impact Guide on Urban Habitat elaborates on how GRI can contribute to the urban habitat by:

- Providing food and refuge for birds, amphibians, bees, butterflies, and other species.
- Creating habitat for insects and birds that enhance pollination and seed dispersal.
- Providing landscape connectivity and encouraging the movement of species between habitat patches.
- Improving water quality and maintaining hydrology that supports instream habitats.

Traits of GRI that Contribute to Biodiversity

The effectiveness of GRI in supporting biodiversity largely depends on plant selection, vegetation density, and landscape connectivity. Specific traits of plants and GRI elements play a significant role in fostering diverse habitats and supporting wildlife.

- **Plant Traits**: The GIST model identifies plant traits such as height, flower size, and species richness as key factors for attracting pollinators and supporting a diverse ecosystem (Tran et al., 2020). Other studies suggest that species diversity, including the mix of tall and short species, increases habitat availability for wildlife and optimizes ecosystem functions (Lundholm et al., 2015).

- **Vegetation Density and Type**: GRI that includes a variety of plant types—such as trees, shrubs, and groundcover—can provide multiple layers of habitat. For instance, trees offer nesting sites, while flowering plants provide food for pollinators. A dense canopy and a mixture of plant species can also enhance habitat quality and biodiversity (Jessup et al., 2021).
- **Biodiversity Metrics**: By using tools like the Transversal Connectivity Index (Hysa et al., 2021) and the i-Tree model (Rainey et al., 2022), researchers can assess how plant diversity, landscape connectivity, and the size of vegetated patches contribute to improved biodiversity. Larger, more diverse GRI patches support a wider variety of species, while species with complementary traits help enhance ecosystem functions like habitat provision and resource use efficiency.

Design Modifications and Placement of GRI for Enhancing Biodiversity

The strategic placement and design of GRI are essential for maximising their biodiversity benefits. Several design modifications can enhance the effectiveness of GRI in providing habitats and supporting urban biodiversity.

- **Habitat Connectivity**: One of the most critical design considerations is ensuring that GRI installations are placed in areas where they can connect fragmented habitats and form wildlife corridors. For example, the HQ model (Ronchi & Salata, 2022) stresses the importance of linking new green spaces to existing habitats to facilitate species movement and genetic exchange. The Three Ps Framework (Locke et al., 2011) also prioritizes planting near ecological corridors to improve landscape connectivity and enhance wildlife movement.
- **Vegetation Placement**: The effectiveness of GRI is enhanced when vegetated areas are strategically located in areas with existing vegetation. Adding green infrastructure in proximity to existing green spaces creates larger, more continuous habitats that support more species. For example, the study in Los Angeles by Jessup et al. (2021) demonstrated that adding vegetation to isolated patches could support pollinators, while expanding existing habitats benefited larger species.
- **Patch Size and Quality**: The Transversal Connectivity Index (Hysa et al., 2021) and other models highlight that larger and higher-quality vegetated patches provide more extensive habitats and support greater species diversity. For instance, larger habitat patches in urban areas are crucial for species survival, as they offer more resources and less risk of fragmentation.
- **Site Selection**: The siting of GRI in areas with lower human disturbance, such as green rooftops or rain gardens in quieter urban zones, can also improve biodiversity outcomes. Lower human impact areas support greater species diversity and ensure better conditions for wildlife (Ronchi & Salata, 2022).

The **GSI Impact Guide on Urban Habitat** warns that isolated GRI interventions will have limited value to biodiversity if organisms are unable to disperse to and from the habitat; however, if strategically placed near existing habitat patches or corridors, the same intervention can increase available habitat or provide important connectivity benefits. In general, factors to consider when assessing the context of a project location include:

- Opportunities to link or expand existing habitat corridors.
- Areas that are also high priority for stormwater management.
- Size of the project area.

- Intended use of the project area.
- Sun exposure and intensity.
- Water availability and frequency of floods.

Habitat and biodiversity benefits can be enhanced with an understanding of the various factors that affect successful implementation for this purpose. This varies by GRI practice type.

Urban Ponds and Wetlands. The types of habitats that can thrive in urban ponds and wetlands depend on multiple factors:

- Proximity to major transportation corridors, impervious surfaces, buildings, or large natural turf areas treated with pesticides or fertilizers. Locations close to these conditions are likely to carry heavy metal and nutrient loads, which will affect the design and type of plants the project can support. Project sites with higher nutrient loads are ideal for native plants or animals that can survive, or even filter out, nutrients.
- Proximity to other ponds, wetlands, or natural green spaces. Projects close to other areas are more likely to benefit from cross-pollination and species interaction.
- Design elements including surface area, depth, bank slope, shoreline consistency, and the availability of shade will affect the project's ability to provide habitat for different species.

Green roofs. Intentional green roof siting and design can support a diversity of insects - especially pollinators and spiders, which can in turn support a network of secondary consumers. Green roofs are more effective when surrounded by other green roofs and natural green spaces. Green roofs on taller buildings appear to be less effective at supporting biodiversity, bee nesting, and bat activity than roofs on shorter buildings. A deeper and richer substrate will support broader and more complex plant diversity. Selecting native and blooming plants also generally helps to support greater biodiversity.

Other GRI. Other GRI practices, such as urban gardens, rain gardens, bioretention, and tree planting can also support habitat and biodiversity. Larger bioretention basins with more leaf litter, vegetation structure, and number of flowering plants support more insect diversity than other

Land Cover Type	Overall Rating (Biodiversity + TBL)	Biodiversity Rating
Native Landscaping (tallgrass prairie plants)	High	High
Bioretention/Bioswales	High	High
Rain Gardens	High	High
Wetlands	High	High
Greenways	High	High
Urban Agriculture	High	High
Stormwater Trees	High	High
Green Roofs	High	Medium
Green Alleys, Streets, and Parking Lots	Medium	Medium
Soil Amendments	Medium	Medium
Porous Pavement	Medium	Low
Rainwater Catchment	Low/Medium	Low

Table 5. The Milwaukee Metropolitan Sewerage District's relative ratings of biodiversity and additional economic, social, and environmental Benefits (triple bottom line or TBL) of various land cover types.

basins. Native trees and larger tree species support higher diversities and abundance of insect and bird species compared with non-native and smaller urban trees.

The guide then goes into quantifying the value of GRI habitat benefits, with willingness-to-pay estimates from existing studies and existing tools and methods for quantifying and monetising habitat benefits. For different GRI practices there are different Relative Ecosystem and Biodiversity Rankings (5-point scale) and Water Quality Ladder (10-point scale) that result in different values per acre per year.

5.2 FINDINGS FROM INTERVIEWS

The findings from the interview with GI Leadership Exchange and the Nature Conservancy shed light on the promotion and implementation of GRI across local governments and water agencies in the United States and Canada. Common challenges to the implementation of GRI in many U.S cities were limited regulatory frameworks and funding. Many stormwater management programs focus solely on compliance with stormwater regulations due to limited financial resources. The interviewees highlighted the need for integrated, multi-stakeholder approaches to successfully implement GRI at the local level, emphasising the importance as well as the complexity of developing tailored tools that consider local geographical and weather conditions, ensuring political buy-in, having the right policies and funding mechanisms in place, and fostering inter-departmental collaboration.

5.2.1. HOW DO CITIES JUSTIFY THAT GRI CAN ADDRESS HEAT, BIODIVERSITY, AND RAINWATER?

All three cities are exploring **multiple co-benefits** of GRI beyond **stormwater management.** These benefits include **urban heat island mitigation**, **improved air quality**, **biodiversity enhancement**, and **mental and physical health benefits**.

ADDRESSING URBAN HEAT:

- **Toronto:** Toronto's Eco-Roof Incentive Program supports the installation of green roofs and cool roofs on both existing and new buildings. The city is actively working on a model to quantify the heat mitigation benefits of green infrastructure, particularly green roofs, using models and equations (though acknowledging challenges in accuracy and local adaptation). They utilize tools like i-Tree and are developing in-house equations to better reflect local conditions. The impact is recognized as varying significantly based on building type and size.
- **Detroit:** Focuses on urban heat island mitigation through tree planting and reforestation, linking this to neighbourhood revitalization and environmental justice. Quantitative assessment of heat reduction from GRI is less developed than in Toronto.
- **Philadelphia:** Recognizes the cooling potential of GRI, particularly trees and cool roofs, but lacks a comprehensive, citywide system for tracking and quantifying heat reduction. Pilot programs and data collection are underway, but a structured approach is still developing. They highlight the cost-effectiveness of trees compared to green roofs for cooling.

The cities justify GRI's role in addressing heat through:

- **Modelling and Simulation:** Toronto is starting to use sophisticated models to estimate temperature reductions.
- **Empirical Observation:** All three cities observe the cooling effects of vegetation and reflective surfaces.
- **Environmental Justice:** Detroit and Philadelphia emphasize the importance of GRI in reducing heat exposure in vulnerable communities.

ENHANCING BIODIVERSITY:

- **Toronto:** PollinateTO grant program (for community-led projects) directly supports pollinator habitats, though biodiversity tracking beyond plant species is often done through collaborations with external partners.
- **Detroit:** Uses native plants in GRI projects to enhance biodiversity, but lacks a comprehensive system for tracking biodiversity impacts.
- **Philadelphia:** Acknowledges biodiversity as a co-benefit, particularly through urban forestry initiatives and collaborations with organizations like the National Audubon Society. However, citywide, comprehensive biodiversity tracking linked to GRI is lacking.

The cities justify GRI's role in enhancing biodiversity through:

- **Native Plant Selection:** Detroit's use of native species in GRI directly supports local ecosystems.
- **Habitat Creation:** PollinateTO and other initiatives create habitats for pollinators and other species.

Partnerships with organizations specialising in biodiversity monitoring provide data and expertise. In Toronto, the PollinateTO program leverages collaborations with graduate students and citizen science initiatives to conduct detailed monitoring, such as bee counts, providing more nuanced data on project impacts than would be possible through city staff alone. Philadelphia partners with the Academy of Natural Sciences and the National Audubon Society to track biodiversity, particularly bird diversity, in areas undergoing restoration projects.

MANAGING RAINWATER:

- **Toronto:** Emphasizes stormwater management through green roofs and other GRI, using equations (though acknowledging challenges in accuracy) to quantify the benefits.
- **Detroit:** Prioritizes stormwater management, using pre- and post-installation modeling and sewer flow data to assess the effectiveness of GRI projects.
- **Philadelphia:** Focuses on GRI assets like rain gardens and tree pits for managing rainwater runoff.

The cities justify GRI's role in rainwater management through:

- **Modeling and Data Analysis:** Detroit and Toronto use models and data to demonstrate reduced stormwater runoff.
- **Observed Impacts:** All three cities observe the positive effects of GRI on reducing stormwater volume and improving water quality.
- **Reduced Flooding:** The reduction in runoff contributes to mitigating flood risks.

LESSONS LEARNED AND KEY FINDINGS:

- **Quantification Challenges:** Accurately quantifying the co-benefits of GRI is complex and requires sophisticated models and data collection systems. Assumptions within models need constant scrutiny and local adaptation.
- **Data Integration and Monitoring:** A lack of comprehensive, citywide systems for tracking the impacts of GRI across all co-benefits is a significant limitation.
- **Collaboration and Partnerships:** Collaboration with external experts and organizations can enhance data collection, analysis, and the overall effectiveness of GRI initiatives.
- **Equity Considerations:** Prioritising GRI implementation in underserved communities is essential for addressing environmental justice concerns.
- **Need for Locally Relevant Tools:** Existing tools for calculating GRI benefits often need adaptation to local conditions. There is a strong need for updated, region-specific tools.

5.2.2. WHAT ROLE DOES GRI PLAY IN CLIMATE ADAPTATION OR IN WIDER CITY STRATEGIES?

Toronto has integrated GRI into its climate resilience strategies through several initiatives, including the **PollinateTO program**, which offers funding for community-led projects, such as pollinator habitats and rain gardens, with an emphasis on biodiversity and public visibility. **Stormwater management** through **bioswales** and similar features often complements these efforts. Although there are no formal long-term biodiversity targets, the program adopts an incremental approach, expanding existing initiatives. GRI design modifications in Toronto include a push for **biodiverse green roofs**, moving away from sedum-based installations that are less beneficial for pollinators. The **Eco-Roof Incentive Program**, which has been active for 15 years, promotes green roofs and cool roofs through financial incentives and is being restructured to better integrate biodiversity.

However, despite these efforts, GRI is **not fully integrated into Toronto's broader climate action plans**, such as the **TransformTO initiative**. Green roofs, while recognized for their environmental benefits, are still under consideration for full incorporation into these strategies, and **equity considerations** regarding their accessibility and effectiveness are not yet fully addressed in the city's main climate goals.

Detroit has also recognized the value of GRI in adapting to climate impacts, particularly with **stormwater management** in response to increased flooding and intense rainfall. The city integrates GRI through updated **design standards** for stormwater management and incentives for **private property owners** to install GRI, such as rain gardens and green roofs. Developers can earn credits for stormwater management, incentivising private sector participation.

Public sector GRI projects include large-scale initiatives in **parks, vacant lots**, and **green streets**, led by departments like the **Department of Public Works** and **Detroit Water and Sewage Department (DWSD)**. However, Detroit faces challenges such as **inter-departmental silos**, where different city departments (e.g., DWSD, Office of Sustainability) have overlapping but sometimes conflicting priorities, complicating coordinated GRI efforts.

One notable challenge in Detroit is the **technical limitations** of retrofitting older buildings for green roofs, which may not have the structural capacity to support these features. Additionally, **private developers** may not always embrace GRI to its full potential, opting for minimal compliance with stormwater regulations instead of robust green infrastructure solutions.

Philadelphia has been a pioneer in GRI, with extensive use of **rain gardens, tree trenches**, and **vegetated swales** to manage stormwater in the right-of-way (**public**) while also addressing **urban heat island** effects and enhancing **biodiversity**. The city's GRI program is integrated into its **climate resilience** and **climate adaptation** strategies, focusing on cooling in heat-stressed areas. **Private property incentives** are available through programs like the **Rain Check Program**, which helps property owners install green infrastructure. However, the **effectiveness** of these solutions is sometimes questioned, as some installations have failed during major storms, underscoring potential vulnerabilities in even well-meaning projects.

Philadelphia's efforts also highlight the importance of **tree planting** as part of GRI, especially in neighbourhoods affected by urban heat. The **Philly Tree Plan** integrates tree canopy expansion into climate adaptation goals, addressing both cooling and stormwater management. However, challenges remain, such as a **lack of centralized coordination** for tracking and quantifying the broader **co-benefits** of GRI (e.g., heat reduction, biodiversity) and the **private sector's preference** for less green, more gravel-based stormwater solutions.

KEY THEMES ACROSS CITIES:

All three cities face **funding and resource constraints** that affect the scale and speed of implementing green infrastructure solutions, particularly on private properties. GRI implementation on private properties is often driven by financial incentives, but in all cities, there are concerns that private developers and property owners may only comply minimally with regulations unless there are stronger incentives to embrace full-scale GRI solutions.

- **Toronto** has made significant investments in GRI through **policy mandates** and **incentive programs** for developers to integrate green roofs in new buildings. Their **green roof bylaw** is an example of top-down regulatory action that helped scale up green roof adoption, mandating green roofs on large buildings, especially in the downtown area. This has allowed Toronto to scale up green roof installations quickly, although challenges remain due to the high initial cost and in ensuring ongoing maintenance and evaluating long-term performance.
- **Detroit** faces challenges related to **urban blight** and a shrinking population, which complicates the integration of green roofs into the city's **revitalization** strategies. **Limited capacity** for **technical expertise** in GRI has slowed progress, but the city is gradually increasing its capacity through partnerships with external organizations.
- **Philadelphia** has struggled with implementing **long-term management** of GRI in public spaces. While the **Philly Tree Plan** has been instrumental in prioritising tree planting in heat-exposed areas, the city faces challenges in managing the **evolving needs** of urban forestry and **green stormwater infrastructure**. **Community engagement** and **funding** remain key challenges, particularly in high-need neighbourhoods.

Retrofitting existing urban infrastructure for GRI, particularly green roofs, presents technical challenges, especially in older buildings with inadequate structural support. This issue is especially prominent in Detroit.

Ongoing maintenance of GRI features, particularly those on private properties, remains a concern in all cities. Philadelphia's experience with **Rain Check Program** installations that failed during storms is a case in point, indicating the need for more robust monitoring and long-term maintenance strategies.

All three cities face **difficulties in inter-departmental coordination**, with multiple departments (e.g., water, sustainability, parks) responsible for different aspects of GRI. This can lead to fragmented or delayed efforts.

Equity considerations in GRI are still evolving, with efforts often focusing on addressing the needs of underserved communities where heat exposure and poor air quality are more prevalent. Toronto's PollinateTO program seeks community involvement but doesn't yet fully address how GRI projects can target vulnerable or underserved populations. Philadelphia's Tree Plan focuses on high-heat neighbourhoods, but challenges remain in how to ensure equitable distribution of resources and access to green infrastructure.

LESSONS LEARNED:

- **Incremental Expansion and Long-Term Planning**: Cities have learned that GRI works best as part of a long-term, incremental strategy rather than through sudden, large-scale implementations. Small, community-based projects in Toronto and Philadelphia's approach of expanding GRI in phases are good examples.
- **Integration with Broader Strategies**: Integrating GRI into broader **climate action** plans and ensuring that different departments collaborate effectively is crucial for success. Philadelphia's GRI, combined with its Tree Plan, shows that combining stormwater management with other climate adaptation measures (e.g., heat stress mitigation) can provide co-benefits.
- **Incentivising Private Sector Adoption**: Financial incentives, such as credits for developers and grants for private property owners, are effective but need to be structured to encourage more than just compliance with the minimum standards.

5.2.3. LESSONS LEARNED IN ADAPTIVE MANAGEMENT INITIATIVES FOR GRI

1. Tracking impacts remains a challenge. All three cities highlight the difficulty of comprehensively tracking the impacts of their GRI initiatives. While Toronto has robust tracking for some programs (PollinateTO, EcoRoof Incentive Program, green roof bylaw – though with limitations in long-term private property maintenance and outdated methodologies), data collection faces challenges related to:

- **Private vs. Public Land:** Maintaining consistent monitoring across privately and publicly owned land is difficult. Homeowner turnover affects Toronto's PollinateTO program, while Detroit struggles with comprehensive monitoring across both sectors.
- **Data Gaps and Outdated Methodologies:** Philadelphia's lack of a citywide system for tracking GRI impacts on heat reduction and biodiversity, and Toronto's outdated EcoRoof

methodology, demonstrate the need for continuous improvement in data collection and analysis methods.

- **Resource Constraints:** Philadelphia explicitly mentions resource limitations hindering long-term monitoring, particularly in underserved neighbourhoods. This suggests that effective adaptive management requires sufficient funding and staffing.
- **Data Integration:** While individual programs may have tracking mechanisms, integrating data across different initiatives to get a holistic view of GRI effectiveness is a challenge. Philadelphia's reliance on different partners for biodiversity tracking illustrates this issue.

2. Adaptive Management Requires a Proactive, Not Just Reactive, Approach: Philadelphia's Parks Department's reliance on work orders as a measure of success highlights the importance of shifting from a reactive to a proactive approach. Effective adaptive management necessitates:

- **Setting Clear, Measurable Goals:** Defining specific, measurable, achievable, relevant, and time-bound (SMART) goals is essential for effective monitoring and evaluation. While some programs (like Toronto's PollinateTO) have clear goals, others lack this clarity.
- **Regular Evaluation and Adjustment:** Adaptive management is an iterative process. Regular evaluation of program effectiveness and subsequent adjustments based on data are crucial. Toronto's reassessment of the EcoRoof Incentive Program due to declining applications demonstrates this.
- **Incorporating Feedback:** Detroit's use of post-installation surveys to gather community feedback on quality-of-life impacts shows the value of incorporating social considerations into adaptive management.

3. Collaboration and Partnerships Enhance Adaptive Management: Successful adaptive management often relies on collaboration:

- **Inter-departmental Coordination:** Toronto's coordination between different city divisions (Parks, Transportation Services) for PollinateTO demonstrates the importance of internal collaboration.
- **Community Engagement:** Detroit's community surveys and Philadelphia's focus on underserved communities highlight the need for community involvement in both implementation and evaluation.
- **External Partnerships:** Philadelphia's collaborations with the Academy of Natural Sciences and the National Audubon Society for biodiversity tracking illustrate the benefits of leveraging external expertise and resources.

6. RECOMMENDATIONS

6.1 JUSTIFYING THE USE OF GRI TO ADDRESS URBAN HEAT, BIODIVERSITY AND RAINWATER MANAGEMENT

The existing literature review demonstrates the effectiveness of GRI in mitigating urban heat, enhancing biodiversity, and managing rainwater in various climates. Models like GIST, GISP, ENVI-met, and i-Tree consistently show positive impacts. The GSI Impact Guide provides valuable quantitative data on heat reduction and biodiversity benefits, including monetization estimates. However, the transferability of these findings to Vancouver's specific climate and context requires further consideration.

While the general principles are transferable, Vancouver's unique climate (e.g., temperate rainforest, specific microclimates, precipitation patterns), topography, and existing urban fabric necessitate a localized assessment. The literature provides a strong foundation, but a tailored study can:

- **Validate existing models:** Determine the accuracy and applicability of existing models (e.g., ENVI-met, i-Tree) for Vancouver's specific climate and urban morphology. This involves calibrating models using local meteorological data and high-resolution land cover information.
- **Quantify local impacts:** Generate site-specific data on the effectiveness of different GRI types (trees, green roofs, other vegetated GRI) in reducing LST, improving air quality, enhancing biodiversity, and managing stormwater. This requires field measurements and potentially advanced remote sensing techniques.
- **Address Vancouver's unique challenges:** Consider Vancouver's specific challenges, such as steep slopes, proximity to water bodies, and existing green spaces, in the design and placement of GRI. The study should explore how these factors influence the effectiveness of GRI interventions.
- **Assess equity implications:** Ensure that the study incorporates an equity lens, analysing the distribution of GRI benefits across different neighbourhoods and socio-economic groups. This will inform strategies for equitable implementation of GRI.

Existing studies offer a strong foundation for understanding the potential benefits of GRI. A literature review can highlight transferable findings from other cities, quantifying of the co-benefits of GRI, such as urban heat island mitigation and biodiversity enhancement. These findings can provide justification for investing in GRI, offering evidence of its broader impacts across different geographic contexts. However, a localized study on the effectiveness and relative impacts of GRI in Vancouver would offer deeper and more context-specific insights. By tailoring models to Vancouver's unique urban, climatic, and topographical factors, a localised study can better inform GRI implementation strategies and policies to maximise the benefits of GRI. This can build on the data from the GI team's projects and experience on the contribution of ground infiltration of GRI in streets and boulevards, to include urban heat island mitigation, biodiversity enhancement in both the public and private realm. This would not only address urban ecological challenges but also ensure that investments in green infrastructure are equitably distributed, particularly to those neighbourhoods most in need of climate resilience interventions.

6.1.1 SCOPE OF WORK FOR NATURAL ASSET VALUATION STUDY (PHASE I)

In the context of urban densification in Vancouver, where the expansion of tree canopy may be constrained by space limitations, green roofs (a building-based GRI) could provide a viable alternative in terms of ecosystem services such as urban heat reduction, biodiversity support, rainwater diversion, and carbon sequestration. The city's current scope of work for the proposed **Natural Asset Valuation Study** includes both tree canopy and green roofs, focusing on evaluating their respective contributions and potential trade-offs. The author understands that the Study method proposes to assess ecosystem services and corresponding valuations of current and future natural assets, undertake an ecosystem service and valuation gap assessment, and perform a sensitivity analysis to determine the relative value of different natural assets to minimize that gap.

If the city wishes to conduct a high-level investigation of the potential benefits of GRI, starting with existing data sets such as LIDAR and tree canopy mapping, this preliminary approach can provide a general understanding of the spatial distribution and current extent of natural assets like tree canopy and green roofs, alongside a rough assessment of their associated ecosystem services. While this approach is less detailed and offers a broad overview of the current situation, it remains a cost-effective and faster way to begin the process. It can inform future studies and provide a useful baseline for more refined analyses.

However, if the city aims to achieve more accurate and context-specific results—particularly to assess trade-offs between different GRI options and ensure that investments in GRI are effective and equitable—it should consider adopting a calibrated model approach. This approach would involve tailoring models to Vancouver's unique urban conditions, utilizing high-resolution microclimate data, land cover maps, and other locally relevant datasets. Such a calibrated model would align with adaptive management strategies outlined in section 6.3, enabling the city to assess the performance of GRI in real-time across the urban landscape. This method would provide more precise and actionable insights into the impacts of green roofs and tree canopy in various neighborhoods, including heat-vulnerable or underserved areas. Other project scope considerations and recommendations are included below.

Natural Assets to be assessed: The city's current scope of work proposes to include both current **tree canopy** and **green roofs** as natural assets in Vancouver's urban landscape.

- For tree canopy, variation in tree species, density, and canopy cover may have an effect on the co-benefits of the tree canopy cover.
- Consider various types of green roofs:
    - **Extensive green roofs** (lightweight, low maintenance with sedums, mosses),
    - **Intensive green roofs** (heavier, supporting a wider range of plants and potential small trees).
- A follow-up study could include the effects of other vegetated GRI such as rainwater tree trenches, bioretention practices; permeable paving (albeit only on heat reduction and rainwater diversion); larger landscape approaches such as constructed wetlands and stream daylighting; and the impact of increased connectivity of blue-green systems, as for example planned along the greenways. These considerations are further elaborated upon in section 6.2.6.

Co-Benefits to Be Valued: The city's current scope of work proposes to include urban heat reduction, biodiversity, rainwater diversion, and carbon sequestration.

- **Urban Heat Reduction**: Assess how GRI and tree canopy help reduce local temperatures.
- **Biodiversity**: Assess how tree canopy and GRI support local wildlife and increase habitat availability and connectivity.
- **Rainwater Diversion**: Evaluate GRI's role in mitigating stormwater runoff and its impact on flood risk management.
- **Carbon Sequestration**: Quantify the amount of CO2 sequestered by trees and green roofs.

Geography: The city's current scope of work proposes to assess co-benefits by different geographic areas, including: citywide, catchment area, and by property ownership (public, private).

- Citywide or neighborhood-level (focus on areas with high heat vulnerability, stormwater concerns, and limited open space), depending on the level of resources available and level of detail desired.
- Include both **public and private properties**, including residential, commercial, and institutional properties with existing or potential green roofs, but differentiate assets between public and private in the valuation analysis to be able to make recommendations on investments, incentive programmes based on their respective contributions.

6.1.2 METHODOLOGY FOR CO-BENEFITS VALUATION

BASELINE ASSESSMENT

Quantify Current Assets:
- Map existing **tree canopy** (using high-resolution satellite imagery, NDVI, and LIDAR data). Metrics: Tree canopy cover (m², %) and tree density.
- Quantify existing **green roof** areas (using satellite imagery and GIS data to distinguish between intensive and extensive green roofs). Metrics: Area of green roofs (m²), type of green roof (intensive vs extensive), vegetation type and coverage.

Determine Benefits of tree canopy and green roofs to calculate baseline ecosystem service benefits, including heat reduction, biodiversity enhancement, rainwater diversion, and CO2 sequestration.

To quantify **heat reduction benefits (°C),** especially temperature mitigation during peak heat events, use:
- **i-Tree Eco Model**: Utilize i-Tree Eco to quantify the heat island mitigation effects of tree canopy, including the influence of trees on local temperatures and UHI reduction at a citywide scale.
- **Microclimate Modeling**: Use high-resolution models like **ENVI-met** (Makido et al., 2019; Epelde et al., 2022) to simulate temperature changes at a fine spatial scale. This model helps assess the impact of different green roof configurations on local temperatures across various neighborhoods.
- **GSI Impact Calculator**: Leverage the GSI Impact Calculator for additional resources to quantify heat reduction benefits, including the ability to estimate the temperature mitigation potential of green roofs at the city level.

To quantify **biodiversity support (habitat quality and connectivity)** benefits, use:
- **Biodiversity Surveys**: Draw on existing and conduct field surveys to assess the current biodiversity in Vancouver's urban areas, focusing on species richness, population dynamics, and the availability of habitat types.

- **Habitat Quality Rating**: Quantify biodiversity by using the **Habitat Quality (HQ) model** (Ronchi & Salata, 2022) to assess the quality of habitat provided by green roofs. The habitat quality rating ranges from low to high, based on factors like vegetation diversity and the provision of critical resources for species.
- **Habitat Connectivity**: Evaluate habitat connectivity using the **Transversal Connectivity Index** (Hysa, 2021), which measures the extent to which GRI enhances habitat connectivity across fragmented urban landscapes.
- **GSI Impact Calculator**: Use the GSI Impact Calculator for a broader assessment of habitat quality and connectivity, offering metrics that combine habitat value and the ability to connect isolated ecosystems.

To quantify **rainwater retention/diversion (m^3 or Litres per Year)**, use:

- **Hydrological Modeling**: Use hydrological models such as EPA's **SWMM** (Storm Water Management Model) to assess how tree canopy and green roofs impact stormwater runoff and flooding. These models will simulate the interaction between GRI and local topography, rainfall patterns, and drainage infrastructure in Vancouver.
- **GSI Impact Calculator**: Utilize the GSI Impact Calculator for additional resources, including data on flood risk reduction and the ability of GRI to retain rainwater and reduce runoff.

To quantify **CO_2 Sequestration (kg or Tons CO_2 per Year)**, use:

- The **i-Tree Eco** to estimate the carbon sequestration potential of tree canopy by modeling tree growth, carbon storage, and sequestration over time. The tool applies allometric equations to predict how much carbon is sequestered by trees based on species, diameter, and canopy size. This will help estimate how much CO_2 is sequestered annually and in the long term (tons per year).
- The i-Tree tool can also be used to quantify the trees' ability to remove air pollutants such as PM2.5, O3, and CO2. This aspect can be modeled using the i-Tree Eco tool, which estimates the mass of pollutants removed by trees.

Comparative analysis:

- Perform a comparative analysis using the models to quantify the benefits per square meter of tree canopy and green roof.
- Generate a summary of the co-benefits in terms of carbon sequestration (kg CO2 per m^2/year), heat reduction (°C), rainwater diverted (m^3), and biodiversity support (species richness, habitat quality).
- Make a relative comparison of co-benefits effects of tree canopy vs green roofs.

MONETARY VALUATION AND EQUITY ANALYSIS:

The city's current scope of work proposes to explore the economic benefits of GRI and potential monetization of ecosystem services (e.g., carbon sequestration, heat reduction, improved air quality). A cost-benefit analysis may also be part of this work. The GSI Impact Guide provides a useful framework for understanding economic benefits. This could include valuing the canopy cover and green roofs as part of the "Phase II" modeling work to justify their uptake.

Starting points:

- Apply economic valuation frameworks (e.g., **Natural Capital Protocol**) to estimate the monetary value of ecosystem services provided by both tree canopy and green roofs.
- Use **social cost of carbon** for carbon sequestration and other market-based frameworks for heat reduction and stormwater management benefits.

- Employ **benefit transfer** techniques or **ecosystem service valuation frameworks** (e.g., TEEB or Natural Capital Protocol) to estimate the economic value of these services.

6.1.3 FUTURE PROJECTIONS

The city's current scope of work proposes to forecast changes in quantity of natural assets.

Forecast Future Natural Assets: Model how future urban densification and development might impact the tree canopy and green roof coverage (e.g., through increased construction or retrofitting of buildings).

Land Use Change Models (e.g., UrbanSim, LUCC) can be used to simulate the impact of urban densification on the spatial distribution of tree canopy and green roofs, taking into account factors like construction, retrofitting of buildings, and urban renewal projects.

Forecast changes in the type, density, and extent of tree canopy and green roofs, considering potential land use changes and regulatory incentives for GRI installations.

GIS tools (e.g., ArcGIS, QGIS) can be used to map and visualize potential areas of expansion or loss in tree canopy and green roofs due to construction or retrofitting.

i-Tree Eco can be used to project future tree canopy coverage based on expected growth patterns, species selection, and planting strategies. The tool can also model the effect of regulatory incentives, like tree planting programs or GRI mandates.

Based on these forecasts, conduct scenario planning for two primary strategies:

1. **Add More Tree Canopy**: Model the potential increase in tree canopy cover in various urban zones, considering planting strategies, species choices, and space availability.
2. **Add More Green Roofs**: Simulate the expansion of green roofs, factoring in regulatory incentives (e.g., green building codes, stormwater management credits) and spatial availability on rooftops.

Hana Larson's (2022) research shows a methodology for a site suitability analysis, that might assist with the planning of future green roofs: [link to StoryMap]

Forecast Benefits: Use projection tools like **i-Tree Eco, ENVI-met microclimate modeling, HQ model, Transversal Connectivity Index, SWMM, GSI Impact Calculator** to assess how increasing tree canopy or expanding green roof coverage could mitigate heat islands, enhance biodiversity simulate potential changes in carbon sequestration runoff based on varying GRI scenarios.

6.1.4 GAP ANALYSIS AND VALUATION

The city's current scope of work proposes to undertake an ecosystem service and valuation gap analysis relative to a baseline reference.

Quantify the gap in tree canopy and green roof coverage compared to a desired future state (e.g., based on city targets or climate resilience goals). The ecosystem service demand can be derived from an overlay with for example the heat exposure/sensitivity/vulnerability maps from the Vancouver Health Authority and the sensitive ecosystems map from Metro Vancouver.

Valuation Gap: Estimate the monetary gap in ecosystem service benefits (e.g., reduced heat island effect, carbon sequestration, rainwater retention) relative to baseline levels.

The outcomes of the study can be used to provide recommendations for the strategic implementation of GRI, considering factors such as cost-effectiveness, feasibility, and socio-spatial equity. The natural asset valuation study might benefit from being complemented with:

- **Species-Specific Analysis:** The CoV might want to conduct a detailed analysis of the local flora and fauna to inform the selection of appropriate plant species for GRI projects. This will ensure that the chosen species are well-suited to Vancouver's climate and contribute to biodiversity enhancement.
- **Equity-Focused Assessment:** The CoV should conduct an equity analysis to ensure that the benefits of GRI are distributed fairly across all neighbourhoods, addressing potential disparities in access to green spaces and environmental benefits.
- **Cost-Benefit Analysis:** A comprehensive cost-benefit analysis is needed to evaluate the economic viability of different GRI options. This should consider both the upfront costs of implementation and the long-term benefits, including reduced energy consumption, improved public health, and enhanced property values.
- **Community Engagement:** Meaningful community engagement is crucial to ensure that GRI projects are aligned with community priorities and preferences. This will increase the likelihood of successful implementation and long-term maintenance.

6.1.5 CHALLENGES TO CONSIDER

Data requirements: High-resolution land cover, microclimate, and socio-economic data are critical for modeling and analysis. Consider potential gaps in available data and the need for additional data collection.

Modeling Complexity: High-resolution urban modeling requires expertise in both environmental and urban planning fields. The proposed RFP should emphasize the need for collaboration with local experts in urban forestry, ecology, hydrology, and climate modeling. This will ensure the study's relevance and accuracy.

Cost & Time: Ensure that sufficient time and budget are allocated for model development, calibration, data collection, and analysis.

Information Gaps: While the literature review and case studies provide valuable insights, further research may be needed to address specific information gaps relevant to Vancouver, such as:

- **Local species data:** Detailed information on the biodiversity of Vancouver's urban ecosystems is needed to inform biodiversity modeling.
- **Microclimate data:** High-resolution microclimate data for different neighbourhoods in Vancouver is needed to calibrate microclimate models accurately.
- **Community preferences:** Understanding community preferences and priorities regarding GRI is essential for ensuring equitable and effective implementation.

This updated scope ensures that both tree canopy and green roofs are valued not only in terms of their standalone benefits but also for how they complement each other in the context of Vancouver's urban landscape. By focusing on both ecological and economic valuation methods, this study will provide Vancouver with actionable data to guide future urban greening strategies, optimize ecosystem service benefits, and meet sustainability goals.

6.1.6 CONSIDERATIONS FOR EXPANSION OF SCOPE

Proposed Expansion	How to Quantify	Pros	Cons
1. Include Other Vegetated GRI (e.g., bioretention, rainwater tree trenches) and entire park areas (shrubs, grass, water)	**Heat Reduction**: Use tools like ENVI-met to examine temperature variations in areas with diverse vegetation and green infrastructure. **Ecological Surveys**: Utilize GIS mapping and field surveys to assess biodiversity, species richness, and plant diversity across vegetated GRI and park areas. **Hydrological Modeling**: Apply models (e.g., EPA's SWMM) to evaluate how different vegetated green infrastructure impacts rainwater management. **Carbon Sequestration Calculations**: Estimate CO2 sequestration potential from different vegetated surfaces using the i-Tree Eco tool.	Including all vegetated green infrastructure allows for a comprehensive assessment of their relative benefits, enabling informed trade-offs in urban planning, especially crucial in the context of increasing densification. This can build on existing data from the GI team on the contribution of ground infiltration of GRI in streets and boulevards. The effort to include these elements is manageable and can significantly enhance the understanding of how different vegetation types contribute to urban resilience and sustainability.	While rainwater management data already exists for vegetated GRI on streets and boulevards, parks and private spaces would need to be included to be complete. There are relatively fewer studies that quantify heat reduction, biodiversity, and sequestration benefits from other vegetated GRI tools compared to trees and green roofs. Therefore, methodologies would need adaptation to effectively capture these benefits. Could increase time and costs associated with data aggregation and analysis.
2. Include Permeable Paving	**Heat Reduction**: Employ thermal imaging and microclimate models to examine local temperature changes in areas with permeable paving. **Hydrological Modeling**: Assess the impact of permeable paving on stormwater management using models to measure rainwater diversion effects.	Simpler to quantify than other green infrastructure components. Addresses specific urban issues like heat and stormwater runoff.	Impacts are limited to specific areas like heat reduction; broader co-benefit evaluations may not align with natural asset valuation. As a result, it is difficult to include these findings to make holistic tradeoffs regarding biodiversity and carbon sequestration.
3. Include Impact of Landscape Approaches (Restoring streams and Constructed Wetlands)	**Heat Reduction:** While direct effects may be limited (these measures might be implemented in areas with lower UHI effect), use land surface temperature analyses to quantify any localized cooling effects associated with these approaches. **Ecological Impact Assessments**: Measure changes in biodiversity and habitat quality in response to larger landscape interventions. **Hydrological Modeling:** Assess changes in water retention and quality through constructed wetlands and daylighted streams. **Carbon Sequestration**: Specific modeling tools may be necessary to quantify the sequestration potential of wetland vegetation, as i-Tree Eco primarily focuses on tree canopy. Can employ other ecological models focused on wetland dynamics to estimate carbon benefits.	While larger landscape approaches are complex to manage, quantifying their benefits can provide a compelling justification for investing the necessary effort, showing that the long-term ecological and social returns are worth the complexity involved. This expanded scope can help demonstrate to stakeholders the significant impacts that such projects can have on urban resilience, biodiversity enhancement, and overall quality of life in increasingly dense urban settings.	Expands the scope and complexity of data collection and necessitates collaboration across departments (restoring streams is managed by a different department than GRI) Limited existing data specific to the quantification of benefits for larger landscape approaches may necessitate new methodologies. Assessing multiple variables for these projects could significantly extend project timelines.
4. Evaluate the Impact of Increased Connectivity Through Greenways	**Spatial Analysis:** Use GIS to assess changes in connectivity and the Transversal Connectivity Index to measure correlated impacts on local microclimates. biodiversity, rainwater management and carbon sequestration. **Biodiversity Monitoring:** Evaluate species interactions and habitat quality across connected natural assets.	Enhances understanding of how improved connectivity impacts local temperatures, biodiversity, and carbon sequestration. Addresses urban fragmentation, promoting ecosystem resilience and health. Provides data on integrating multi-functional greenways for effective urban planning. Supports evidence-based decision-making for climate adaptation strategies.	Requires advanced GIS tools and additional ecological monitoring, possibly leading to higher costs and complexity of analysis. Extended project timelines due to the necessity for detailed monitoring and studies. Challenges in interpreting multi-faceted data and correlating all benefits accurately.

6.2 ADOPTION OF GRI IN MUNICIPAL CLIMATE ADAPTATION PROGRAMS

This section provides recommendations for the City of Vancouver (CoV) based on learnings from case study interviews in Toronto, Detroit, and Philadelphia, focusing on municipal climate adaptation programs and improving GRI implementation, particularly on private property.

6.2.1 ROLE OF GRI IN MUNICIPAL CLIMATE ADAPTATION PROGRAMS:

The CoV should consider referencing the role of specific GRI types, such as tree canopy and green roofs, in its CCAS. The strategy could clearly articulate the environmental benefits of these GRI types (heat reduction, biodiversity enhancement, stormwater management) and outline specific targets and implementation plans and link them to existing GRI assets. The findings from the Natural Asset Valuation Study could help to quantify and visualise the localised and citywide benefits. This would provide a clear roadmap for action and help to prioritize investments in GRI.

The CoV should consider drawing inspiration from and adapting successful programs from other cities, focusing on several key areas:

- **Community-Led Initiatives (Inspired by Toronto's PollinateTO):** Establish a funding program for community-led GRI projects, emphasising biodiversity and public visibility. This program should prioritize projects that address local needs and involve community members in the design, implementation, and monitoring phases. The program should include clear guidelines for project selection, emphasising biodiversity benefits and community engagement. A key element is public visibility – showcasing successful projects to encourage wider adoption.
- **Integrated Design Standards (Inspired by Detroit):** Consider updating building codes and design standards to integrate GRI considerations into new developments and renovations. This could include requirements for green roofs on new buildings, permeable pavements in parking lots, and the incorporation of rain gardens in landscaping. The standards should be flexible enough to accommodate different building types and site conditions while still achieving significant environmental benefits.
- **Long-Term Monitoring and Maintenance (Addressing shortcomings in all three cities):** Consider establishing a robust system for monitoring and maintaining GRI installations, both in public and private spaces. This should include regular inspections, data collection on performance, and mechanisms for addressing maintenance issues. Consider establishing a dedicated maintenance fund or exploring public-private partnerships to ensure long-term sustainability. The monitoring system should track not only stormwater management but also heat reduction and biodiversity impacts.
  Expand the monitoring system to not only track rainwater detention/ retention but also assess the health of the surrounding ecosystem, such as heat reduction and urban biodiversity. This will help demonstrate the broader environmental benefits of GRI beyond stormwater management.
- **Inter-Departmental Collaboration (Addressing challenges in Detroit and Philadelphia):** Consider establishing a cross-departmental task force or working group to coordinate GRI implementation across different city departments (e.g., parks, water, planning). This will ensure a cohesive and efficient approach, avoiding conflicting priorities and duplication of efforts. Clear roles and responsibilities should be defined for each department.

- **Equity-Focused Implementation (Addressing shortcomings in all three cities):** Use the existing equity framework to guide the implementation of GRI, ensuring that the benefits are distributed fairly across all neighbourhoods. This should involve prioritising projects in underserved communities where heat exposure and lack of green space are most prevalent. Community engagement is crucial to ensure that projects meet local needs and preferences.

6.2.2 IMPROVING GRI IMPLEMENTATION ON PRIVATE PROPERTY

To achieve the desired rainwater detention or retention targets for the private sector, while also maintaining sustainable and scalable approaches, the following recommendations are proposed:

Incentive Programs for Private Property (Building on Toronto and Philadelphia):

- Consider creating an incentive program to reward the incorporation of retention-based GRI, such as green roofs, rain gardens, and permeable pavements. This would help balance detention approaches with other approaches that offer environmental benefits like heat reduction and biodiversity.
- Consider creating a tiered incentive structure where property owners who implement higher levels of rainwater management or incorporate additional GRI features beyond current requirements, receive greater benefits. This could include tax breaks, rebates, or reduced permit fees.
- In addition to offering financial incentives and tax breaks, consider partnering with local utilities to offer water rate discounts for properties with high-quality stormwater management systems. This would create an additional financial motivation for private property owners.
- Any incentive program designed to support private developers through local government initiatives must undergo careful consideration of cost-benefit analyses, ensuring that public funds are utilized effectively and that the incentives truly encourage sustainable practices without placing an undue burden on taxpayers.

Targeted Outreach and Pilots:

- In parallel with development of potential future retention-based policies, consider developing targeted outreach and information campaigns to inform private property developers about the benefits of GRI and available incentive programs. This could include workshops, online resources, and case studies showcasing successful GRI installations.
- Foster strong partnerships between the city, developers, property owners, and stormwater management experts. This should include clear communication about the goals of rainwater policy and the specific requirements under the VBBL.
- For advancing potential retrofit programs, consider engaging private property owners early in the process to explain the benefits of stormwater management, both in terms of compliance and long-term environmental impact (e.g., reduced flooding risk, water conservation).
- Consider implementing pilot projects to test different GRI approaches and gather data on their effectiveness in Vancouver's specific context. This will provide valuable information to inform future implementation strategies.

Maintenance and Performance:

- Consider developing a certification or performance-based recognition program that highlights properties achieving superior stormwater management outcomes (e.g., properties that manage more than that currently required). These could serve as examples and encourage other property owners to follow suit.

- Consider creating a dedicated fund for the long-term maintenance of retention-based rainwater management systems, perhaps funded by developers, which ensures systems are well-maintained and operational over time.
- Consider creating a partnership with private contractors or service providers to offer maintenance packages for GRI installations, ensuring that private property owners have access to affordable, professional support for maintaining their systems.

Promote Flexible, Innovative Solutions:

- Allow for more flexibility in how property owners meet retention-based rainwater management requirements. For example, offer the option to aggregate requirements across multiple properties (e.g., shared systems or stormwater cooperatives) to allow for innovative, cost-effective solutions.
- Consider encouraging the use of decentralized stormwater management solutions (e.g., rain gardens or permeable paving) that both reduce pressure on detention tanks and contribute to broader environmental benefits.

Technical Assistance and Streamlined Permitting:

- Consider providing a robust support system for property owners, including design guidelines. This will ensure that property owners can design and install GRI systems that meet the required standards and maximize the effectiveness of detention and retention.
- Consider simplifying the permitting and approval process for retention-based GRI systems and detention systems to encourage greater private sector uptake.

Data-Driven Monitoring and Transparency:

- Set up a citywide, real-time monitoring system to track the performance of rainwater management systems. This data can be used not only to measure compliance with targets but also to provide transparency about the effectiveness of different stormwater management techniques, helping to refine policies over time.
- Incorporate regular inspections of rainwater management systems, with penalties for non-compliance or inadequate maintenance, to ensure long-term sustainability.
- Provide a digital platform with tools such as an online stormwater management calculator, allowing property owners to assess their property's stormwater runoff and design solutions accordingly. This can empower property owners to make informed decisions.

6.3 ADAPTIVE MANAGEMENT STRATEGY FOR GRI

1. DEVELOP ROBUST DATA TRACKING AND INTEGRATION SYSTEMS

Phasing: Short-term Ongoing Improvement

Why: The challenge of tracking GRI impacts, especially on private versus public lands, was a common theme in the interviews. Data gaps and outdated methodologies are a significant barrier for cities like Toronto and Philadelphia in tracking GRI impacts. Vancouver can avoid these pitfalls by developing a modern, scalable system with clear standards for data collection and integration.

RECOMMENDATIONS

Leverage Existing Strategies: Build on the existing data collection efforts outlined in the Urban Forestry Strategy (e.g., LiDAR and i-Tree methods) and the Biodiversity Strategy, which already emphasize regular monitoring of canopy coverage and ecosystem health.

Harmonize Data Tracking of Climate Adaptation Progress: Bring together data from different departments in one platform (convert data types where necessary) and formulate goals for the data tracking system to be relevant to the latest climate change adaptation strategies (e.g., tree planting goals in underserved neighbourhoods from the Climate Change Adaptation Strategy). Ensure the system tracks performance indicators identified in the natural asset valuation study, such as changes in tree canopy extent, stormwater runoff, and biodiversity quality.

Pilot Scalable Tracking Systems: Establish a formal process for integrating data across different GRI initiatives (e.g., green roofs, permeable pavements, parks) into a holistic monitoring system. This could involve the development of digital platforms like a public-facing dashboard or interactive maps for ongoing public engagement and decision-making.

Develop a Digital Platform: Establish a comprehensive, citywide integrated GIS-based mapping system or dashboard for visualising GRI impacts such as heat reduction, biodiversity, stormwater retention, and CO2 sequestration across the city. This should integrate data from both public and private land, ensuring continuity even with changes in property ownership, considering the challenges of homeowner turnover, as noted in Toronto's PollinateTO program. Include public-facing features to engage residents and stakeholders.

2. SECURE FUNDING AND STAFFING FOR LONG-TERM MONITORING

Phasing: Immediate to Medium-term

Why: One of the critical challenges identified across cities was the issue of resource limitations, especially in underserved neighbourhoods. Without sufficient funding and staff resources dedicated to long-term monitoring, adaptive management efforts will face obstacles in evaluating and improving GRI effectiveness.

RECOMMENDATIONS

Establish dedicated funding programs for long-term monitoring efforts. This should include allocating funds for specialized roles focused on climate adaptation and GRI tracking, ensuring consistent data collection and analysis over time. This could include grants for private property owners to install or maintain green roofs and track their environmental benefits.

Prioritize resources for underserved neighbourhoods, ensuring that vulnerable communities are not excluded from the benefits of GRI initiatives and their monitoring. Prioritize monitoring and adaptation efforts in neighbourhoods with below-average tree canopy coverage, as outlined in the Climate Change Adaptation Strategy. Offer targeted grants or incentives for green infrastructure monitoring in areas with limited access to resources.

Ensure staffing capacity by creating roles within municipal departments (e.g., climate resilience teams) or through collaborations with external organizations. This could include partnerships with external organizations (e.g., academic institutions) for technical expertise in data collection and analysis. Align staff roles with the goals in the Urban Forestry Strategy, especially those around canopy tracking and ecosystem health.

3. SHIFT TO PROACTIVE, NOT JUST REACTIVE, ADAPTIVE MANAGEMENT

Phasing: Medium-term

Why: Many cities, including Philadelphia, have relied on reactive measures (e.g., responding to work orders) as a measure of success. However, effective adaptive management requires a proactive approach, where climate adaptation goals are clearly defined, regularly evaluated, and adjusted based on data.

RECOMMENDATIONS

Establish SMART goals for all GRI programs and climate adaptation initiatives. Establish Specific, Measurable, Achievable, Relevant, Time-bound goals for GRI implementation in alignment with broader climate adaptation objectives (e.g., increasing canopy cover to 30% by 2050). These goals should address heat reduction, biodiversity enhancement, rainwater management and decarbonisation as defined in the RCS, Climate Change Adaptation Strategy, Urban Forestry Strategy, and Biodiversity Strategy.

Incorporate regular evaluation cycles (e.g., every 1–2 years) to assess the effectiveness of adaptation measures. This can involve revisiting program goals, collecting data from various sources, and adjusting strategies as necessary to meet climate targets. Use tools like i-Tree Eco and stormwater management models to evaluate success and guide adjustments.

Implement regular program adjustments based on monitoring outcomes, ensuring that GRI initiatives evolve to address emerging climate challenges (e.g., increased stormwater events or shifting biodiversity patterns).

Develop Early Warning Systems: Establish proactive systems to identify emerging challenges (e.g., increased flood risk, biodiversity shifts) and adjust GRI strategies accordingly.

4. STRENGTHEN COMMUNITY ENGAGEMENT AND EXTERNAL PARTNERSHIPS

Phasing: Short-term to Medium-term

Why: Effective adaptive management requires collaboration between multiple stakeholders, including internal city departments, the community, and external experts. Lessons from Detroit and Philadelphia highlight the value of community feedback and external partnerships in shaping adaptive strategies.

RECOMMENDATIONS

Expand community engagement efforts through surveys, workshops, and participatory planning processes. This will ensure that local perspectives, particularly from vulnerable and underserved communities, are incorporated into climate adaptation strategies.

Foster inter-departmental collaboration by establishing cross-functional teams (e.g., from Parks, Transportation, Housing, and Environmental Services) to ensure that GRI efforts are integrated into broader urban planning and climate resilience strategies.

Leverage external partnerships with academic institutions, NGOs, and other experts (e.g., for biodiversity monitoring, stormwater management best practices). These partnerships can help bridge knowledge gaps and provide additional resources for implementing and evaluating adaptation measures.

5. DEVELOP ADAPTIVE TOOLS FOR REAL-TIME MONITORING AND EVALUATION

Phasing: Medium to Long-term
Why: Real-time monitoring and the ability to adapt quickly to new data is a key element of successful adaptive management. Tools that provide timely insights into climate adaptation efforts allow for quicker responses to emerging challenges and more informed decision-making.

RECOMMENDATIONS:

Real-Time Digital Platforms: Develop or expand existing digital tools (e.g., mobile apps, online dashboards) to track key performance indicators for GRI and climate adaptation metrics, including heat reduction, biodiversity, stormwater retention, and CO2 sequestration. Make these platforms accessible to both city staff and the public.

Enhance GIS-based mapping tools to provide dynamic, interactive visual tracking of GRI performance across the city, making it easier for city planners, community members, and stakeholders to access actionable insights. This should include visualizations of the spatial distribution of green roofs, tree canopy, and stormwater detention systems.

Create a centralized dashboard for city staff and the public to access relevant data, track performance, and view the status of GRI initiatives across the city. This hub could also include a real-time stormwater runoff calculator for property owners.

7. CONCLUSIONS AND LIMITATIONS

This study provides valuable insights into how Green Rainwater Infrastructure (GRI) can be utilized by the City of Vancouver (CoV) to address climate adaptation challenges, specifically urban heat reduction and biodiversity enhancement. Drawing from the literature review, expert interviews, and case studies in other jurisdictions, it was evident that GRI systems, such as green roofs, urban forests, and permeable pavements, have shown significant potential in mitigating urban heat, improving biodiversity, and enhancing stormwater management. The study also emphasizes the need for a tailored approach, taking into consideration Vancouver's unique climatic conditions, urban structure, and topography.

Key findings include:

1. **Effectiveness of GRI:** The use of models to measure GRI implementations in cities like Toronto, Detroit, and Philadelphia have demonstrated the effectiveness of these systems in reducing surface temperatures, improving biodiversity, and managing rainwater. However, the models used to demonstrate the effectiveness of GRI systems in other cities often require adaptation/calibration to Vancouver's context, given its temperate rainforest climate and diverse urban conditions.
2. **Challenges in Monitoring and Data Collection:** A common challenge highlighted across jurisdictions is the difficulty in tracking the long-term impact of GRI projects due to insufficient data, outdated methodologies, and resource constraints. The City of Vancouver must invest in modernized data tracking systems and more robust monitoring frameworks to overcome these barriers.
3. **Equity Considerations:** Ensuring that the benefits of GRI projects are distributed equitably across Vancouver's neighbourhoods, particularly in underserved communities, is a central concern. Prioritizing vulnerable areas for GRI interventions can help address climate resilience disparities and ensure that all residents benefit from GRI's environmental and social advantages.

Limitations: While this study offers an extensive review of best practices, case studies, and expert insights, there were several limitations in terms of what the study was able to fully address:

1. **Local Context-Specific Data Gaps:** Although the study suggests conducting a localized Natural Asset Valuation Study and modelling GRI impacts using tools like ENVI-met and i-Tree, the actual modelling and data collection specific to Vancouver's diverse microclimates and urban settings were beyond the scope of this project. Further, these models require refinement to accurately reflect the complexities of Vancouver's topography and climate.
2. **Quantitative Validation of GRI Impact:** The study's findings are based primarily on qualitative insights from interviews and case studies, and a more robust quantitative analysis of GRI's effectiveness in Vancouver is recommended. The report does not fully address how specific GRI interventions will quantitatively contribute to urban heat reduction and biodiversity enhancement in Vancouver's unique urban environment.
3. **Limited Engagement with Vancouver-Specific Stakeholders:** While the study includes interviews with experts from other cities and organizations, the direct input from Vancouver-based stakeholders, such as city planners, local environmental groups, and community organizations, was limited due to project scoping and resourcing considerations. Their perspectives would be crucial for understanding local concerns, opportunities, and barriers to GRI implementation within the city.
4. **Long-Term Sustainability and Adaptive Management:** The study outlines recommendations for adaptive management, but it does not fully address the complexities of long-term sustainability. Key aspects, such as ensuring long-term funding for GRI maintenance and the challenge of integrating adaptive management into existing city processes, require further exploration.

In conclusion, while this study provides a strong foundation for the City of Vancouver to move forward with GRI initiatives, further in-depth research, localized modelling, and stakeholder engagement are necessary steps to refine these recommendations and implement GRI successfully at a citywide scale.

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