Scoping an Online Green Roof Asset Tracking and Inventory Management System for the City of Vancouver

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Disclaimer

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Executive Summary

Urban stormwater management is currently undergoing a paradigm shift away from traditional grey stormwater infrastructure, which treats stormwater as a hazard, to nature-based green rainwater infrastructure, which treats stormwater as a resource. Following this shift, the City of Vancouver is exploring the use of green roofs to manage Vancouver's rainwater more sustainably by retaining and treating rainwater where it falls, decreasing peak flows through rainwater detention, and preventing contamination of natural water bodies. Green roofs are partially or fully vegetated roofs that can vary considerably in form and function. They range from extensive roofs planted with sedum with restricted access, to intensive roofs planted with grasses, shrubs, and trees with amenity space accessible to the public. The specific characteristics and features of a green roof determine its use and co-benefits, or the benefits produced by the roof beyond stormwater management. In order to quantify and qualify these co-benefits, providing insight into the impacts of green roof installations within the city, the City of Vancouver is considering implementing a Green Roof Asset Tracker tool and program. Under this program, specific green roof indicators would be systematically tracked by City staff, with the option to develop a public-facing, interactive online map of green roof locations and features to inform and engage Vancouver residents. This study serves to provide foundational information, propose trackable indicators, and present recommendations to the City to prepare for the potential development of the Green Roof Asset Tracker. A mixed-methods approach is used that includes case studies of several municipalities with green roof tracking programs.

Although the impetus for this study comes from the City of Vancouver's Rain City Strategy, green roofs are shown to connect to and support a wide range of City of Vancouver bylaws, guidelines, plans and strategies. Green roof co-benefits can enhance biodiversity, provide residents with access to nature, serve as spaces for childcare, provide opportunities for urban agriculture, mitigate the impacts of climate change, and support equity goals. Trackable green roof indicators were considered across these categories alongside indicators focused on green roof QA/QC. A final master indicator list was compiled based on the findings of a green roof literature review, a City document analysis, informal interviews with City staff and green roof experts, and three case studies. The cities selected for case study provide insight into green roof/green rainwater infrastructure tracking programs in various stages of development. Chicago, Illinois, represents a municipality that has previously conducted studies on green roofs within the city, but has yet to formalize long-term tracking. Portland, Oregon, can provide recommendations for a smaller, more intermediary green rainwater infrastructure tracking program, and Washington D.C. represents a robust and mature green rainwater infrastructure tracking program. The case studies serve as a basis for making indicator, public-facing map, and tracking program recommendations.

Short-term and long-term recommendations are made based on the results of this study with focus on four topics: 1. green roof indicators to be tracked by the program, 2. features and management of a public-facing mapping tool, 3. operation requirements and function of a green roof/green rainwater infrastructure asset tracker program, and 4. possible next steps in preparation for potential development of the City's Green Roof Asset Tracker tool and program. While green roofs are only one of many forms of green rainwater infrastructure used in Vancouver, they are uniquely situated to allow for public engagement and education, and the case studies provide evidence for significant public interest in green roofs, as well as examples of possible academic and private partnerships. This study is meant to serve as a starting point for future work that holistically considers green rainwater infrastructure networks in Vancouver, building from the green roof-specific results and methods presented in this report.

1. Introduction and Study Objectives

As urban populations increase and climate change alters global precipitation patterns, cities across the world increasingly face water quantity and quality issues. One method by which to manage urban stormwater more sustainably and improve the resilience of existing water supplies is for cities to make the shift from traditional grey stormwater infrastructure (engineered systems including gutters, drains, pipes, and outfalls) to green rainwater infrastructure (nature-based tools including rain gardens, bioswales, permeable pavement, and green roofs). Many cities, including Vancouver, have historically relied on combined sewer systems that manage both stormwater runoff and wastewater from residential, commercial, and industrial facilities by combining flows into a single pipe. These systems are frequently overwhelmed by high intensity storms and increased wastewater from growing urban populations (Pennino, McDonald, & Jaffe, 2016). The transition from grey to green rainwater infrastructure marks a paradigm shift away from command-and-control stormwater management, under which stormwater is treated as a hazard to be transported away from populated areas as quickly as possible, towards more sustainable, nature-based stormwater management that treats stormwater as a resource and manages rainwater where it falls to mimic natural flow regimes. Green rainwater infrastructure can enhance groundwater recharge, minimize flooding and overland flow, mitigate the water quality issues presented by polluted urban runoff entering surface water bodies, and can in some cases increase water supplies by supplementing available water for non-potable, outdoor use (Halsall, 2010; Shafique, Kim & Rafiq, 2018).

In November, 2019, the City of Vancouver implemented the Rain City Strategy, which was developed in response to the city's stormwater management challenges and calls for improved water quality, increased water supply and climate resilience, and enhanced city livability. Green roofs, or roofs that are "partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane", are mentioned by the strategy as a specific form of green rainwater infrastructure that can help accomplish the city's stormwater goals (Rain City Strategy, 2019, p.142). Green roofs are also listed as a preferred 'Tier 1' solution in the City's Rainwater Management Bulletin. Green roofs have been shown to effectively manage rainwater on site, mitigate urban heat island effects, reduce building carbon emissions associated with heating and cooling, and provide amenity space for residents (Halsall, 2010). However, these potential benefits are tied directly to the specific characteristics of a green roof, which can range in design from extensive roofs planted only with grass or sedum that are inaccessible to residents, to intensive roofs planted with a variety of trees, shrubs, and grasses that can be accessed by residents for multiple uses (Halsall, 2010; Shafique, Kim & Rafiq, 2018). While green roofs are prevalent in North American cities, their characteristics, and thus specific performance, function and benefits, are often not quantified or tracked (Greenroofs.com, 2023). Tracking specific green roof characteristics and features spatially and temporally can provide insight into the overall performance of a city's green roofs as tools for stormwater management as well as a range of other potential functionalities, such as climate change mitigation and adaptation, biodiversity support, access to nature, and amenity space provision.

In order to effectively and transparently track Vancouver's green roofs and their associated impacts, the City of Vancouver seeks to explore development of a GIS-based Green Roof Asset Inventory and Mapping Tool (Green Roof Asset Tracker). The Green Roof Asset Tracker is envisioned to use a comprehensive set of indicators to store and track data on green roof projects and associated performance trends, displaying both public- and internal-facing information, thereby serving as an educational and adaptive management policy tool that advances both quality assurance and demonstrates optimization of co-benefits. The aim of this report is to provide foundational information, propose trackable indicators, and present recommendations to the City to prepare for the potential development of the Green Roof Asset Tracker. The following questions will be addressed:

1) What co-benefits can Vancouver's green roofs provide to advance a wide range of City goals such as stormwater management, urban heat island mitigation, biodiversity enhancement, access to nature, amenity space provision, urban agriculture accommodation, childcare space enhancement, and public education? How can these co-benefits support specific City of Vancouver strategies, policies and programs?

2) Which green roof features and characteristics (indicators) should be tracked by the City in order to assess green roof co-benefits as well as provide quality assurance across all green roof life cycle stages, including the design review process, construction and installation, and operations and maintenance?

3) What operational and programmatic features should the City of Vancouver consider when seeking to develop a useful, robust, and cost-effective Green Roof Asset Tracker program to track, store and evaluate information pertaining to the City's green roofs? What forms of technical, monetary, and staff support would be required to effectively develop and maintain the Green Roof Asset Tracker program?

4) How could the information collected via the Green Roof Asset Tracker be used to support current City of Vancouver strategies and goals, as well as provide quantitative rationale for ongoing policy adjustments?

This report serves to address these questions via a mixed-methods approach, with three main deliverables: 1) a compilation of the co-benefits of green roofs relevant to a range of City of Vancouver goals and strategies, 2) a comprehensive and prioritized list of indicators to be included in the Tracker, and 3) operational and logistical recommendations for the Tracker, based on a literature review of best practices and case studies of existing third-party green rainwater infrastructure/ green roof tracking programs. Recommendations for further research and pathways to support the development and implementation of the City's Tracker program will also be made.

This report begins with an overview of green roof technologies and the specific ways that green roofs are used and roles that they play within the broader context of Vancouver, British Columbia. Following this background and context section, the methods used to meet the study objectives are described and justified. The findings of the primary and secondary research methods are then presented, followed by a discussion of the results as well as their limitations and potential biases. The resulting Green Roof Asset Tracker recommendations are then presented, including possible next steps for further research and preparation for developing a potential Green Roof Asset Tracker tool and program.

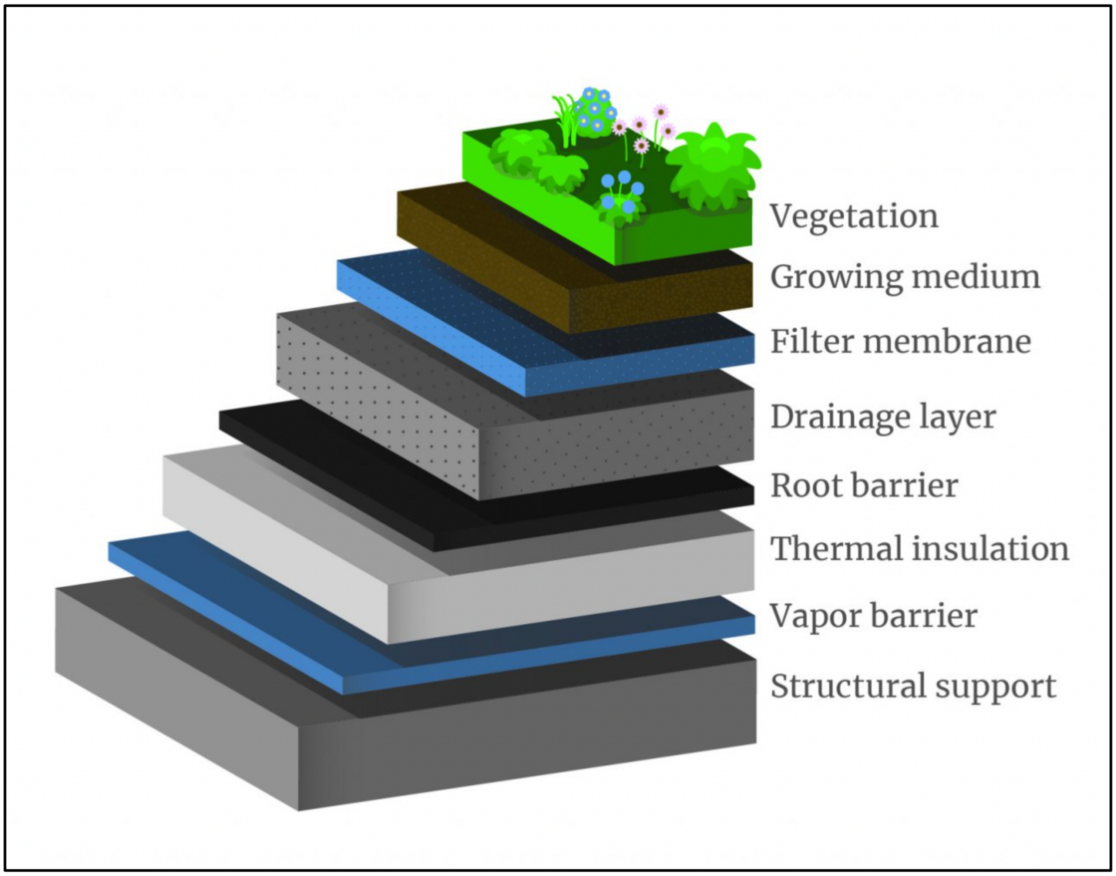
2. Background and Context

2.1 Green Roofs

2.1.1 Green Roof Definition and Components

Green Roofs, as mentioned previously, are roofs that are partially or completely covered with a vegetated growing medium installed over a waterproofing membrane. Green roofs are also referred to as living roofs, eco roofs, blue roofs, and blue-green roofs, depending on the context and the specific roof features. However, all green roofs typically include the same components, namely (from the top surface downward), vegetation, engineered growing media, filter fabric, a drainage layer or water retention layer, a root barrier, a waterproofing membrane, insulation, and a vapour barrier overlaying the building roof structure (see Figure 1) (Droguett, 2011). The filter fabric needs to be porous enough to drain water, but fine enough to prevent soil loss. The drainage layer allows water to drain from the growing media to roof drains, but also retains water for passive irrigation (Lösken et al., 2018). The root barrier, usually made of high-density polyethylene or polyvinyl chloride (PVC), prevents roots from cracking the waterproofing membrane and causing roof structural damage (Lösken et al., 2018). The waterproofing membrane, in turn, further protects the roof structure and is typically made of layers of felt and asphalt, two-ply modified bitumen, or synthetic rubber sheeting (Lösken et al., 2018). Irrigation schemes may be included, especially for roofs with more complex plantings, in order to keep the vegetation healthy during dry months.

Figure 1.
Diagram of a green roof cross section showing typical composition layers.



Environmental Protection Agency, 2023: https://www.epa.gov/heatislands/using-green-roofs-reduce-heat-islands)

2.1.2 Types of Green Roofs

The depth of the growing media determines the type of vegetation that can be planted, the expected level of biodiversity, and the rate of water retention, with deeper growing media increasing each of these factors (Halsall, 2010). Variations in these factors are used to classify green roofs into extensive roofs, intensive roofs, or semi-intensive roofs. Each of the three green roof types is described in greater detail below.

Extensive Green Roofs

Extensive roofs typically have a growing media depth of 6 inches (in) (15.2 centimeters [cm]) or less, and a saturated weight of 16 to 35 pounds per square foot (lbs/ft^2) (78 to 171 kilograms per square meter [kg/m^2]) (Lösken et al., 2018). They support shallow-rooted vegetation (e.g. grass, moss, succulents), are usually drought resistant, and do not typically require dedicated irrigation systems (Lösken et al., 2018). Extensive roofs are not usually publicly accessible and, due to their relatively self-sustaining design and resultant low maintenance needs, may only be accessed for maintenance.

Intensive Green Roofs

Intensive roofs typically employ growing media deeper than 6 in (15.2 cm), and a saturated weight between 40 and 200 lb/ft^2 (195 and 977 kg/m^2) (Lösken et al., 2018). They can support any combination of ground cover plants, shrubs, and trees, and can support a wide variety of uses including public access (Lösken et al., 2018). Some form of dedicated irrigation is usually required to support the greater diversity of plantings, and maintenance requirements are typically higher relative to extensive roofs (Lösken et al., 2018).

Semi-Intensive Green Roofs

Semi-intensive roofs combine features from both extensive and intensive roofs. Their growing media depth ranges from 5 to 10 in (12.7 to 25.4 cm), and saturated weight ranges from 25 to 50 lb/ft^2 (122 to 244 kg/m^2) (Lösken et al., 2018). These roofs can be more diverse in plantings and function than extensive roofs while requiring less irrigation and maintenance than intensive roofs.

Green roofs can also be combined with additional technologies for additional co-benefits. Biosolar roofs take advantage of the sunlight received by green roofs with solar panel installations. The solar panels must be spaced far enough apart to allow adequate sunlight to reach the green roof's vegetation or, alternatively, plants that thrive in shade can be utilized. Planting vegetation underneath the solar panels helps to regulate the temperature, improving photovoltaic efficiency (Velazquez, 2021). Blue-green roofs combine the features of green roofs with other stormwater management technologies to further reduce stormwater runoff. These technologies can be active, meaning valves are used to control the release of retained runoff, or passive, meaning rainwater ponding is allowed via flow-restricted drains, modular tray systems, and/or check dams (Massachusetts Department of Environmental Protection, 2016). Blue-green roofs serve to retain more stormwater onsite, which can lessen the strain on municipal stormwater systems, provide irrigation, and reduce heat island effects by cooling the roof (Massachusetts Department of Environmental Protection, 2016). Green roofs with rainwater harvesting systems allow for the rainwater detained by green roofs to be put toward other beneficial uses. Rainwater harvesting systems can be installed with green roofs and typically include some form of storage (e.g. a rain barrel or tank) connected to drain piping or downspouts to move collected rainwater from the roof to the point at which it will be used. Rainwater harvested from a green roof can be used for outdoor irrigation, car washing, toilet flushing, and even potable purposes if onsite treatment is included (Hammond, Lewis & Wolfe, 2019).

2.1.3 Green Roof Benefits

Green roofs combined with other technologies not only serve to more sustainably manage stormwater, but also to help provide clean energy and assist with water reuse. Green roofs can also provide benefits similar to other forms of urban green space. Studies have identified green roofs as tools for improving biodiversity, urban tree coverage, air quality, carbon sequestration, and providing more equitable access to nature (Peterson, 2022). Access to nature has in turn been shown to improve quality of life and provide mental and physical health benefits (Kolokotsa et al., 2020; Nature-Based Solutions Initiative, 2017). In densely populated urban spaces, green roofs can provide and enhance amenity space to support urban agriculture, childcare, and public education. In addition, green roofs can offer fire protection, sound attenuation, and increased property value for the buildings on which they're installed, while also increasing the longevity of the building's roof by reducing exposure and weathering.

2.2 Green Roofs and Vancouver

2.2.1 The Vancouver Context

Vancouver is a densely populated city located in the Lower Mainland region of British Columbia. The city's population, currently within the top ten highest for cities in Canada, has seen steady growth over the past two decades, with a current population of approximately 690,000 and a projected population of 857,000 by 2050 (City of Vancouver 2021 Census). The city's relatively warm winter temperatures, coastal location, and surrounding topography leads to high annual rainfall, around 146 cm/year, making Vancouver one of the rainiest cities in Canada. Climate change is expected to alter regional precipitation patterns, causing not only an overall increase in the volume of precipitation received, but also higher intensity storms, with 63% more rain on high precipitation days (City of Vancouver, 2023). As previously mentioned, in many cases Vancouver relies on combined sewers to manage both the city's stormwater and wastewater via a single system. During intense storms, the added stormwater volume can overwhelm the aging grey infrastructure, causing sewage diluted with stormwater to overflow into surrounding natural water bodies leading to contamination and negative impacts on aquatic ecosystems (Rain City Strategy, 2019). In addition, climate change is expected to contribute to not only wetter winters, but drier summers in the city with a projected 19% decrease in summer precipitation (City of

Vancouver, 2023). Residents of the city already face water shortages and use restrictions during summer months. As Vancouver's population rises, these problems are further exacerbated, and alternative water management solutions, such as green roofs, will be required to ensure adequate water quality and quantity in the city in the future.

Vancouver is known for being an environmentally friendly city. According to the Vancouver Economic Commission, Vancouver is the third greenest city in the world based on its green economy, progressive environmental policies, and promotion of clean energy, green buildings, and green rainwater infrastructure technologies (Vancouver Economic Commission, 2023). City of Vancouver strategies focus on supporting local biodiversity, increasing urban forests, and improving quality of life for residents with additional green space and access to nature (e.g., Biodiversity Strategy, 2016; Urban Forest Strategy, 2018; Vancouver Plan, 2022). However, because of its coastal location and aging infrastructure, the city is also susceptible to the impacts of climate change. Many City of Vancouver plans and strategies seek to mitigate the effects of climate change and adapt Vancouver to a new normal involving hotter temperatures, higher sea levels, and more intense storms (e.g. Climate Change Adaptation Strategy, 2019; Climate Emergency Action Plan, 2019).

2.2.2 Significance of Green Roofs in Vancouver

The motivation for the current study originated from the City of Vancouver's Rain City Strategy (2019), which presents the goal of capturing and treating 90% of Vancouver's average annual rainfall close to where it lands. The strategy also identifies a 2050 implementation target for capturing and cleaning rainwater from 40% of Vancouver's impervious areas using green rainwater infrastructure (Rain City Strategy, 2019). Implementation of the Rain City Strategy is being undertaken in three city 'areas': Parks and Beaches (P&B), Streets and Public Spaces (S&PS), and Buildings and Sites (B&S), and each has its own high-level action plan. The B&S action plan, including B&S 2 (review and compliance improvement) and B&S 6 (green roof options, opportunities and barriers), provide the impetus for investigating green roofs with respect to improving education, uptake, quality assurance, tracking, and reporting. The City of Vancouver also seeks more sustainable and resilient means by which to manage the city's stormwater, as well as ensure adequate water supply over the coming decades. This involves a heavy focus on shifting to green rainwater infrastructure (GRI), including the installation of more green roofs.

However, while green roofs have been identified as a promising tool for nature-based stormwater management, studies have shown that their co-benefits (defined as the simultaneous multiple benefits, in addition to rainwater management, provided by a green roof or other form of green rainwater infrastructure) can cover a wide range of categories. Green roofs are identified by a number of City of Vancouver bylaws, guidelines, strategies, and plans unrelated to stormwater. Aside from the Rain City Strategy and Citywide Integrated Rainwater Management Plan, green roofs are specifically indicated as tools for supporting the goals of the Biodiversity Strategy, the Bird Friendly Design Guidelines, the Climate Change Adaptation Strategy, the Vancouver Building Bylaw, the Vancouver Plan, and the Water Wise Landscape Guidelines.

Green roofs have already been installed across Vancouver, prominent examples of which include the green roofs of Olympic Village, the Vancouver Convention Centre West, and the VanDusen Botanical Garden Visitor Centre. They are being utilized for a number of purposes and co-benefits, and yet data on the city's installed green roofs is limited. Certain aspects of green roofs are tracked through site stormwater management requirements, but without a wider range of tracked indicators, it would be difficult to quantify the full impact of green roofs in Vancouver.

2.3 The Green Roof Asset Tracker Tool

The impetus for preparing for development of the Green Roof Asset Tracker Tool and Program arises from the B&S Action Plan of the Rain City Strategy, as described in section 2.2.2, and includes researching and potentially developing tools for tracking, monitoring, and promoting green roofs. The planned Green Roof Asset Tracker is envisioned to potentially store and track data on green roofs via a comprehensive set of indicators (i.e., indicators that tie into stormwater management performance and maintenance as well as a range of other City strategy goals). The results of this tracking will have both public- and internal-facing components in order for the tool to serve as both a tool for education as well as for adaptive policy management. An online, publicly accessible GIS-based map could be used to show the location of Vancouver's green roofs and associated select indicator information, all supported by a dedicated green roof tracking program that is anticipated to track, store, and utilize a broad range of indicator data across the life cycle of each green roof.

3. Methods

3.1 Mapping Methods to Objectives

The study's objectives are threefold: 1) understand and compile the co-benefits of green roofs relevant to a range of City of Vancouver goals and strategies, 2) develop a comprehensive and prioritized list of indicators to be included in the Tracker, and 3) provide operational and logistical recommendations for the Tracker. Combinations of primary and secondary and qualitative and quantitative research methods were selected to meet each of these objectives (see Table 1). The selected research methods are discussed in further detail in the following sections.

Table 1.

Methods mapped to study objectives.

	Objective	Methods Employed	Description
1.	Understand and compile the co-benefits of green roofs relevant to a range of City goals and strategies.	Literature review, document analysis, and informal interviews	Literature review of green roof functions and benefits, document analysis of City goals and strategies, and informal interviews with City staff with green roof expertise
2.	Develop a comprehensive and prioritized list of potential indicators to be tracked.	Literature review, informal interviews, and quantitative ranking analysis	Literature review of green roof features and characteristics, informal interviews with City staff with green roof expertise, and development of a points-based indicator ranking method
3.	Provide operational and logistical recommendations for the Tracker tool and program.	Case studies with semi-structured interviews	Potential cities for case study identified based on set criteria, followed by virtual interviews with case study city staff using predetermined question set

3.2 Methodological Framework

3.2.1 Literature Review

A literature review was conducted to gather key information on green roofs and their associated technologies. The literature review was organized around answering the following questions:

1) What is a green roof, how is it defined, and what requirements must be met to be categorized as a green roof versus another form of green or blue infrastructure?

2) What are the major types of green roof, what are the co-benefits and drawbacks of each type, and how can these co-benefits and drawbacks be supported or mitigated?

3) What are the key implementation barriers, and what are the general maintenance requirements to ensure longevity and performance?

4) What are the quantifiable and qualifiable indicators associated with green roofs, how are they measured, and what co-benefits do they tie into?

The review used past Greenest City Scholar reports on green roofs as a starting point to answer basic questions and source academic literature for further information (Marshall, 2020; Peterson, 2022). The review also included a search for literature relevant to green roof indicators specifically. A keyword search was used in the Google Scholar search engine, which provides full text or metadata for an extensive collection of scholarly literature across academic disciplines. Reports produced for other municipalities (e.g. Toronto), were also reviewed following informal interviews with staff (Halsall, 2010).

3.2.2 Document Analysis

To identify areas of overlap between potential green roof co-benefits and the City of Vancouver's specific goals and strategies, 18 City documents and resources (three bylaws, five guidelines, four strategies, three plans, three websites, and one database) were analyzed for content relevant to green roof features, functionalities, or installations. The following resources were analyzed:

- 2018 Health Bylaw
- 2023 Sewer and Watercourse Bylaw
- 2022 Vancouver Building Bylaw

- 2015 Bird Friendly Design Guidelines
- 2013 Boulevard Gardening Guidelines
- 2021 Childcare Design Guidelines
- 2015 Urban Agriculture Guidelines for the Private Realm
- 2009 Water Wise Landscape Guidelines
- 2014 Citywide Integrated Rainwater Management Plan
- 2019 Climate Emergency Action Plan
- 2022 Vancouver Plan
- 2016 Biodiversity Strategy
- 2018 Climate Change Adaptation Strategy
- 2019 Rain City Strategy
- 2018 Urban Forest Strategy
- City of Vancouver Rezoning website: https://vancouver.ca/home-property-development/rezoning-applications.aspx
- City of Vancouver Development Permit website: https://vancouver.ca/home-property-development/development-permit.aspx
- City of Vancouver Building Permit website: https://vancouver.ca/home-property-development/building-permit.aspx
- Site Green Rainwater Infrastructure (GRI) Database

3.2.3 Indicator Categories and Master List

Following the document analysis, indicator categories were selected based on a comparison of the features, functionalities, and co-benefits of green roofs determined from the literature review with the major categories of City of Vancouver strategies, plans, and goals. Informal interviews with city staff with expertise in green roofs also informed the category selection, including the specifics of the quality assurance indicator category.

A master list of indicators was compiled over the course of the study. The master list was intended to contain as many measurable or qualifiable green roof indicators as possible. Indicators were identified during the green roof literature review, city document analysis, informal interviews with City of Vancouver staff, and following the interviews with city staff from other municipalities based on the indicators tracked by their programs.

3.2.4 Case Studies

To help inform recommendations for Vancouver's tracking tool and associated program, it was decided that other municipalities with successful green roof or GRI tracking programs would be profiled, and representative staff members would be interviewed. Case study city identification was undertaken in three steps: 1) review of online resources to identify urban areas with high numbers of green roofs, 2) review of city online resources (websites and GIS tools) to identify cities with public-facing green roof or GRI tracking maps, and 3) prioritization of identified cities based on how closely their tracking map resembled the desired features of the Green Roof Asset Tracker.

The case study locations also had to meet the following criteria:

- City is in Canada or the United States of America
- City has verified green roof installations
- City has an online map of all identified green roof locations
- Map was produced by a city department
- Map includes information about individual green roofs

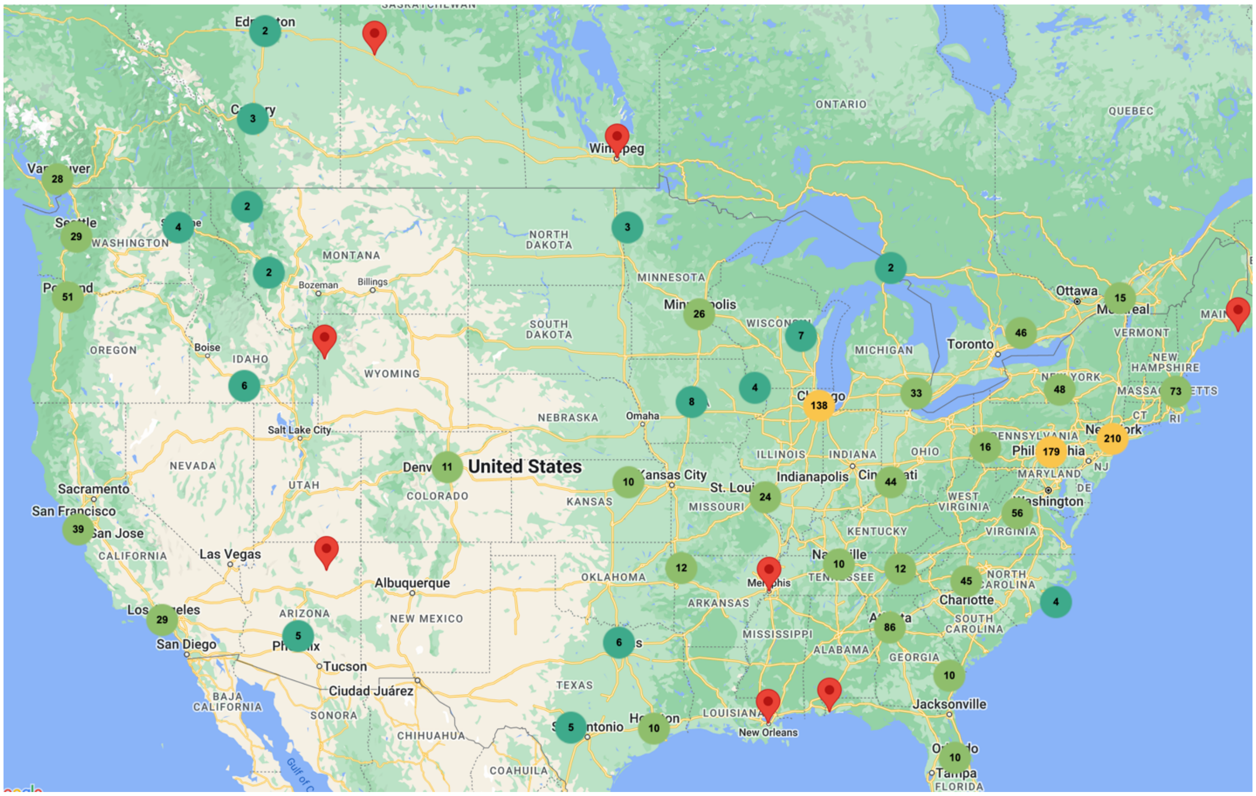
Cities in Canada and the United States were sought to lessen any time zone constraints around interview scheduling, as well as to ensure some similarity to Vancouver's climate and regulatory context. Public, city-produced green roof tracking maps were assumed to be indicative of the existence of an active green roof tracking program, although this was not always the case.

The first step of case study identification involved using online resources to locate all cities in Canada and the United States that had significant numbers of green roofs so that these cities could be reviewed further. The online resources at Greenroofs.com, a website dedicated to providing the public with comprehensive media and information on green roofs, connecting those seeking to implement green roofs with experts and collaborators, and promoting green roof best practices, were used. Greenroofs.com hosts a world map displaying registered green roof locations (greenroofs.com/projects/). See Figure 2 for an image of the map displaying the selected study area.

It should be acknowledged that the greenroofs.com map is not a complete representation of green roof installations; the projects included in the map are sourced from published public accounts or are documented by the project owners, designers, and/or stakeholders. It is not meant to be used as a complete list of existing green roof projects and is a living document updated regularly with community-based participation. It was used for the purposes of this study because it provided a means to quickly locate cities with significant numbers of green roofs (i.e., more than ten), and because it was assumed that cities that prioritized publicly accessible green roof information would be likely to provide information that would be sourced by greenroofs.com for map entries.

Figure 2.

Map of the study area selected for case studies showing green roof installation locations.



greenroofs.com/projects/

The Canadian and American cities that were shown by greenroofs.com to have more than ten green roof installations were:

- Atlanta, GA (75)
- Asheville, NC (11)
- Baltimore, MD (19)
- Boston, MA (35)
- Chicago, IL (76)

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- Cincinnati, OH (17)
- Detroit, MI (12)
- Grand Rapids (23)
- Indianapolis (11)
- Ithaca, NY (31)
- Los Angeles, CA (12)
- Milwaukee, WI (15)
- New York City, NY (104)
- Philadelphia, PA (41)
- Portland, OR (45)
- St. Louis, MO (18)
- San Francisco, CA (14)
- Seattle, WA (19)
- Toronto, ON (28)
- Vancouver, BC (13)
- Washington D.C. (78)

Once identified, the online resources relevant to green roofs for each city were reviewed. Eleven of the 22 cities, e.g., Boston, MA, Ithaca, NY, and Philadelphia, PA, did not have public-facing online information about their green roofs, or none that could be identified after extensive online searching. Of the remaining 11, only five cities had publicly accessible GIS-based maps that both displayed green roof locations (either alone or as part of a broader green roof infrastructure map) and were produced by city staff, versus a third party. Some cities did have online maps, but the maps were produced by private organizations or as part of student research projects, and therefore would not be useful for identifying cities with city-run green roof tracking programs. The five qualifying cities (San Francisco, Portland, Chicago, Washington D.C, and New York) were prioritized in order to determine which staff would be approached for interviews. Cities with maps that displayed the highest quantity of green roof indicators were given higher priority, as were cities with easily identifiable contact information for relevant city staff. Interviews were then sought with identified staff members.

3.2.5 Interviews

Once contact had been established, and receptivity to study participation was indicated, semi-formal interviews were scheduled. The interviewees received a list of interview questions several days ahead of time so that they could review and prepare answers if desired. See Appendix A for the set of interview questions used during all interviews. Interviews were held for one hour or one and a half hours depending on staff availability, with either one or two city staff members participating. The interviews were held virtually and were recorded with interviewee permission. During the interviews, the prepared questions were asked in order, with opportunity given to pursue other relevant topics not covered by the questions. The transcripts from the interviews were verified against the video recordings, and interview summaries were compiled using the verified transcripts. Interviewees were given the opportunity to review the study report and request edits or redactions of any potentially sensitive information before the report was finalized and submitted.

3.2.6 Indicator Ranking Analysis

Following the creation of the indicator master list, a ranking system was established to prioritize tracking of key indicators. While tracking of all indicators in the master list may impart valuable information, there are restraints on City of Vancouver staff time and resources, as well as developers' capacity to report information on their buildings' green roofs. Because this limits the number of indicators that can be realistically tracked long-term, prioritizing indicators will allow staff to focus on collecting the most important, representative, or actionable green roof information.

The creation of the ranking system was an iterative process. Three ranking categories were chosen: 1) relative importance within category, 2) ease of collection and 3) relevance to City strategies. "Relative importance within category" refers to the importance of collecting information for a specific indicator based on how it compares to the other indicators within its indicator category, with between 3 and 1 points possible. The idea was to convey which indicators are essential within their categories, and which indicators may be less critical. This ranking category served to redistribute some of the weighting within the rankings. Certain categories, such as the green roof technical specifications indicator category, could be overrepresented in the overall rankings since many of those indicators are already tracked, and so rank highly in the "ease of collection" category. Each indicator category was thought to contain important indicators, and therefore should be represented within the final list of indicators recommended for tracking.

The "Ease of collection" category has two components: how easy it is to measure or qualify the indicator, and how much effort is required by City staff or developers to gather the information, with between 4 and 0 points possible. For example, indicators that are included in permitting information required by the City to approve development projects, such as the area of the proposed green roof, would be easy to track, as the information is already being collected and represents no added effort. In contrast, indicators that are not already being tracked, and that also require some level of expert knowledge or would necessitate the establishment of specific guidelines, such as whether a plant included in a green roof supports bird habitat creation, would be both difficult to qualify and time consuming to collect.

As an intermediate step prior to ranking, each indicator was reviewed for direct connections to City bylaws, guidelines, plans, and strategies. These City documents were categorized based on their focus, and the number of categories that each indicator is relevant to was noted. The City strategy categories were biodiversity, stormwater management, amenities, childcare, urban agriculture, climate resilience, and equity. Points assigned in the “relevance to City strategies” ranking category represent the number of City strategy categories that the indicator supports, with 7 to 0 points possible. City strategy categories were used over a direct count of supported bylaws, guidelines, plans and strategies so that the number of documents on a specific topic would not affect the perceived importance of an indicator. For example, there are four City documents that focus on water use, versus two that focus on biodiversity, and so an indicator that connects to water use would automatically have been ranked higher than one that connects to biodiversity support.

Each indicator was assigned a number of points in each of the ranking categories, and the scores were tallied to provide an overall ranking, with a higher score indicating a higher ranking (i.e. higher importance). It should be noted that the ranking system is subjective. While attempts were made to ground the rankings in replicable and quantifiable methods, ultimately best judgement had to be used, and the point values assigned to each indicator for each ranking category are to some degree arbitrary. It was decided that the ranking system would only be based on three categories for simplicity, but also to avoid compounding biases in the scoring. This ranking method is ultimately only meant to be a starting point for more refined future indicator rankings receiving input from a broader sample of city staff and green roof experts.

4. Findings

4.1 Green Roofs and City Strategies

4.1.1 Green Roof Co-Benefits

As mentioned in Section 2, green roofs can provide a number of co-benefits and serve multiple functions. Green roof co-benefits are discussed below, organized by the category of service. Because green roofs can differ significantly in design and components, which affects their function and performance, the limitations and dependencies of these co-benefits are also discussed.

Biodiversity Support

Green roofs can provide habitats for a number of animal, bird, and insect species, as well as represent opportunities to increase the presence of native and non-invasive plant species in cities (Halsall, 2010). They can provide habitat, food, nesting sites, and shelter for birds and insects, including pollinators. Studies on green roof biodiversity support have shown that hundreds of species can be supported via green roofs, including threatened and endangered species (Halsall, 2010). Opportunities for biodiversity support are dependent on the size of the green roof, as well as plant species diversity and location (e.g. roofs on high rises may not represent realistic habitat for insects, although butterflies have been found to be able to access green roofs as many as 20 stories high) (Halsall, 2010; Manso et al., 2021). Integration with other forms of GRI and green space can also help to create wildlife corridors and networks, decreasing negative human-animal interactions and increasing habitat range (Manso et al., 2021).

Stormwater Management

Green roofs have been shown to retain between 50 and 88% of the rainwater that falls within their borders, depending on vegetation type, growing media depth, roof slope, and rainfall intensity, among other factors (Halsall, 2010; Shafique, Kim & Rafiq, 2018). This makes them an exceptional tool for stormwater management, as they reduce peak flows and runoff volumes, and prevent flash flooding. With the addition of other green and blue infrastructure, such as rainwater harvesting systems, green roofs can also be tools for water conservation and reuse. In addition, green roof substrate and vegetation has been shown to absorb stormwater contaminants, retaining them onsite and preventing them from contaminating natural water bodies and negatively impacting local ecosystems (Shafique, Kim & Rafiq, 2018). However, fertilizer use on green roofs can also negatively impact water quality, leading to higher amounts of organic compounds in roof runoff (Shafique, Kim & Rafiq, 2018).

Amenities Provision

Green roofs can provide space for recreation, education, childcare, urban agriculture, and access to nature in densely populated areas where green space is lacking (Manso et al., 2021). If designed to support human activities, green roofs can provide quieter, safer spaces for childcare than are found on the ground level due to reduced traffic noise and separation from street activities (Shafique, Kim & Rafiq, 2018). Urban agriculture fosters more sustainable, local food production, reducing ecological footprints (Manso et al., 2021).

Climate and Environmental Resilience

Green roofs have been shown to reduce air temperatures above the roof by 2 to 8 degrees Celsius (C), with the roof itself remaining 30 degrees C cooler than traditional roofs at peak summer temperatures, helping to reduce heat island effects common in densely populated areas (Halsall Associates, 2010). In addition, green roofs provide added insulation to the buildings on which they're installed. Combined with greater shading, evapotranspiration, and thermal mass, green roofs help to regulate indoor temperatures, reducing building heating and cooling requirements and the resulting carbon emissions (Halsall Associates, 2010; Manso et al., 2021). They can also help to remove air pollution, trapping particulates and sequestering gasses, with a single roof removing 6.9 grams/m^2/year (Halsall Associates, 2010). The removal rate may not be high in comparison to typical air pollutant emission rates associated with building use (~160 grams/m^2/year for a typical office building in Toronto, ON) (Halsall Associates, 2010); however, when combined with a green roof's ability to reduce building heating and cooling, emissions are further reduced.

Equity Enhancement

There are significant disparities in who is able to and has the resources to access nature, especially in urban areas. Factors such as ethnicity, socioeconomic group, and health status affect not only access to nature, but more specifically access to green space acreage and quality, with low socioeconomic and ethnic minority people having both the least overall access to natural spaces and access to the lowest quality natural spaces (Rigolon, 2016). Green roofs can offer access to nature to city residents who otherwise would have had little opportunity, providing mental and physical health benefits (Kolokotsa et al., 2020; Nature-Based Solutions Initiative, 2017). These services are mitigated, however, by any access restrictions placed on the roof (e.g., whether it's open to the public, only accessible to building residents, or not accessible except for maintenance), although there are some benefits received if the roof is visible from the street (Halsall, 2010). In addition, indirect benefits, such as overall peak temperature reduction, improved air quality, and reduced carbon emissions, have no dependence on access (Mell & Whitten, 2021).

4.1.2 Supporting City Goals

Listed below are each of the City documents that were reviewed for the study, along with brief summaries of the contents, and their connections to green roofs and associated co-benefits. Some of the documents reviewed (i.e., the Boulevard Gardening Guidelines, the Health Bylaw, and the Sewer and Watercourse Bylaw) were found to have connections to green roofs that directly overlap with other documents, and so are not discussed below.

Vancouver Building Bylaw

The Vancouver Building Bylaw regulates design and construction of buildings, along with associated permitting, inspections, and the enforcement of requirements (Vancouver Building Bylaw, 2019). It has also provided the City the opportunity to be a leader with respect to building regulations, in areas such as safety, health, accessibility, alteration to existing and heritage buildings, energy utilization, and stormwater management methods. Green roof design and installation is regulated under the bylaw, indicating that green roof design standards and best practices are already supported by the City.

Bird Friendly Design Guidelines

The Bird Friendly Design Guidelines provide recommendations for preventing bird collisions with buildings, as well as conserving and supporting bird habitat. This includes encouragement of native and non-invasive vegetation and minimizing disturbance from humans (Bird Friendly Design Guidelines, 2015). As discussed in the previous section, green roofs have been shown to represent opportunities to provide bird habitat, nesting sites, food, shelter, and water. The guidelines suggest planting diverse native trees and shrubs as part of landscaping to support birds, which can be done on semi-intensive and intensive green roofs. Importantly, green roofs can provide bird habitat on top of buildings versus next to buildings, which greatly reduces the chances of bird collisions with building windows. Stormwater retention and irrigation associated with green roofs also can provide birds with water, a key component of habitat.

Childcare Design Guidelines

The Childcare Design Guidelines describe regulations and best practices for childcare sites (Childcare Design Guidelines, 2021). Rooftop play spaces are encouraged, according to the guidelines, because they “allow access to open outdoor space on densely developed sites, and present opportunities for separation from traffic and noise and greater access to sunlight” (Childcare Design Guidelines, 2021, p. 19). The guidelines stipulate that outdoor childcare spaces should receive sunlight, be protected from wind, pollution, and noise, with acoustic buffering from traffic and parking. Green roofs are buffered from street noise, and vegetation may be able to reduce play area exposure by providing shade and wind shielding. Depending on their installation height and the surrounding buildings, they can offer sunlight exposure in highly developed areas. In addition, the guidelines require natural features and vegetation in outdoor spaces associated with childcare, and encourage the presence of native and edible landscaping, all of which can be provided by green roofs.

Urban Agriculture Guidelines for the Private Realm

Urban agriculture, which is the “range of activities for the growing of plants for food and other related uses, within or surrounding cities and towns”, is promoted in Vancouver, as is the use of roof space for agriculture (Urban Agriculture Guidelines, 2015, p.1). Shared garden plots and plots accessible to multiple-dwelling developments are ideal, but urban agriculture can also be promoted in common amenity spaces at offices, schools, and community centers. Green roofs, which can be used as common amenity spaces on residential buildings, offices, schools, community centers, and more, provide opportunity for shared garden plots to be installed. Because green roofs already support vegetation in some form, and often have associated irrigation systems, conditions are already conducive to the addition of edible landscaping and crop growth. This is of course subject to building roof access, as safe and equitable residential or public access would be required for activities associated with urban agriculture, but if access is not restricted, then green roof amenity space can be enhanced by the social opportunities present in shared gardening and horticulture, and the building’s ecological footprint can be further reduced through provision of local food for residents.

Water Wise Landscape Guidelines

These guidelines are meant to be used to inform landscape planning for new private property development projects. The guidelines emphasize landscape livability, urban ecology, and long-term viability with suggestions for drought tolerant vegetation and water conservation best practices (Water Wise Landscape Guidelines, 2009). Green roofs can help to integrate water conservation into a building’s landscape. Outdoor water use for irrigation accounts for approximately 60% of household water use in Vancouver (CTV News, 2022). Rainwater capture allows for passive irrigation, saving potable water for indoor use, and green roofs, in theory, are able to supply more water than they require for irrigation, depending on precipitation conditions and the type of green roof (Water Wise Landscape Guidelines, 2009). Green roofs that include rainwater harvesting systems can also supply residents with water for other beneficial uses in addition to irrigation (Hammond, Lewis & Wolfe, 2019; Water Wise Landscape Guidelines, 2009).

2014 Citywide Integrated Rainwater Management Plan

The Citywide Integrated Rainwater Management Plan uses a comprehensive ecosystem approach to rainwater management, treating stormwater as a resource and reducing potable water demand through water reuse. The plan includes a long-term GRI strategy to protect local surface water bodies (Citywide Integrated Rainwater Management Plan, 2014). Green roofs, as discussed in other sections of this report, are included in this suite of GRI, and provide many rainwater management benefits.

2019 Climate Emergency Action Plan

The Climate Emergency Action Plan represents the City of Vancouver's response to its declaration of a Climate Emergency in 2019. It presents goals and accompanying actions set around reducing the city's carbon emissions, with specific recommendations for land-use planning, transportation, buildings, infrastructure, and support of natural systems (Climate Emergency Action Plan, 2019). As previously mentioned, green roofs can help reduce emissions directly and indirectly. By insulating buildings against temperature extremes, green roofs directly limit the need for heating and cooling, which accounts for a significant portion of building energy use. Collectively, green roofs can also help indirectly reduce the energy needed for cooling buildings by reducing the overall urban heat island effect.

2022 Vancouver Plan

The Vancouver Plan is a long-range land use plan to make Vancouver more livable, affordable, and sustainable for all residents. The plan emphasizes sustainable and nature-based solutions for climate protection and ecosystem restoration (Vancouver Plan, 2022). The plan was derived from a multi-year public engagement process, during which Vancouver residents emphasized the need to create more housing, support the local economy, and address the climate crisis. Green roofs can provide access to nature for residents even with increased density, can act as sites to increase urban tree canopy, support waterways by reducing urban stormwater runoff and associated contamination, and lower building carbon emissions. Promotion of green roofs can also create more job opportunities in the green building sector, growing the Vancouver green economy.

2016 Biodiversity Strategy

This strategy is born from Vancouver's commitment to supporting and celebrating biodiversity. The strategy includes greening operations and habitat restoration throughout the city to enable a city-wide ecological network (Biodiversity Strategy, 2016). The strategy objectives are to restore habitats and species, support biodiversity within City-owned lands, protect and enhance biodiversity during development, employ education and stewardship to celebrate biodiversity, and track progress and measure success via monitoring. As previously discussed, green roofs support biodiversity in a number of ways. Specifically, they can provide opportunities to create additional habitat for birds and pollinators, sites for the promotion of native plant species, and also help preserve existing aquatic ecosystems through prevention of contamination by urban stormwater runoff. One of the strategy's goals was to restore and enhance 25 hectares of natural area. Green roofs can be counted towards that area, and also represent opportunities to promote education and stewardship on private property (Biodiversity Strategy, 2016.

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2018 Climate Change Adaptation Strategy

The strategy aims to increase Vancouver's resilience to the shocks and stresses associated with climate change. The strategy looks at specific climate hazards and proposes adaptation measures for future heat domes, flooding, and sea level rise (Climate Change Adaptation Strategy, 2018). The strategy encourages the use of GRI, including green roofs, for more natural stormwater management methods. It also encourages climate resilient buildings, which stay cooler during hotter summers via insulation, increased tree shade, and reduction of heat island effects with increased urban vegetation. As discussed, green roofs can be used to insulate buildings from temperature extremes and mitigate heat island effects, and the strategy cites this directly, calling for the introduction of requirements for or facilitation of "an increase in application of green roofs" (Climate Change Adaptation Strategy, 2018, p.51). The strategy discusses the importance of healthy natural areas and green space, which green roofs can provide.

2019 Rain City Strategy

As mentioned previously, the Rain City Strategy was developed in response to the city's stormwater management challenges and calls for improved water quality, increased water supply and climate resilience, and enhanced city livability. It lays out strategies to capture and treat 90% of Vancouver's average annual rainfall close to where it lands, and sets a 2050 implementation target for capturing and cleaning rainwater from 40% of Vancouver's impervious areas using GRI (Rain City Strategy, 2019). The strategy identifies GRI, and green roofs specifically, as tools for meeting strategy goals through more sustainable, nature-based stormwater management.

2018 Urban Forest Strategy

This strategy sets goals for protecting and enhancing urban forests in Vancouver. Urban forests provide a number of services, including habitat provision, air quality improvement, street and building shading, and rainwater interception for stormwater management (Urban Forest Strategy, 2018). Actions are laid out to accomplish the strategy goals, which include protecting the urban forest during development activities, planting more trees, managing trees for health and safety, engaging citizens in the urban forest, and monitoring the status and condition of the urban forest. Intensive green roofs represent opportunities for increased tree plantings, especially in densely developed areas where trees would not otherwise have space or conducive growing conditions.

4.2 Green Roof Indicators

4.2.1 Indicator Categories

The indicator categories selected for organizing and contextualizing the master indicator list are shown in Appendix B, with the master list of indicators. The categories are first organized by the scale at which they're relevant, and then split into subcategories to cover specific aspects at each scale. The Green Roof category lists indicators relevant to the green roof itself. The Building Roof category includes indicators that describe the characteristics of the building roof on which the green roof is installed. The Building and Context category provides indicators that describe aspects of the building on which the green roof is installed, as well as contextual information for the area surrounding the building. Below are explanations of the meaning and intention of each indicator subcategory.

Green Roof Category

- *Dimensions*: indicators in this subcategory describe the physical dimensions of the green roof.

- *Technical Specifications*: indicators in this subcategory include information on the type of green roof and specifics on materials used and technologies present.

- *Access to Green Roof*: indicators in this subcategory describe whether or not the green roof is publicly accessible (for direct access and visually from the street), as well as in what ways the green roof is accessible, for instance, whether or not it can be walked on.

- *Planting Specifications*: indicators in this subcategory provide details on the type, number, and function of vegetation planted on the green roof.

- *Stormwater Management*: indicators in this subcategory provide details on the green roof's stormwater management capacity.

- *QA/QC, Maintenance and Performance Assessment*: indicators in this subcategory are to be filled in from maintenance inspections, and describe how well the green roof is functioning as intended.

- *Green Roof Intended Purpose*: indicators in this subcategory describe the reasons underlying the decision to add a green roof installation to a development

Building Roof Category

- *Building Roof Intended Use*: indicators in this subcategory describe the broader building roof's access requirements and the types of activities for which the roof was designed.

- *Building Roof Features*: indicators in this subcategory add information on what additional features the building roof has, including seating and lighting.

- *Amenity Capacity*: indicators in this subcategory cover technical aspects of the building roof's ability to support amenity activity, including details on weight limits and the presence of garden plots.

- *Building Roof Characteristics*: indicators in this subcategory provide details on the building roof's exposure level and construction details, such as its height and area.

Building and Context Category

- *Location*: indicators in this subcategory provide details on the location of the building on which the green roof is installed. Location includes such aspects as the building's neighborhood, watershed, sewer catchment and zoning district, as well as address and latitude and longitude.

- *Building Specifications*: indicators in this subcategory cover the specifics of the building's design, including its number or storeys, construction materials, and intended use.

- *Permit*: indicators in this subcategory cover details about the site/building's permit status.

- *Site Stormwater Management Details*: these indicators provide further details on the stormwater management plan for the entire building site, of which the green roof may only be one aspect.

4.2.2 Indicators Master List

See Appendix B for the full master list of indicators selected for this study. The list contains 136 indicators, and represents all of the indicators identified during the green roof literature review, the City document analysis, informal interviews with City staff, and semi-structured interviews with staff from other municipalities. The Site Green Rainwater Infrastructure Database (Site GRI Database) is a repository of the data collected from developers on the GRI and stormwater management plans for their properties. The database includes categories for collecting and tracking information on green roofs. Every indicator in the Site GRI Database that was applicable to our study focus was added to the master indicator list, and are marked with an asterisk. The master indicator list is meant to be as comprehensive as possible, and while not all the indicators listed may be critical to the Green Roof Asset Tracker Tool or program, they can all impart valuable information via tracking. A prioritized list will be presented in the recommendations section of the report (Section 5.1), with the top 55 indicators and co-benefits discussed in detail.

4.3 Case Studies

4.3.1 Case Study City Selection

The following cities met the criteria set forth for case study selection, ranked in order of initial preference for interviews:

1. San Francisco, California, United States of America

2. Portland, Oregon, United States of America

3. Chicago, Illinois, United States of America

4. The District of Columbia (Washington D.C.), United States of America

5. New York City, New York, United States of America

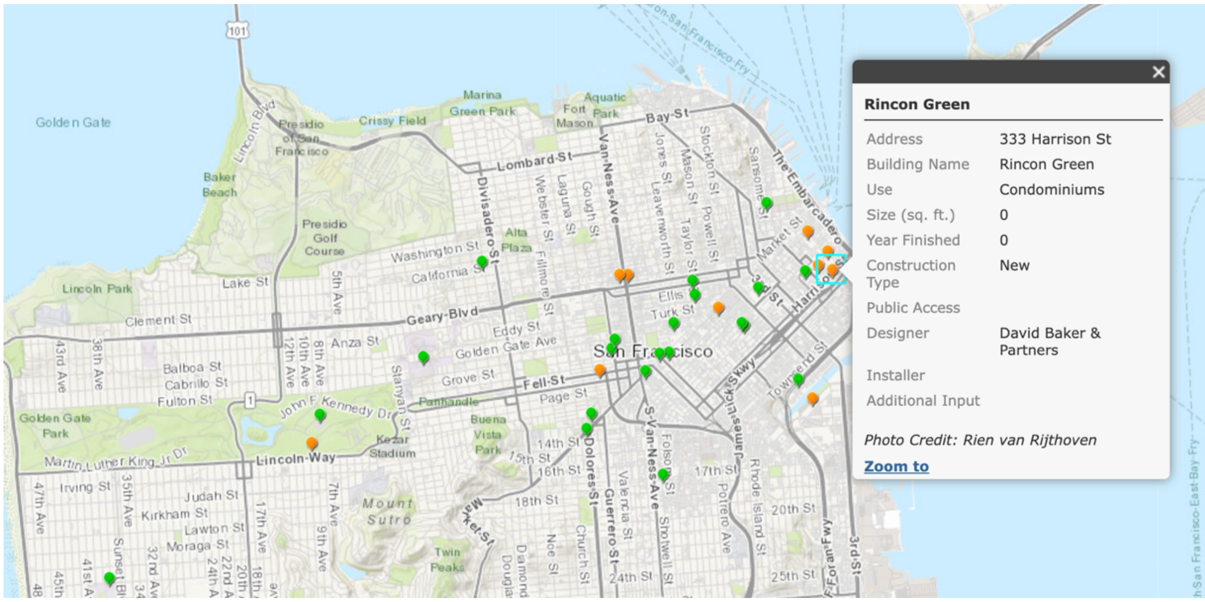
San Francisco received the highest prioritization because the online map (produced by the City of San Francisco Planning Department) included the highest quantity of green roof indicators (ten) of all maps reviewed, and all of the indicators were relevant to the options being considered for Vancouver's program (see Figure 3 for map). Contact information for the map was also clearly listed, leading us to believe that setting up an interview would be straightforward. Portland received the second highest prioritization because their map, produced by City of Portland's Environmental Services in collaboration with faculty and students from Portland State University, included seven public-facing indicators, which again were all relevant to Vancouver's options (Figure 4). The City of Chicago produced a public-facing map that showed four indicators, as did the map available for Washington D.C., although the origin of that map was not clear (Figures 5 and 6). Following the interview with Washington D.C. staff members, a second green rainwater infrastructure map was presented (Figure 7). This map was far more comprehensive than the original map found for this study. The online map found for New York City showed only green roof locations and dimensions, and so was given fifth priority (Figure 8).

While the list represents our initial prioritization for coordinating interviews, upon contact with city staff, it became clear that the detail provided in the cities' publicly accessible online GIS-based maps was not directly correlated to an active green roof tracking program. For instance, while San Francisco's map was green roof-specific and included many of the indicators that had been identified as desirable for tracking in Vancouver, the map represents a snapshot of the green roofs installed in the city at a single point in time. Although San Francisco developed a useful and progressive tool, it does not currently have an active green roof tracking map or supporting green roof tracking program. Similarly, Chicago's map was produced in association with a 2013 green roof study, and therefore shows green roofs installed as of the study period. While the City of Chicago tracks information on other forms of green rainwater infrastructure, green roof installations specifically are not actively tracked at present.

Staff members at each of the selected cities were contacted, and interviews were performed with staff from Chicago, Portland, San Francisco, and Washington D.C. The case studies discussed below focus on Portland, Oregon, and Washington D.C., both of which have active green roof tracking programs and regularly updated GIS-based map tools that display green roof locations and information, either alone or as part of a broader green rainwater infrastructure focused program. Washington D.C. proved to have the most robust, comprehensive, and well-established tracking program of all cities reviewed.

Figure 3.

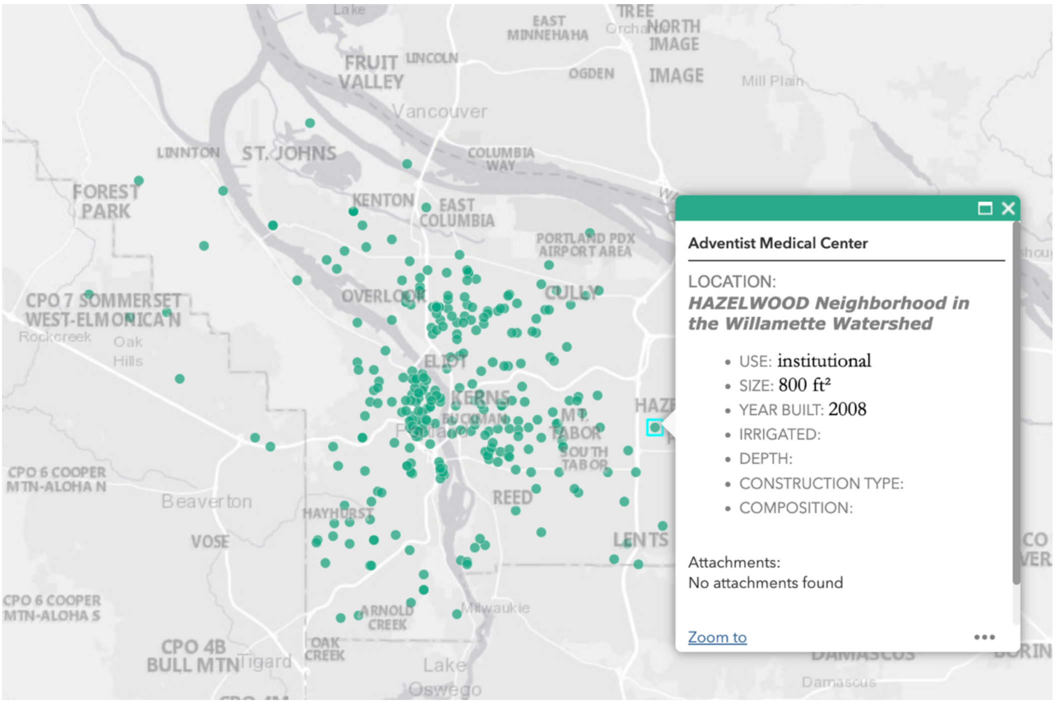
Image of the Green Roofs in San Francisco map with indicator information shown.



https://sfplanning.org/resource/green-roofs-map

Figure 4.

Image of Portland Ecoroof Map with indicator information shown.



https://pdxedu.maps.arcgis.com/apps/webappviewer/index.html?id=9aec6bd67d5844f9bedc5a74e516d372&extent=-13693379.0623%2C5676857.8926%2C-13604712.1095%2C5737013.8339%2C102100

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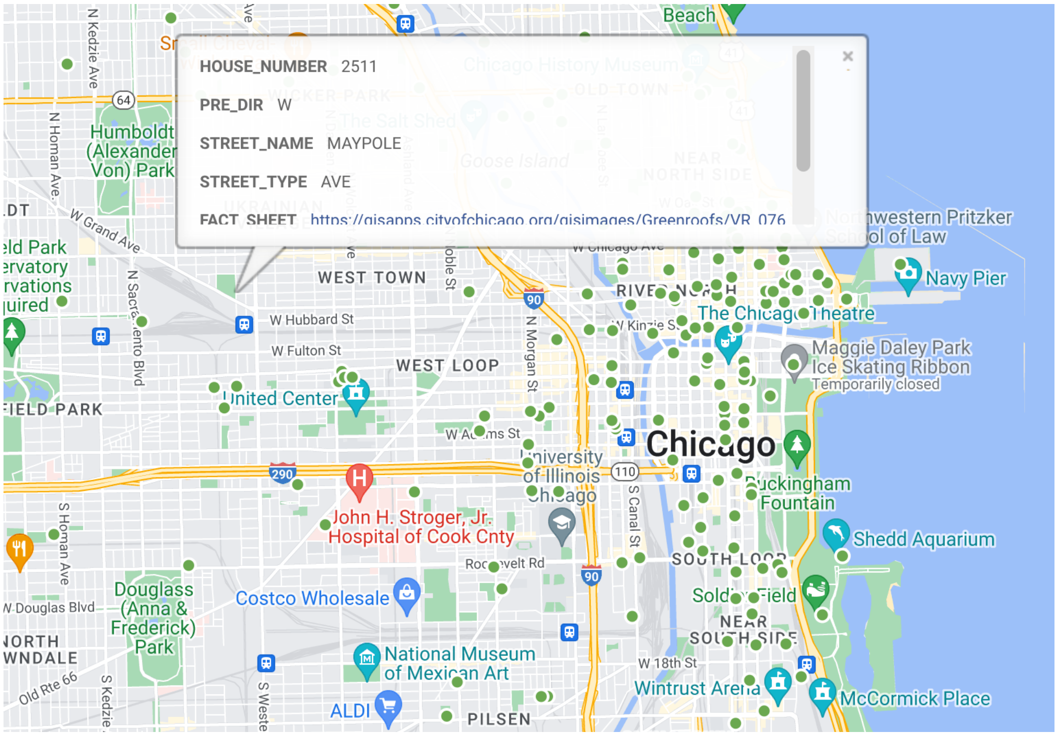
Figure 5.

Image of the Chicago Green Roofs Map with indicator information shown.



https://data.cityofchicago.org/Environment-Sustainable-Development/Green-Roofs-Map/u23m-pa73

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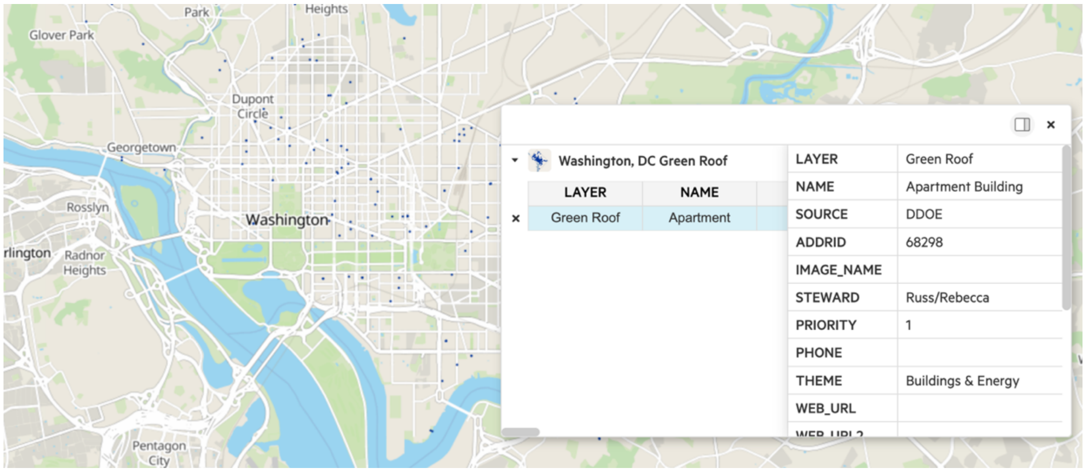
Figure 6.

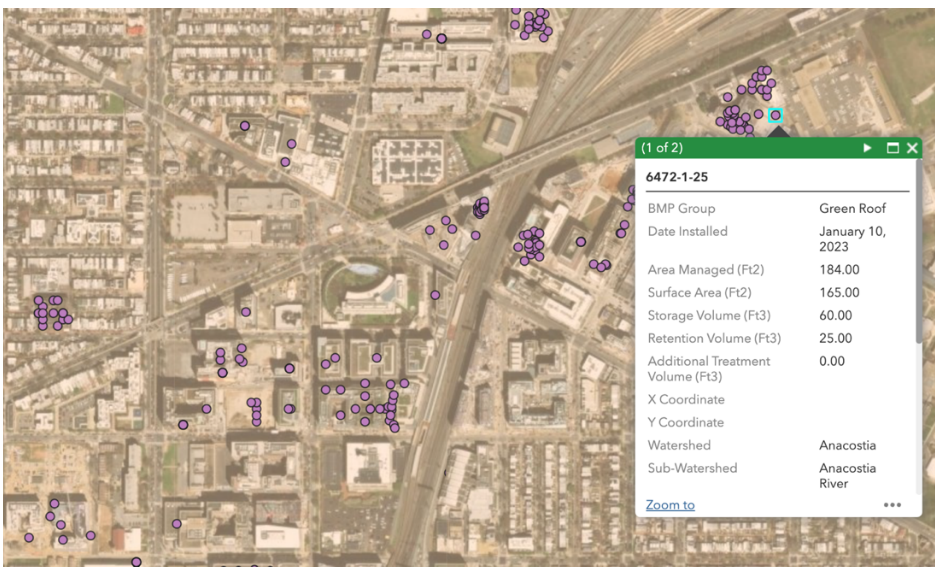
Image of the Washington D.C. Green Roof map with indicator information shown. Map initially found for Washington D.C.



https://koordinates.com/layer/96696-washington-dc-green-roof/

Figure 7.

Image of the Washington D.C. Green Rainwater Infrastructure Practices in the District map with green roof layer, with indicator information shown. Map identified during interview with Washington D.C. staff.



https://dcgis.maps.arcgis.com/apps/webappviewer/index.html?id=cc7f1d49c5074427a28f76154543fa98

Figure 8.

Image of the New York City Urban Systems Lab- Data Visualization Hub: Green Roofs map. No indicator information available.

http://nyc.urbansystemslab.com/?locationKey=%22-L6-k2TKsF3Wz2SM_Ph1%22&mapKey=%22-LXWldsBmv1nw1PxADK1%22#

4.3.2 City 1: Portland, OR

4.3.2.1 Background

Portland is the most populous city in the state of Oregon, United States of America, with a population of approximately 650,000 people. It’s located in the Pacific Northwest, with a climate similar to Vancouver’s: rainy winters and warm, dry summers. While annual precipitation in the city is high, it is significantly less than that of Vancouver, with an average precipitation total of 94 cm/year.

4.3.2.2 Interview Details

Two members of the City of Portland staff were interviewed for this case study, both from the city's Bureau of Environmental Services. The interviewed staff members will be identified as Portland Interviewee 1 (PI 1) and Portland Interviewee 2 (PI 2). Note that in the interview summary, the terms green roof and eco roof are used interchangeably. The duration of the interview was approximately one and a half hours.

4.3.2.3 Interview Summary

City Objectives

Q1: Tracker Program Scope: Do you have a green infrastructure (GI)[1] tracking program at the City? If so, is it dedicated to green roofs or a wider array of GI tools? Does it cover GI on public and/or private property?

A: The Portland Eco Roof map was developed in 2018 with a Portland State University faculty member and her students, with the City of Portland providing the mapped data. In terms of a GI tracking program, there is no single, unifying tracking mechanism. There are multiple databases with various functions and drivers that collect information on Portland's GI. PI 1 has maintained a green roof excel spreadsheet since approximately 2007 as part of his work at the City of Portland's Bureau of Environmental Services that covers public and private property. PI 2, also associated with the Bureau of Environmental Services, also maintains a GI database that receives data from the AMANDA permitting software database (Bureau of Development Services and Bureau of Technology Services). PI 2's database tracks information pertaining to inspection and maintenance of stormwater management infrastructure, including green roofs (eco roofs) as well as other GI, on private property.

Q2: Tracker Objectives: What was the purpose or motivation behind beginning the GI/green roof tracking program at your city? What are the specific objectives of the Tracker program?

A: The green roof program began in 2008, with targets set by the Commissioner on green roof number and square footage in the city. It was a five-year program. "The point of our eco roof program was kind of just to build the industry up in the city and hopefully after the five years the industry could kind of keep the momentum and go with that" (PI 1). Tracking of green roofs was done to track use of the available grant money associated with the five-year program ($5/square

[1] Note that green infrastructure (GI) and green rainwater infrastructure (GRI) are used interchangeable in the interview questions and responses.

foot of green roof). PI 1 continued to track green roofs after the program ended in 2013, visiting sites he was notified of by word of mouth and using aerial images to keep tabs on new developments. PI 2's tracking is associated with the GI maintenance inspection program, which applies to permitted projects entered into the AMANDA database, ensuring compliance with the projects' approved operations and maintenance plans and meeting the Stormwater Management Manual requirements. PI 2's tracking is only associated with green roofs installed for the purpose of stormwater management, and not necessarily for amenity space or any other function.

Q3: Public Objective: What does the city hope that the public will gain from having access to green roof tracking information?

A: The Portland eco roof map was developed as part of a mutually sought out partnership between the City of Portland and Portland State University (PSU). The city formerly held green roof tours, and members of the public would often ask for green roof maps. When the tours were halted, the city suggested that members of the public conduct their own self-guided tours, and there was higher demand for information concerning the location and accessibility of the city's green roofs. The Portland chapter of the Green Roof Information Think-Tank (GRiT) expressed interest, and a faculty member from PSU had students who were interested in putting together an interactive GIS-based map tracker, so they decided to move forward with it based on public interest and expressed need. City of Portland already had an internal-facing GIS layer to track green roofs in the city, so the data was provided from that for the PSU project.

Q4: Relationship to other City Strategies: How does the tracking of green roof indicators fit within broader city strategies and goals?

A: There are a number of city plans that discuss the multiple benefits of green infrastructure, including heat island mitigation and habitat provision. Green roofs specifically aren't called out very often, but are implied within the broader category of GI. Eco roofs are mandated in the Central City 2035 Plan, which requires green roofs on city-owned buildings of 20,000 square feet or more, but there isn't any associated tracking. PI 1 and PI 2's work with green roofs is limited to their stormwater management function. Capacity issues in the downtown core's combined sewer system were also a major driver for the green roof mandate.

Indicators

Q5: Indicators: Which indicators are tracked by the program?

A: The PSU green roof map tracks green roof use, size (ft2), the year built, whether or not the roof is irrigated, the depth of the growing media, the roof construction type (reroof or new), and the green roof's composition. PI 1 tracks the green roof type, addresses, neighborhood, watershed, size, year built, combined sewer vs separated sewer vs UIC (underground injection control), presence of photovoltaic panels over vegetation, visibility from the street, accessibility (whether or not anyone can walk on it), and presence of rooftop agriculture. In 2009 or 2010, PI 1 also partnered with Audubon to do a citizen science project monitoring bird activity on eco roofs during spring and fall migration. The four-year study was summarized in a report. In addition, PSU students conducted a project tracking insects and habitat goals on green roofs, including the presence of native vegetation. PI 2 has access to AMANDA's tracked fields, which include technical specifications for projects, such as square footage of the facility and impervious surfaces, discharge point, discharge to combined sewer, separate stormwater system, or UIC (e.g. drywell). In addition, PI 2 tracks the depth of the green roof as an indicator of media maintenance, the roof type (intensive or extensive), and general vegetation health.

Q6: Why: Why were these indicators selected for tracking?

A: The majority of the motivation for specific indicator selection comes from a compliance perspective: ensuring that stormwater management permit requirements are met. There is also some motivation based on public interest, as well as tracking of the goals set out by the green roof program that ended in 2013.

Q7: Public v Private: Which indicators are public-facing (mapped), and which are collected for internal purposes? What was the motivation behind publicly displaying green roof data, specifically?

A: The majority of the tracked indicators are only private-facing, but are accessible to anyone via Public Records requests. The public-facing Portland Eco Roof Map displays the location of the green roof (not the actual address because of privacy concerns, but the closest intersection), building use, size in square feet, year built, whether or not the green roof is irrigated, its depth, the building construction type, and a category for composition (growing media type and source).

Q8: Decisions: How were decisions made regarding which indicators would be tracked publicly, and which would only be tracked internally?

A: The public-facing indicators were selected based on public interest and request, available data, and the discretion of the PSU students who developed it.

Q9: Missing Indicators: Are there other indicators that are not currently tracked that you think would be beneficial to track?

A: Additional desirable indicators for tracking include maintenance details, irrigation details (whether or not they're irrigated and how they're being irrigated), vegetation survival rates, and accessibility.

Tracker Platform and Ownership

Q10: Software Platform: What are the technical requirements for the tool? E.g. software requirements, hardware requirements, data storage requirements, etc.

A: The tool is run using Esri ArcGIS-based software.

Q11: Data Ownership: Who owns the data displayed by the tool? Are there any liability concerns around data ownership and access?

A: The City owns the data, as it's mostly gathered by PI 1 or PI 2, or scraped from building development applications submitted to the city by developers. PI 1 also calculates square footage from satellite imagery, which is publicly available. The decision was made to not display the eco roofs' exact addresses on the public-facing map, not necessarily to avoid liability concerns, but as a best practice measure to prevent building owners or residents from being contacted for commercial purposes (vendors).

Data Source, Collection, Storage, Mapping, and Reporting

Q12: Departments involved: Which Departments/staff members play a role in green roof indicator tracking? Does indicator tracking fall under the jurisdiction of a single city department? Or is it split between multiple departments or groups?

A: The Bureau of Environmental Services is the only department working to track green roof information. PI 2 receives his information from the AMANDA permit database, which is run out of the Bureau of Development Services and Bureau of Technology Services.

Q13: Data Source: What is the source of data?

A: The data is sourced from development applications and aerial images. What's input into AMANDA represents the final form of the development application/approved permit, and so is usually similar to what is actually built and the building state post-occupancy; however, PI 1 does some ground-truthing of this. Site visits are also conducted (PI 1's site visits to ground-truth for his tracking, as well as maintenance inspections that occur once every two years to ensure stormwater management function).

Q14: Data Input: How is information input from the source into the tracker tool, and by whom?

A: The building developer inputs GI project data into a form that gets reviewed by the Development Review team, and when approved, input into AMANDA. PI 2 downloads GI project data from AMANDA and inputs it into his own stormwater management spreadsheet. PI 1 provides data to PSU for eco roof map updates.

Q15: Information Collection: At which stages of the development process is information on the indicators collected?

A: Developers fill out a form for their development application, and when this form is approved it's entered into AMANDA. PI 2 uses this information, but also gathers more post-occupancy for maintenance inspections. PI 1 also gathers more data post-occupancy when he does site visits and checks aerial imagery.

Q16: Data Storage: How and where is indicator data stored?

A: The data is stored in PI 2 and PI 1's spreadsheets. PI 1 also populates the City's eco roof GIS layer using the data.

Q17: Data Mapping: Who maps the data? How often is the map updated with new information?

A: PI 1 provides the data to PSU students about once a year so that they can update the map.

Q18: Data Reporting: How does the City use the collected data? Are reports produced? How often? By whom?

A: The data is used for the annual Combined Sewer Overflow report, which goes to Oregon's Department of Environmental Quality, and also serves to meet clean water and National Pollutant Discharge Elimination System (NPDES) permit requirements. In the report PI 1 calculates the annual volume of water being diverted from the combined sewer system (based on a previous study, for modeling it is assumed that eco roofs retain 50% of the annual rainfall, and peak flows are assumed to be reduced by approx. 98%). PI 2 uses the data from annual MS4 (municipal separate storm sewer systems) reporting, which reports on the number of new developments, amount of new impervious area, number of facilities installed, and number of inspections.

Staff and Funding

Q19: Staff Time: How much time is required from city staff to support the green roof indicator tracking program?

A: PI 1 requires 1 to 3 days per year. PI 2 does quarterly pulls of the permit records from AMANDA and this represents about two or three weeks-worth of work. Adding additional indicators to what's being tracked is not anticipated to create more demands on staff time.

Q20: Funding: How much support does the tracking program receive in terms of available funding?

A: Funding for the tracking is tied to normal staff salary within the Bureau of Environmental Services. There was a five-year period (2008-2013) when a special grant was provided to be used as incentive for eco roofs in the city, as well as funding for the tracking of eco roofs.

General Advice

Q21: Advice: What advice would you give to other city staff preparing to begin their own green roof indicator tracking program?

A: From PI 2: "From my perspective, I think kind of bridging the gap between…when a developer submits their permit proposal and construction and …post construction maintenance. There's some gaps in there and…that tends to account for some of the discrepancies with information…We started playing a more central role in reviewing [the building permits], so that's helped quite a bit…but then there's just, some information gets kind of lost in how it's categorized and how it's tracked in the permit software. And so when I'm trying to pull the information there, you know it's not, it's not very clean…There's a lot of cleanup to be done to get that information out".

From PI 1: "I think ideally you'd have like an app that connected to a map and have the ability for the person who's collecting the data the most…to modify the app, because it seems like you always get asked for a slightly different twist on the data that you weren't prepared for…We have tried to convert the excel to an app a couple of different times over the years…and getting people to modify the app to add the new attributes that we needed would take a long time...But yeah, if there's a way to sort of combine it all into one and have it be as adaptable as possible".

4.3.3 City 2: Washington DC

4.3.3.1 Background

Washington D.C. is the capital of the United States of America. The district is located on the east coast of the U.S., along the Potomac River, with a population of approximately 700,000 people. The climate is typical of the East Coast: cold, snowy winters, and hot, humid summers. Precipitation is received throughout the year. Annual precipitation is approximately 106 cm, with snowfall contributing up to 35 cm of this total.

4.3.3.2 Interview Details

Two members of the Washington D.C. staff were interviewed for this case study, both from the district's Department of Energy and Environment (DOEE). The interviewed staff members will be identified as Washington D.C. Interviewee 1 (WI 1) and Washington D.C. Interviewee 2 (WI 2). The duration of the interview was approximately one hour.

4.3.3.3 Interview Summary

City Objectives

Q1: Tracker Program Scope: Do you have a GI tracking program at the City? If so, is it dedicated to green roofs or a wider array of GI tools? Does it cover GI on public and/or private property?

A: Washington D.C.'s Department of Energy and Environment tracks all of D.C.'s green infrastructure to ensure stormwater management compliance as well as voluntary installations via their Surface and Groundwater System (SGS) platform. Green roofs are one of the 13 types of GI (e.g. bioretention cells, dry wells, rainwater harvesting, permeable pavement, extended channels) that are tracked on public (federal government or district government) and private property. GI best management practices (BMPs) are tracked along with site stormwater management plans, which may include multiple BMPs.

Q2: Tracker Objectives: What was the purpose or motivation behind beginning the GI/green roof tracking program at your city? What are the specific objectives of the Tracker program?

A: The main motivation was to create a centralized system for regulation adherence and enforcement: “Lack of a centralized approach to our regulations, essentially. The…main impetus was to enable us to, in a very transparent way, adhere to and enforce[e] our regulations in a consistent manner” (WI 1). Having this centralized approach allows for seamless planning, reporting, reviewing, installing, and inspecting with easily extractable data. “It was to enable us to effectively enforce our stormwater regulations from beginning to end and it also allows us to seamlessly report to all the people that we need to report to, [the Environmental Protection Agency] being the kind of keystone there, in an effective and consistent manner” (WI 1). Prior to establishing the SGS platform, there were multiple systems without effective communication between user groups, which caused frequent inconsistencies in data depending on the source methodology and who entered it. Establishing the SGS cut down weeks of required staff time. “The centralized database system has been hugely important for reporting, which is really critical to funding and maintaining funding sources to do these projects” (WI 2).

Q3: Public Objective: What does the city hope that the public will gain from having access to green roof tracking information?

A: Part of the motivation for providing publicly accessible information was Environmental Protection Agency (EPA) requirements for public-facing reports and mandates for public resources, but the map of the data has also proven highly useful for outreach, education, and connecting community members to resources. “I know in the MS4 permit and…the 319, which is our non-point source pollution permit or projects, they require education and outreach as part of those, those funding sources. And I know that we often refer to this map as a good training opportunity…or I go to community meetings sometimes and talk…and a lot of them are virtual, so I can pop this map up and be like, listen, like this is the kind of work we’re doing. If you’re interested, feel free to dive in…it’s a good opportunity to help people kind of like grasp how close it is and how embedded in their community these projects are” (WI 2). Included in the education and outreach aspect of the program is providing other municipalities with resources to begin or improve their own GI tracking systems. “We do a lot of…Q&A sessions with folks in order to show them how we leverage the ability to track all of this information” (WI 1). The SGS provides varying levels of information to users depending on their permission level: if someone has submitted a stormwater management plan, then they can view their plan and its associated progress in the system.

Q4: Relationship to other City Strategies: How does the tracking of green roof indicators fit within broader city strategies and goals?

A: Tracking GI in Washington D.C. currently mainly serves to meet goals and expectations around stormwater management in the district. However, connecting GI to other co-benefits and maximizing these benefits is a longer term goal: “Once we’re able to…start using a methodology that…we think is effective, it likely will be tied directly in with this data tracking in order to produce results…based on the type of BMP, the location of the BMP overlays with heat maps and other data sources will be used to quantify the co-benefits of GI. The fact is…that's still a riddle that I don't think anyone has really solved yet" (WI 1). WI 1 also mentioned the Green Infrastructure Leadership Exchange: "In the exchange there are a lot of professionals and a lot of like government officials that are part of this organization that are all working towards like, easier, more effective, more long-term approaches to expanding green infrastructure throughout the…U.S. And they have taken a very keen interest in developing tools to really exploit the potential for using co-benefits as a way to convince cities and states that aren't necessarily on board yet of the benefits of shifting from a gray infrastructure approach to a green infrastructure approach…The system [SGS] will certainly be used in the long term to quantify co-benefits of GI, but it isn't necessarily being done on a day-to-day basis now" (WI 1).

Indicators

Q5: Indicators: Which indicators are tracked by the program?

A: The indicators tracked by the program include everything associated with the projects' stormwater management plans, square footage of BMPs installed, amount of retention achieved by the BMPs, amount of storage volume, retention volume acres retrofitted, compliance with stormwater management plans and requirements (whether or not the BMP is out of compliance), inspection dates, depth of the growing media, depth of the storage layer, intensive vs extensive green roof type, installation date, funding source, and others. The key performance indicators (KPIs) change approximately every other year, depending on interest and need.

Q6: Why: Why were these indicators selected for tracking?

A: The impetus behind the indicator selection is to track performance, compliance and quality assurance. "It was either…because they were metrics that we knew we wanted to track for our own internal performance records, or because they were things that we knew we needed to track because there were requirements for reporting or funding" (WI 1). "Most of the data we track is…because we want to be effective, transparent, and cohesive in the review, approval and maintenance…inspections" (WI 1).

Q7: Public v Private: Which indicators are public-facing (mapped), and which are collected for internal purposes? What was the motivation behind publicly displaying green roof data, specifically?

A: The indicators included in the Green Roof layer of the public-facing map are the BMP group (e.g. green roof or other GI), installation date, area managed (ft2), surface area (ft2), storage volume (ft3), retention volume (ft3), additional treatment volume (ft3), X and Y coordinates, watershed (i.e. name of watershed), sub-watershed (i.e. name of sub-watershed), number of trees, latitude and longitude, sewershed, ward (i.e. ward number), major regulated activity (yes or no), SRC generation (yes or no), RiverSmart Rewards (yes or no), Green Roof Rebate (yes or no), and RiverSmart Homes (yes or no). The last three indicators signify participation in specific Washington D.C. water management programs. The public-facing indicators were mostly chosen based on what was mandated to track and what was required by funding sources.

Q8: Decisions: How were decisions made regarding which indicators would be tracked publicly, and which would only be tracked internally?

A: DOEE selected the indicators to track, and public-facing indicators were selected based on requirements from regulatory agencies and funding sources.

Q9: Missing Indicators: Are there other indicators that are not currently tracked that you think would be beneficial to track?

A: WI 1 mentioned that he'd like to track daily rainfall in the area, in partnership with the National Oceanic and Atmospheric Administration (NOAA), in order to compile a daily rate for water retention for each BMP: "Assuming proper maintenance and functionality of a BMP, if we can get that daily rainfall data, then we would be able to show daily performance of the BMPs that have been installed throughout the district" (WI 1).

Tracker Platform and Ownership

Q10: Software Platform: What are the technical requirements for the tool? E.g. software requirements, hardware requirements, data storage requirements, etc.

A: The map is ArcGIS-based. The SGS system is a Quickbase app owned by the D.C. government.

Q11: Data Ownership: Who owns the data displayed by the tool? Are there any liability concerns around data ownership and access?

A: The district owns the data, and removes any personally identifiable information for public viewing. Users can login with two-factor identification and unique user credentials that are associated with specific viewing rights.

Data Source, Collection, Storage, Mapping, and Reporting

Q12: Departments involved: Which Departments/staff members play a role in green roof indicator tracking? Does indicator tracking fall under the jurisdiction of a single city department? Or is it split between multiple departments or groups?

A: The SGS is run by DOEE staff. The District Department of Transportation also tracks GI installations, but also submits plans into the SGS, so everything ends up in this central repository.

Q13: Data Source: What is the source of data?

A: Some of the data is imported from third party grantees, some is entered by WI 1's staff at DOEE, and the majority of data is entered by licensed engineers associated with specific development projects. The accuracy of the data is reviewed on the ground by DOEE engineers, and amended as needed. Four years ago, they also opened a self-inspection option, where people associated with the project can take pictures and fill out a form that, once approved by DOEE staff, is input directly into the SGS. Some fields in the fillable forms are populated using preexisting information tied to a GIS system (e.g. lot location, sewershed, watershed, and property value)

Q14: Data Input: How is information input from the source into the tracker tool, and by whom?

A: The data is automatically extracted from the filled forms in the SGS database.

Q15: Information Collection: At which stages of the development process is information on the indicators collected?

A: Developers initially enter information during the design stage; however, no data is finalized until the project is reviewed and confirmed as built. This ensures that the information in the database is as accurate as possible.

Q16: Data Storage: How and where is indicator data stored?

A: The data is stored in the SGS Quickbase database, which is backed up weekly.

Q17: Data Mapping: Who maps the data? How often is the map updated with new information?

A: The data mapping is automatic: the latitude and longitude coordinates input in the project's fillable form are extracted to map the project on the GIS-based map.

Q18: Data Reporting: How does the City use the collected data? Are reports produced? How often? By whom?

A: Multiple reports with multiple associated reporting periods (e.g. semiannually, annually, quarterly, monthly) are compiled and submitted. Reports are compiled for the EPA, as well as the Washington D.C. mayor's office (quarterly), and funding agencies (e.g. Non-Point Source Pollution Grant, the Chesapeake Bay program grant, the MS4 program).

Staff and Funding

Q19: Staff Time: How much time is required from city staff to support the green roof indicator tracking program?

A: There are two dedicated DOEE staff members as well as two consultants who work fulltime on the tracking program. WI 1 estimates that the expense associated with the staff time to build the system was around $175,000 (USD), and the annual grant with the contractor comes in at $200,000 (USD). He estimates $250,000 (USD) as being required to start and maintain a small program.

4.3.4 City 3: Chicago, IL

4.3.4.1 Background

Chicago, Illinois, is a city in the Midwest region of the United States with a population of 2.7 million. It has the highest population in the state, and the third highest population in the U.S. The city is located on the shore of Lake Michigan, and the climate is typical of the Midwest: cold, snowy winters, and hot, humid summers with mild springs and autumns. Annual precipitation in Chicago is approximately 91 cm.

4.3.4.2 Interview Details

A single staff member, the City of Chicago's Coordinator of Economic Development, was interviewed for this case study. The interviewed staff member will be identified as Chicago Interviewee 1. The duration of the interview was approximately one and a half hours. It should be noted that the City of Chicago does not have an active green roof tracking program or public-facing map, but the City does track information around stormwater management and GI installations. Excerpts from the interview that are relevant to general GI tracking methodologies or are focused on preparation for a future green roof tracking tool are presented below.

4.3.4.3 Interview Summary

City Objectives

Q1: Tracker Program Scope: Do you have a GI tracking program at the City? If so, is it dedicated to green roofs or a wider array of GI tools? Does it cover GI on public and/or private property?

A: The map that's available online is a 2013 snapshot of green roofs in Chicago created for a study, and not part of an ongoing green roof tracking program. Green Infrastructure, e.g. open space, urban farms, community gardens, community managed open space, is tracked by the city, but green roof installations specifically are not tracked. Most of the tracking conducted by the City of Chicago is for compliance purposes, i.e. meeting objectives laid out by the Sustainable Policy, tracking what types of projects are complying and how. The green roof study looked at both private and public lands, but the focus was on private sphere (where most of the green roofs are located).

Q2: Tracker Objectives: What was the purpose or motivation behind beginning the GI/green roof tracking program at your city? What are the specific objectives of the Tracker program?

A: The 2013 study was motivated by a general lack of statistics and confirmed information on green roofs in Chicago—the City had some record of intended green roof projects via entitlements and assigned permits, but no data on what was actually installed or where. A consulting company was hired to identify green roof spaces, as well as create a general permeability index. "The main motivation was to establish a baseline and… existing conditions of…where we were at at that point in time" (CI 1). Going forward, the goals of a future tracking program would include amalgamating all GI information into a single tracker and estimating percentage of stormwater diversion from the combined sewer system.

Q3: Public Objective: What does the city hope that the public will gain from having access to green roof tracking information?

A: The 2013 map was made publicly available to show that the existing policy around green roofs was resulting in the installation of green roofs in the city, and having an overall positive benefit. Going forward, a public-facing map attached to a future tracking program could do the same (provide proof of concept and quantify benefits), but also assist with broader transparency goals and "allowing people to know what's being constructed in the city…I think there's an appetite for that from the general public" (CI 1).

Q4: Relationship to other City Strategies: How does the tracking of green roof indicators fit within broader city strategies and goals?

A: Green roofs in the City of Chicago tie into the city's Sustainable Policy (in which they play a role within the broader category of green infrastructure) and the Climate Action Plan. The Climate Action Plan discusses green roofs as nature-based solutions for climate action and adaptation, as well as energy use and cost reductions through improved insulation. The city doesn't have a biodiversity strategy, but improving and preserving biodiversity are themes within the We Will Chicago plan (citywide plan) and the Climate Action Plan. Developers are allowed to receive credits for up to 10% above and beyond their vegetated space, either for stormwater or ecological management, or for amenity space (development policy). Also, green roofs help reduce site imperviousness, which falls under the Stormwater Ordinance but also the Sustainable Policy (credits received towards Sustainable Policy by exceeding requirements in Stormwater Ordinance).

Indicators

Q5: Indicators: Which indicators are tracked by the program?

A: The map created for the 2013 study tracked location (building address), total roof size (square footage), total green roof size, percent of total roof that green roof makes up, and included an aerial photograph of the roof, obtained via satellite imagery. In addition to those indicators, they also attempted to track relative health of the green roof vegetation, but it was difficult to do via the satellite imagery alone. They also wanted to track measures of roof surface temperature before and after green roof installation, but haven't yet found a replicable way to track that over time. In addition, they considered tracking costs of the green roofs, but don't have access to that type of data for privately funded green roofs. Outside of the map, only location and size data are collected, and compliance checks are conducted once the green roofs are completed in order to ensure stormwater management performance.

Q6: Why: Why were these indicators selected for tracking?

A: They were considered the baseline indicators for green roofs, and were all that could be tracked given budget, time, and data restraints.

Q7: Public v Private: Which indicators are public-facing (mapped), and which are collected for internal purposes? What was the motivation behind publicly displaying green roof data, specifically?

A: The motivation for the snapshot map was to provide transparency for the public on the completion and location of green roof projects in the city. All of the tracked indicators were shown via the map, and so were public-facing.

Q9: Missing Indicators: Are there other indicators that are not currently tracked that you think would be beneficial to track?

A: "One thing we're looking at is…sort of this idea of cumulative impacts of development, both the positive and negative…What types of pollution or negative impacts industrial development is having on particular parts of the city. I think it would be really interesting to think about cumulatively what benefit development is having. You know, is there a way to quantify the total amount of underground storage, total amount of storage within sort of green infrastructure installments" (CI 1). This includes total site permeability as well as volumes of stormwater diverted. It was also mentioned that tracking specifics around biodiversity, e.g., conducting bird counts, could be useful, along with the previously mentioned rooftop temperatures, green roof costs, and vegetation health.

Tracker Platform and Ownership

Q10: Software Platform: What are the technical requirements for the tool? E.g., software requirements, hardware requirements, data storage requirements, etc.

A: ESRI GIS-based software.

Q11: Data Ownership: Who owns the data displayed by the tool? Are there any liability concerns around data ownership and access?

A: The data that went into the map was satellite imagery that the city purchased from a private provider. There were liability and security concerns about publishing photos of sites; however, they decided to publish them because those images are easily available via google maps. CI 1stated that in future iterations of the map, publicly accessible satellite imagery could be used (e.g. from NASA, other USA federal agencies), and significant costs could be saved without the need to purchase data.

Data Source, Collection, Storage, Mapping, and Reporting

Q12: Departments involved: Which Departments/staff members play a role in green roof indicator tracking? Does indicator tracking fall under the jurisdiction of a single city department? Or is it split between multiple departments or groups?

A: The Planning Department and the Building Department are the predominant agencies involved in green roof projects. Personnel involved with stormwater are split between the Building Department and the Department of Water Management. The inspections and technical reviews are conducted by staff in the Department of Buildings.

Q13: Data Source: What is the source of data?

A: The source of the data displayed by the map was satellite imagery. The data that the department tracks around GI in general comes from Google forms that developers fill out to indicate their compliance with city ordinances, and this information is entered into a master spreadsheet. The developers provide information on construction plans, stormwater compliance, and stormwater calculations to show how green infrastructure helps meet requirements.

Q15: Information Collection: At which stages of the development process is information on the indicators collected?

A: Developers fill out a form during the permitting process, and CI 1 follows up with them once it is submitted

Q16: Data Storage: How and where is indicator data stored?

A: The data is stored in a spreadsheet, which is automatically populated from the developer forms.

Q18: Data Reporting: How does the City use the collected data? Are reports produced? How often? By whom?

A: The data is mostly collected for compliance review purposes, and the information that's reported is based around the number of projects reviewed and approved for budgeting purposes.

Staff and Funding

Q20: Funding: How much support does the tracking program receive in terms of available funding?

A: In reference to a future comprehensive tracking program: "I don't know if that's a full time yearly staff person…I think certainly setting up the system would be costly, but ongoing maintenance and that sort of reporting I don't think would take that much staff time, depending on the system that's set up. So if it were efficient enough to collect the information, or we could push that on to development teams to provide that information, I think it could go a long way towards you know, streamlining it. If…the data had to be gleaned from either construction plans or, you know, stormwater calculations or other technical data, I think that would sort of necessitate the need for more staff" (CI 1).

General Advice

Q21: Advice: What advice would you give to other city staff preparing to begin their own green roof indicator tracking program?

A: Final thoughts: "I think there's a lot of value in more data collection. We just have to develop the tools and get the political will behind it".

5. Discussion

5.1 Lessons Learned and Takeaways

5.1.1 Green Roof Co-Benefits and City Goals

While it has been established that the use of green roofs can provide a wide range of co-benefits in support of City of Vancouver strategies, it should be emphasized that green roofs are explicitly identified by eight City strategies, plans, guidelines and bylaws as tools to support Vancouver's current and future goals (i.e., the Biodiversity Strategy, the Bird Friendly Design Guidelines, the Citywide Integrated Rainwater Management Plan, the Climate Change Adaptation Strategy, the Rain City Strategy, the Vancouver Building Bylaw, the Vancouver Plan, and the Water Wise Landscape Guidelines). This indicates that green roofs are already theorized to be useful tools for combatting a number of City issues. Many of these City documents lay out specific, actionable targets for sustainable outcomes, and tracking the characteristics of Vancouver green roof installations could help quantify the co-benefits being provided, tying green roof use directly to achieving City targets and goals and providing rationale for promoting installations. This connects to lessons learned from the case study cities: staff emphasized the public's desire for transparency and accountability from city government on the results of city policies around green roofs and co-benefits.

Although green roofs represent only a single GRI tool within a broader GRI network, it is important to also note that they are distinctively situated to draw public interest and engagement. Many forms of GRI, while functional and beneficial, aren't as visual, aesthetically pleasing, or accessible as green roofs are. Green roofs are somewhat unique in their visibility (depending on the roof height), as many forms of GRI, if they are functioning correctly, are mostly invisible as they serve to replicate natural systems and prevent any stormwater issues that may draw attention, such as flooding. The results of the City document analysis and green roof literature review emphasize the opportunities green roofs can present to improve quality of life for Vancouver residents beyond stormwater management.

5.1.2 Green Roof Indicator Ranking

Appendix C contains the master list of indicators with ranking categories and overall ranking scores for each indicator. As shown, the highest scoring indicators received overall rankings, or total scores, of 8 or 9, while the lowest scoring indicator received an overall ranking of 2. The majority of high scores went to indicators that were easy to collect, scoring 4 or 3 in that category, aside from 'building roof exposure', which is predicted to require some effort to collect (based on required knowledge of weather conditions and the effects of neighbouring buildings on sun and wind exposure), but ranks highly in both category importance and relevance to City strategies. The indicator subcategories with the highest scoring indicators were 'green roof dimensions', 'green roof technical specifications', 'building roof intended use', 'building location', and 'site stormwater management details'. The stormwater management details had by far the most highly ranked indicators (scoring between 9 and 7), and while it was also the subcategory with the most indicators in general, most of its indicators are already being tracked by the City, and so it makes sense to continue to collect this information for a green roof-specific or larger green rainwater infrastructure program.

Every indicator that scored a 7 or above connected to at least one City strategy category (aside from 'permit acceptance date', which is an indicator that is already being tracked, and scored highly for category importance). Table 2 displays the top 55 scoring indicators and their rankings, with Appendix D showing these 55 indicators and the City strategy categories that they support. Table 3 shows a subset of this list. Each indicator subcategory contains at least one indicator that scored at 7 or above, and so is represented in Table 2.

The ranking system and top scoring indicator list are meant to serve as a means to recommend indicators for the Green Roof Asset Tracker Tool and program, based on a diverse set of criteria with strong emphasis on the expression of the full range of possible green roof co-benefits. However, for practical reasons, other indicators may be selected. For instance, no indicator scored higher than a 7 in the 'QA/QC, maintenance, and performance assessment' subcategory. This is more so due to a lack of direct connection to multiple City strategies than it is due to lack of importance of indicators within the subcategory. Indicators related to QA/QC and maintenance are objectively an important set of indicators, and would presumably be tracked as part of any green roof maintenance and performance assessment inspection procedure. Lack of high scoring indicators within a subcategory does not imply that that subcategory is not worth including in a tracking program, just that, using the current study methodology, which is based on certain preferences and priorities, other indicators score higher.

Table 2.

Top 55 ranked indicators with overall ranking scores.

CATEGORY	SUBCATEGORY	INDICATOR	OVERALL INDICATOR RANKING SCORE
Green Roof	Dimensions	Area	9
		Percent of total roof area that is green roof	9
	Technical Specifications	Type of green roof	8
		Green roof category	7
		Irrigation	7
		Supplemental technologies included	8
	Access to Green Roof	Access type	8
	Planting Specifications	Number of edible plants	7
		Number of trees	7
	Stormwater Management	Volume of rainwater diverted from runoff	7
	QA/QC, Maintenance, and Performance Assessment	Dead or stressed vegetation	7
		Dry grass or vegetation	7
		Stormwater management	7

	Green Roof Intended Purpose	Biodiversity support	7
Building Roof	Building Roof Intended Use	Access restrictions	8
		Means of access	7
		Enhanced universal access	8
		Agriculture	7
	Roof Features	Children's play area	8
		Water features	8
	Amenity Capacity	Weight limit	7
		Number of available garden plots	7
	Building Roof Characteristics	Building roof exposure	8
		Total building rooftop area	7
Building and Context	Location	Site address	8
		Sewer catchment	7
		Drainage basin	7
		Neighbourhood	7
	Building Specifications	Building intended use	7
	Permit	Acceptance date	7
	Stormwater Management Details	Rainwater management plan submitted	7
		Pre-development runoff	7
		Post-development unmitigated runoff	7
		Post-development controlled runoff	7
		Mitigated flows	7
		Controlled unit release rate	7
		% Tier 1	7
		% Tier 2	7
		% Tier 3	7
		% Not managed	7
		% Tier 1- green roof	8
		% Tier 1- rainwater harvesting	8
		% Tier 1- infiltration	7

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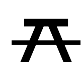
		% Tier 3- detention storage	7
		Detention tank	7
		Detention tank volume	7
		Pumping of tank	8
		Water quality treatment percent	7
		Infiltration system	7
		Rainwater harvesting tank with pump	9
		Sewer type	7
		Drainage area managed	7
		Pre-development impervious area	7
		Post-development impervious area	7
		Impervious area managed	7

Table 3.

Subset of the top 55 ranked indicators with supported City strategy categories.

CATEGORY	SUBCATEGORY	INDICATOR	BIODIVERSITY	RAINWATER MANAGEMENT	AMENITIES	URBAN AGRICULTURE	CHILDCARE	CLIMATE RESILIENCE	EQUITY
	Dimensions	Area							
		% of total roof area that is green roof							
	Technical Specifications	Type of green roof							
		Supplemental technologies included							

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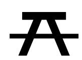
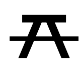
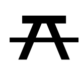
	Access to Green Roof	Access type							
	Planting Specifications	Number of edible plants							
		Number of trees							
	QA/QC, Maintenance, and Performance Assessment	Dead or stressed vegetation							
Building Roof	Building Roof Intended Purpose	Access restrictions							
		Enhanced universal access							
	Roof Features	Children’s play area							
		Water features							
	Building Roof Characteristics	Building roof exposure							
Building and Context	Location	Site address							
	Building Specifications	Building intended use							
		% Tier 1- green roof							
		% Tier 1- rainwater harvesting							
		Detention tank							
		Pumping of tank							
		Rainwater harvesting tank with pump							
		Sewer type							

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5.1.3 Case Studies

5.1.3.1 Green Roof Indicators

For Portland, Washington D.C., and Chicago, tracked green roof/GI indicators mostly fall under the categories of stormwater management compliance and performance. This can be explained by the fact that the impetus for tracking GI indicators in all three cities came from stormwater management compliance and performance mandates. As such, these indicators are viewed as providing a baseline from which to add indicator categories, as all three city interviewees also expressed the desire to track additional indicators not directly related to stormwater management (e.g., roof costs, vegetation survival rates, cumulative impacts of GI, biodiversity indicators, accessibility restrictions, etc.).

5.1.3.2 Public-Facing Map Tool

In terms of technical recommendations for the tool, all four of the online maps in the case studies were run using Esri's ArcGIS platform. Three of the maps were green roof specific, while Washington D.C.'s map contains various display options, green roofs being only one of multiple forms of GI that can be shown on the map. The public-facing indicators for each map provide (collectively) basic information on green roof location, size, depth, composition, planting specifics, stormwater management capacity, year of construction, accessibility, and information about the building on which the green roof is installed.

All interview participants emphasized the presence of public interest in green roofs and the importance of opportunities for public education around GI in general. While the publicly available green roof maps produced for Chicago and San Francisco aren't associated with an active green roof tracking program, staff from both cities acknowledged the value of providing this information to the public. CI 1 specifically mentioned the value of transparency and accountability: showing that green roof installations are occurring in the city provided proof of follow-through on City policies promoting green roofs, and allowed residents to track City GI construction trends in a quantifiable way.

One take away from the Portland case study is that there is public interest in green roofs, and that this interest can be cultivated due to the level of interaction possible with green roofs. The majority of the public-facing indicators viewable on the Portland Eco Roof Map were selected based on public interest and request, indicating that Portland residents value having access to green roof information, and benefit from educational resources. Portland's public-facing indicator list is also a good example of how to promote public engagement. The list is composed in part as answers to the questions City of Portland staff would receive from the public about green roofs.

An interesting difference between the Portland case study and the Washington D.C. case study is the motivation behind providing publicly accessible information. The Washington D.C. tracking and mapping program was designed around providing information necessary for reporting on compliance and program success. This means that the scope of the program is limited to basic green roof information and stormwater management metrics, and that the publicly accessible online map was born from mandates, and not necessarily any desire to meet or inspire public interest. However, the Washington D.C. program is very focused on outreach and education in other ways, as will be discussed in the next section.

5.1.3.3 Green Roof/Green Rainwater Infrastructure Tracking Program

The three case studies explored for this report can be seen as representing green roof or green rainwater infrastructure programs at three different stages of development. Chicago does not currently have an active green roof tracking tool or program, but expressed interest in this study and hopes of building on their 2013 green roof study. Chicago staff stated that the goal of a future tracking program would be to amalgamate information from all city GI into a single tracker to allow for estimation of the percentage of stormwater diverted from combined sewer systems. The purpose of the program would be to quantify and qualify green roof/GI co-benefits. The program is anticipated to require a single staff member working part time on tracking and the map tool.

Both Portland and Washington D.C.'s green roof tracking programs are nested within broader GRI tracking programs. The Portland case study presents an example of a GRI tracking program in an intermediate stage: while the tracking program is established, staff recognize opportunities for improved workflow and the tracking of additional indicators. The City of Portland's green rainwater infrastructure tracking requires limited effort from staff, necessitating only a few weeks of work per year between two staff members. In addition, the Portland case study provides notable examples of public and private partnerships for the advancement of green roof tracking and mapping. The Eco Roof Map exists as a collaboration with Portland State University faculty and students, who have taken the lead on providing public-facing information. Shorter term studies, such as the Audubon citizen science bird project, represent a novel way to involve the community in data collection and gather useful information that may be outside of the scope of a program run solely by City staff. Even though the more diverse indicators were only tracked temporarily in association with these studies and so weren't associated with the ongoing tracking program, they did serve as a means to bring in community partners and educate the public.

Washington D.C.'s green rainwater infrastructure tracking program is well established, robust, and efficient. The district's program is also extremely comprehensive. It integrates 13 forms of GI into a single tracking system with a central database, easy data entry for GRI project developers, seamless data collection, and a consistent reporting methodology. It showcases the benefits of allowing developers and permit holders easy access to information on their project by establishing different permission levels for GRI data access, which reduces issues around liability, and supports QA/QC efforts. This has majorly contributed to the effectiveness of the program. In addition, input of green roof tracking information is allowed at any and all stages of the development process (development permit or building permit) with information only being finalized and publicized after an as-built inspection is completed, streamlining the data entry process. The program employs four fulltime staff, which is necessary due to how prolific green roofs are in the district. Washington D.C. not only has an impressive GRI tracking program, but also an impressive track record for successfully promoting and supporting green roof installations. WI 1 estimated that there were 3,200 green roofs installed within the district. This success is due in part to a grant supporting green roof installations on private property, as well as the passing of stormwater legislation with specific stormwater management requirements that foster the use of green roofs, but also because of the success of the maintenance program. Any green roof that falls out of compliance is quickly brought back into compliance via actionable recommendations, meaning that very few of the district's green roofs are ever decommissioned. Another reason for the success of green roofs in the district is that significant support is available to those who want to install green roofs, whether that support takes the form of financial incentives (the grant and rebate program), hosted trainings, technical guidance, skillset building, or just informational sessions for residents to learn about the green rainwater infrastructure in their communities. It represents what is possible for a mature program, and Washington D.C. often consults with other municipalities to provide advice and resources.

While the district's program is an aspirational example in many ways, the program has only just begun to attempt to tie green roof functions and co-benefits to other district strategies and goals. Staff acknowledge the importance of tracking green roof co-benefits and are grappling with developing effective methodologies for quantifying and tracking co-benefits outside of stormwater management. WI 1 mentioned receiving assistance with this process from the Green Infrastructure Leadership Exchange, indicating that this issue is receiving attention at a national level, and has been prioritized by leaders in the field of GI.

5.2 Study Limitations

The limitations and biases present in various methods and conclusions of the study have been acknowledged in other sections of this report. Case study selection was based on a map of green roof installations in Canada and the United States of America that is not complete. In addition, case study cities were selected based on the ability to find public-facing green roof maps online. Some of these maps, even those that appeared to be similar to what is desired for Vancouver, were instead just snapshots of green roof installations in a city, and did not include active green roof tracking components. The most robust GI tracking program turned out to originate in Washington D.C., a location we'd listed fourth in our case study prioritization, in part because the map that had been identified for the district was not actually the district's official map. It is possible that we missed opportunities to review robust and effective green roof tracking programs because their online resources didn't appear in internet search results. However, the case studies that were performed did provide useful and actionable information.

In terms of the indicator ranking, some aspects of the developed scoring system were somewhat subjective, and the ranking should not be viewed as a purely quantitative analysis. Indicators that are already tracked by the City were typically scored higher because of their ease of collection, and many indicators, although they scored highly in relevance to City strategies, ranked lower overall due to the difficulty of collection or lack of guidelines for qualification, such as whether or not a specific plant species provides bird habitat support. Ultimately, the indicators that were recommended for tracking in this report are the outcome of a single set of priorities, and should be viewed as a starting point for future studies.

The focus of many green roof and green rainwater infrastructure programs is stormwater management but, as this study reconfirms, green roofs can provide a multitude of other important functions and co-benefits. However, as was made apparent in the interview with Washington D.C. staff, while important for advancing sustainability objectives and further demonstrating the value of green roofs, connecting green roof co-benefits to specific, trackable indicators is no easy feat. Developing a defensible methodology for tracking and quantifying green roof co-benefits would require a study much larger in scope and resources than the study performed in connection to this report. However, one result of this study is the identification of gaps in knowledge, and the identification of next steps and available resources.

6. Recommendations

6.1 Recommendations for Green Roof Indicators

The indicators recommended for tracking by the ranking system developed for this study are shown in Table 2.

Short-term Recommendations

1) Discuss and confirm immediate priorities for the tracking program, and re-rank indicators in the master list accordingly.

2) Prioritize the tracking of critical information, such as the number, dimensions, and types of green roofs installed in Vancouver per year, as well as stormwater management and QA/QC indicators. This can serve as a baseline of indicators to add to once the program is established.

3) Utilize the information that is already being collected by the City for permitting

purposes as easily gathered and cost-effective indicators for tracking.

Long-term Recommendations

1) Nest the tracking of green roof indicators within a broader GRI tracking program, with specific indicators for a suite of GRI types.

2) Following more comprehensive studies with broader scopes, and follow ups with other municipalities working towards this goal, add indicators to tracking that can directly quantify and qualify green roof co-benefits for supporting a wide range of City strategies and goals.

6.2 Recommendations for Public-Facing Mapping Tool

6.2.1 Tool Indicators

If ten indicators are to be displayed in connection to any mapped City of Vancouver green roof, the following would be suggested to provide both basic, foundational information about the city's green roofs as a means of public education and awareness, as well as to spark further interest and support.

- Geographic coordinates (in replacement of building address, for privacy concerns)
- Green roof area (m^2)
- Green roof height (m, ft, storeys)
- Green roof type (extensive, semi-intensive, or intensive)
- Year built (year)
- Green roof access restrictions (public, private, maintenance-only, or no access)

- Visibility (viewable from street, viewable from adjacent buildings)

- Building intended use (residential [market or non-market], commercial, industrial, government, education, public, or mixed-use)

- Green roof intended purpose (stormwater management, biodiversity support, amenity space, education, climate resilience, equity enhancement, etc.)

- Volume of rainwater diverted from runoff (L)

6.2.2 Tool Features

Short-term Recommendations

1) Use the Esri ArcGIS platform to create a green-roof specific asset tracker map showing green roof general location and ten tracked indicators (see above).

2) Include clearly identifiable and up to date contact information for a City of Vancouver staff member who can field questions about the map from the public.

Long-term Recommendations

1) Nest green roof asset tracker map within broader GRI tracker map with layers showing each of the GRI types tracked by the City of Vancouver to provide a more holistic picture of GRI networks in Vancouver.

2) Include options for showing other map layers not directly connected to GRI, such as city demographic information, heat maps, or green space maps that provide information for better analyzing green roof installations in the city against social and environmental justice concerns.

3) Seek input from the public and interested parties on what GRI indicators they would like to see tracked.

6.2.3 Tool Data Management

Short-term Recommendations

1) Update data displayed by map once per year, manually, for simplicity until tracking program is more established and workflows can be automated.

2) Confirm green roof installations via satellite imagery or site visits (can be done in conjunction with maintenance inspections).

Long-term Recommendations

1) Automate map updates so that data is automatically scraped and input from developer applications or an indicator database when new green roof installations are approved and installed (may show green roof as 'planned' on the map, until construction is complete).

6.3 Recommendations for Green Roof/Green Rainwater Infrastructure Asset Tracker Program

6.3.1 Data Collection and Storage

Short-term Recommendations

1) Store relevant indicator data in a single, central database, as the involvement of different City departments in data storage quickly complicate data access and use.

2) Ideally, most indicator data would be provided by building developers during the final stages of the building permitting process, and transferred into a central GRI database.

3) Maintenance, compliance, and QA/QC indicator data can be collected by City staff during routine inspections of green roofs and GRI, or, provided by developers via site photos, if procedures allow.

4) Involvement of staff from a single City department in data collection and storage seems to be the most straightforward way to ensure that indicator data is entered correctly, used correctly, and stored in a central location.

Long-term Recommendations

1) Prioritize automation of data collection and storage. The more automated the process is, the less effort and costs are incurred in demands on staff time.

2) Allow developers or permit holders to input information on green roof/GRI projects at any point in the application approval process, with information only being finalized and publicized after an as-built inspection is completed, streamlining the data entry process.

6.3.2 Staff and Funding

Short-term Recommendations

1) While the program is in development, it is recommended that several staff already involved in the tracking and permitting of Vancouver GRI work part-time on the tracking tool and program. This should be sufficient to maintain a program that tracks and maps critical indicators, requiring only a few weeks of staff time per year. However, during the initial stages, it may be best to also employ one fulltime City of Vancouver staff member to spearhead the tracking program and serve as a coordinator and initial developer. Following program startup, fulltime staff may not be required, unless a more comprehensive program is sought.

2) Taking advantage of any opportunities for public and/or private partnerships is recommended. Partnering with academic institutions, private organizations, or utilizing citizen science projects could allow for development of the program as well as more targeted short-term studies without burdening City of Vancouver staff and resources. There is substantial public and academic interest in green roofs and their co-benefits, and the City of Vancouver could harness this interest for promotion of green roofs in the city, as well as assistance with data collection and tracking.

Long-term Recommendations

1) Increase or decrease dedicated staff depending on the program needs and trajectory.

6.3.3 Ownership and Liability

Short-term Recommendations

1) The City of Vancouver will own the data that will be tracked and mapped, as it will be scraped from development/building applications or collected by City of Vancouver staff.

2) Avoid making certain information public, such as the addresses of the buildings where green roofs are installed, and the names or contact information of developers, as best practices for privacy and liability concerns. Satellite imagery is publicly available, however, and so the location (i.e. addresses) of buildings with green roofs may be public knowledge. However, it is recommended to not list addresses or contact information so as not to encourage commercial use of the information.

Long-term Recommendations

1) There would be benefits to allowing developers and permit holders easy access to information on their GRI projects by establishing varied permission levels for GRI data access. This reduces issues around liability, and would support QA/QC efforts. However, developing a user-friendly and passcode protected interface and management system would require substantial effort, and may be prioritized once the program is well established.

6.3.4 Advancement of City Goals

Short-term Recommendations

1) Produce annual reports detailing trends in green roof installations in Vancouver (e.g. number of new installations, number of applications for developments involving green roofs, and the types of green roofs being installed).

2) Quantify overall impacts of green roofs/GRI in Vancouver on stormwater management, as indicators providing this information are already being tracked.

Long-term Recommendations

1) Quantify overall impacts of green roofs/GRI in Vancouver across a broad range of categories, including those discussed in this study (stormwater management, biodiversity, amenity provision, childcare, urban agriculture, climate resilience, and equity enhancement).

6.4 Recommendations for Next Steps

In summary, recommended next steps in preparation for development of a Green Roof Asset Tracker tool and program are as follows:

1) Review the ranked indicator list with green roof experts (staff members and experts who are already involved in GRI tracking) as well as those who will be providing the information (developers etc.) to get more well-rounded input on the importance of specific indicators, the effort required for collection, and the consolidated priorities of a broader range of City staff.

2) Apply relevant methodologies described in this study to a suite of GRI. As mentioned in other sections, tracking and mapping green roofs can represent an excellent starting point for a more holistic, GRI-focused program to be modeled after.

3) Reach out to the Green Roof Leadership Exchange to take advantage of the work they have already begun on quantifying and tracking diverse green roof co-benefits, and continue to track Washington D.C.'s progress on this front. The City of Vancouver should initially concentrate efforts on developing and sustaining a preliminary green roof/green rainwater infrastructure indicator tracking program and tool before tackling the development of methodologies to explore co-benefits in a more quantitative way, as this study was not able to identify examples of this being done in conjunction with a long-term program, versus a short-term snapshot study.

7. Conclusion

Green roofs can provide Vancouver with a number of co-benefits and services based on the variety of green roof forms, functions, and features. While the initial impetus for this project came from the City of Vancouver's Rain City Strategy, green roofs have been shown to enhance biodiversity, increase climate resilience, improve quality of life, offer opportunities for childcare and urban agriculture, and can represent opportunities to enhance equity in Vancouver. Green roofs are also somewhat uniquely situated in that they are a visible form of green rainwater infrastructure that present opportunities for public engagement and education. Tracking green roof information via a comprehensive and holistic Green Roof Asset Tracker tool and program can help to quantify and qualify green roof co-benefits and services, and promote the installation of green roofs in the city. Including a public-facing GIS-based map can provide opportunities for transparency, public education, and to raise public support and interest in installing green roofs. Green roof tracking indicators that tie into and support multiple City of Vancouver strategies and goals and are not difficult or costly to collect should be prioritized under a developing tracking program.

Case studies were conducted on other municipalities with established green roof or green rainwater infrastructure tracking programs with publicly accessible green roof maps. Portland, OR, Washington D.C., and Chicago, IL, serve as examples of tracking programs in different stages.

Portland can provide recommendations for a smaller, more intermediary GRItracking program, and Washington D.C. represents a robust and mature GRI tracking program. The case studies serve as a basis for making indicator, public-facing map, and tracking program recommendations. While the results of this study provide actionable recommendations for the City of Vancouver on a Green Roof Asset Tracker tool and program, study limitations and biases present in the methods should be recognized. This report is green roof-focused because the short project timeframe necessitated a limited scope, but we recognize that green roofs are one part of larger GRI systems, with unique benefits incurred when various forms of GRI are used in tandem, and hope that the results of this project can be used to inform best practices for other forms of GRI in Vancouver. In addition, although attempts were made to ground the study in objective, quantitative, and replicable methods, the green roof indicator ranking system developed for the study is somewhat subjective, and reflects a single set of priorities for tracked indicators. Involving a range of City staff, developers, and green roof experts in further iterations of indicator ranking could reduce biases in indicator selection and represent more diverse priorities. That being said, the comprehensive master indicator list developed for this study may be a valuable resource for further work to build on.

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Appendix A

Interview Questions for Case Study City Staff Members

City Objectives

Q1: *Tracker Program Scope*: Do you have a GI tracking program at the City? If so, is it dedicated to green roofs or a wider array of GI tools? Does it cover GI on public and/or private property?

Q2: *Tracker Objectives*: What was the purpose or motivation behind beginning the GI/green roof tracking program at your city? What are the specific objectives of the Tracker program? (Prompt: what were the problems you wanted to address? Consider adaptive policy management and public education. Consider public v private property. Consider quality assurance)

Q3: *Public Objective*: What does the city hope that the public will gain from having access to green roof tracking information?

Q4: *Relationship to other City Strategies*: How does the tracking of green roof indicators fit within broader city strategies and goals? (Prompt: green roofs can advance strategies related to co-benefits such as urban heat reduction, biodiversity enhancement, rainwater management, access to nature/education, amenity space, general climate resilience, etc.)

Indicators

Q5: *Indicators*: Which indicators are tracked by the program? (Prompt: location, permit, building context, GI and/or Green Roof design, plantings, rainwater management, other co-benefits programming, installation, maintenance and performance/quality assurance)

Q6: *Why*: Why were these indicators selected for tracking? (Prompt: advancement of other city strategies? Advancement of quality assurance? Other?)

Q7: *Public v Private*: Which indicators are public-facing (mapped), and which are collected for internal purposes? What was the motivation behind publicly displaying green roof data, specifically?

Q8: *Decisions*: How were decisions made regarding which indicators would be tracked publicly, and which would only be tracked internally?

Q9: *Missing Indicators*: Are there other indicators that are not currently tracked that you think would be beneficial to track? (Prompt: see Q5)

Tracker Platform and Ownership

Q10: *Software Platform*: What are the technical requirements for the tool? E.g. software requirements, hardware requirements, data storage requirements, etc.

Q11: *Data Ownership*: Who owns the data displayed by the tool? Are there any liability concerns around data ownership and access? (Prompt: specifically consider private property)

Data Source, Collection, Storage, Mapping, and Reporting

Q12: *Departments involved*: Which Departments/staff members play a role in green roof indicator tracking? Does indicator tracking fall under the jurisdiction of a single city department? Or is it split between multiple departments or groups? (Prompt: consider data lifecycle, including data source, collection and input, storage, mapping, reporting)

Q13: *Data Source*: What is the source of data? (Prompt: E.g. from submitted development applications, from separate stormwater management plans, from a form submitted by developers specifically for the purpose of collecting desired indicator information?)

Q14: *Data Input*: How is information input from the source into the tracker tool, and by whom? (Prompt: Online form? Land development submittals transcribed by staff?). How often is new information added?

Q15: *Information Collection*: At which stages of the development process is information on the indicators collected?

Q16: *Data Storage*: How and where is indicator data stored?

Q17: *Data Mapping*: Who maps the data? How often is the map updated with new information?

Q18: *Data Reporting*: How does the City use the collected data? Are reports produced? How often? By whom?

Staff and Funding

Q19: *Staff Time*: How much time is required from city staff to support the green roof indicator tracking program?

Q20: *Funding*: How much support does the tracking program receive in terms of available funding?

General Advice

Q21: *Advice*: What advice would you give to other city staff preparing to begin their own green roof indicator tracking program?

Appendix B

Master Indicator List

CATEGORY	SUBCATEGORY	INDICATOR	INPUT
Green Roof	Dimensions	Area*	ft2 or m2
		Depth of growing media	in or cm
		Percent of total roof area that is green roof*	%
		Dimensions of underlying layers	in or cm
		Green roof slope	%
	Technical Specifications	Type of green roof	extensive, semi-intensive, or intensive
		Green roof category	green, blue, or blue-green
		Materials included	specifics for growing medium, filter fabric, drainage layer, etc.
		Growing media type	e.g. engineered media, soil, etc.
		Irrigation	yes or no
		Irrigation water type	potable, reuse, etc.
		Irrigation energy	active or passive
		Supplemental technologies included	e.g. solar panels, rainwater harvesting, etc.
	Access to Green Roof	Access type	public, private, restricted, maintenance only, or no access
		Visibility	visible from street, visible from installation building, visible from adjacent buildings, not visible
		Roof can be walked on	yes or no
		Roof can be used for active space	yes or no
	Planting Specifications	Number of individual plants included	number
		Number of plant species included	number
		Number of indigenous plants included	number

		Percentage of planting that is indigenous	%
		Percentage of planting that is drought-tolerant	%
		Number of bird or pollinator friendly plants	number
		Number of edible plants	number
		Number of trees	number
		Percentage of planting that is trees	%
		Percentage of planting that is shrubs	%
		Percentage of planting that is grasses	%
		Indigenous species included	names or indigenous plant species
		Bird support species included	yes or no
		Pollinator support species included	yes or no
		Drought-tolerant species included	yes or no
		Pesticide use	yes or no
		Fertilizer use	yes or no
	Stormwater Management	Volume of rainwater diverted from runoff	gallons or L
		Volume of rainwater retained on site	gallons or L
		Runoff diversion rate	L/s
	QA/QC, Maintenance, and Performance Assessment	Legal agreement in place	yes or no
		Maintenance plan submitted	yes or no
		Most recent inspection date	date
		Visible soil erosion	yes or no
		Exposed soil	yes or no
		Dry or shrinking media	yes or no
		Ponding or excessive moisture	yes or no
		Vegetation survival rate	rate or %
		Dead or stressed vegetation	yes or no
		Dry grass or vegetation	yes or no

		Weeds	yes or no
		Soil moisture	water fraction by volume
		Change in rainwater runoff rate	rate
		Roof temperature	degrees C
		Range of biodiversity	low, medium, high
		Clogged drains	yes or no
		Damaged membrane	yes or no
	Green Roof Intended Purpose	Stormwater management	yes or no
		Biodiversity support	yes or no
		Amenity space	yes or no
		Education	yes or no
		Climate resilience	yes or no
		Equity enhancement	yes or no
Building Roof	Building Roof Intended Use	Access restrictions	public, private, restricted, maintenance only or no access
		Means of access	e.g. stairs, elevator, ladder
		Enhanced universal access	yes or no
		Childcare	yes or no
		Education	yes or no
		Agriculture	yes or no
		Recreation	yes or no
	Building Roof Features	Covered area for shelter	yes or no
		Children's play area	yes or no
		Indoor amenity space	yes or no
		Outdoor seating	yes or no
		Lighting	yes or no
		Water features	yes or no
		Publicly accessible water	yes or no
	Amenity Capacity	Number of people who can access roof at once	number
		Weight limit	lbs or kg
		Number of available garden plots	number
		Dimensions of available garden plots	ft or m
	Building Roof Characteristics	Roof exposure	select all that apply: direct sunlight, partial shade, full shade, high wind, low wind
		Roof status	reroof or new construction
		Rooftop height	ft or m

		Total rooftop area	ft2 or m2
Building and Context	Location	Site address*	street address
		Latitude*	degrees
		Longitude*	degrees
		Alternate or former address*	street address
		Watershed	name
		Sewer catchment*	e.g. Cambie/Heather
		Drainage basin*	e.g. False Creek, Fraser River
		Neighbourhood*	e.g. Marpole, Riley Park
		Zoning district	A, C, D, I, M, O, P, R, S, T, U, or W
		Zone	name
	Building Specifications	Building materials	e.g. wood frame, concrete, etc.
		Building height	ft or m
		Number of storeys*	number
		Passive house*	yes or no
		Intended use	(residential [market or non-market], commercial, industrial, government, education, public, or mixed-use)
		Passive irrigation*	yes or no
	Permit	BP Permit ID*	ID
		DP Permit ID*	ID
		Acceptance date*	date
		Acceptance period*	e.g. 2020 Q3
		Accepted for occupancy*	yes or no
	Site Stormwater Management Details	Rainwater management plan submitted	yes or no
		Rainwater management plan acceptance date	date
		Rainwater management plan acceptance period	quarter
		Pre-development runoff*	L/s
		Post-development unmitigated runoff*	L/s
		Post-development controlled runoff*	L/s
		Mitigated flows*	L/s

		Controlled unit release rate*	L/s/ha
		% Tier 1*	%
		% Tier 2*	%
		% Tier 3*	%
		% Not managed*	%
		% Tier 1- green roof*	%
		% Tier 1- rainwater harvesting*	%
		% Tier 1- infiltration*	%
		% Tier 2- landscape on slab*	%
		% Tier 3- detention storage*	%
		Detention tank*	yes or no
		Detention tank volume*	m3
		Pumping of tank*	yes or no
		Water quality treatment %*	%
		Water quality unit type*	e.g. jellyfish, OGS, CB Shield
		Landscape on slab*	yes or no
		Infiltration system*	yes or no
		Rainwater harvesting tank with pump*	yes or no
		Permeable pavement with infiltration*	yes or no
		Permeable pavement area*	yes or no
		Sewer type	e.g. combined or separate
		Drainage area managed*	m2
		Pre-development impervious area*	%
		Post-development impervious area*	%
		Impervious area managed*	m2

* indicates that indicator is already tracked by the City of Vancouver

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Appendix C

Master indicator list with ranking categories and overall ranking scores.

CATEGORY	SUBCATEGORY	INDICATOR	RELATIVE IMPORTANCE WITHIN CATEGORY[1]	EASE OF COLLECTION[2]	RELEVANCE TO CITY STRATEGIES[3]	OVERALL RANKING SCORE[4]
Green Roof	Dimensions	Area	3	4	2	9
		Depth of growing media	2	3	1	6
		Percent of total roof area that is green roof	2	4	3	9
		Dimensions of underlying layers	1	3	1	5
		Green roof slope	1	3	1	5
	Technical Specifications	Type of green roof	3	3	2	8
		Green roof category	2	3	2	7
		Materials included	1	3	1	5
		Growing media type	1	3	0	4
		Irrigation	2	3	2	7
		Irrigation water type	1	3	1	5
		Irrigation energy	1	3	1	5

		Supplemental technologies included	2	4	2	8
	Access to Green Roof	Access type	3	3	2	8
		Visibility	2	3	1	6
		Roof can be walked on	1	2	1	4
		Roof can be used for active space	3	2	1	6
	Planting Specifications	Number of individual plants included	1	2	1	4
		Number of plant species included	1	2	0	3
		Number of indigenous plants included	2	1	2	5
		Percentage of planting that is indigenous	2	1	2	5
		Percentage of planting that is drought-tolerant	2	1	2	5
		Number of bird or pollinator friendly plants	2	1	1	4
		Number of edible plants	2	2	3	7
		Number of trees	3	2	2	7

		Percentage of planting that is trees	1	2	2	5
		Percentage of planting that is shrubs	1	2	2	5
		Percentage of planting that is grasses	1	2	2	5
		Indigenous species included	3	1	2	6
		Bird support species included	3	1	1	5
		Pollinator support species included	3	1	1	5
		Drought-tolerant species included	3	1	2	6
		Pesticide use	3	2	1	6
		Fertilizer use	3	2	0	5
	Stormwater Management	Volume of rainwater diverted from runoff	3	2	2	7
		Volume of rainwater retained on site	2	2	1	5
		Runoff diversion rate	1	2	2	5
		Legal agreement in place	2	3	0	5

	QA/QC, Maintenance, and Performance Assessment	Maintenance plan submitted	2	3	0	5
		Most recent inspection date	2	3	0	5
		Visible soil erosion	2	2	1	5
		Exposed soil	2	2	0	4
		Dry or shrinking media	3	2	1	6
		Ponding or excessive moisture	3	2	1	6
		Vegetation survival rate	1	1	2	4
		Dead or stressed vegetation	2	2	3	7
		Dry grass or vegetation	2	2	3	7
		Weeds	1	2	0	3
		Soil moisture	1	1	0	2
		Change in rainwater runoff rate	1	1	1	3
		Roof temperature	2	1	1	4
		Range of biodiversity	3	1	2	6
		Clogged drains	2	2	1	5
		Damaged membrane	3	2	1	6

	Green Roof Intended Purpose	Stormwater management	2	4	1	7
		Biodiversity support	3	3	1	7
		Amenity space	1	3	1	5
		Education	2	2	1	5
		Climate resilience	2	3	1	6
		Equity enhancement	3	2	1	6
Building Roof	Building Roof Intended Use	Access restrictions	3	3	2	8
		Means of access	2	3	2	7
		Enhanced universal access	3	3	2	8
		Childcare	2	2	2	6
		Education	1	2	1	4
		Agriculture	2	2	3	7
		Recreation	1	2	1	4
	Roof Features	Covered area for shelter	1	3	2	6
		Children’s play area	3	3	2	8
		Indoor amenity space	1	3	2	6
		Outdoor seating	1	3	1	5
		Lighting	1	4	1	6
		Water features	3	3	2	8
		Publicly accessible water	2	2	2	6

	Amenity Capacity	Number of people who can access roof at once	2	2	2	6
		Weight limit	3	3	1	7
		Number of available garden plots	2	3	2	7
		Dimensions of available garden plots	1	3	2	6
	Building Roof Characteristics	Building roof exposure	3	2	3	8
		Building roof status	1	3	0	4
		Building rooftop height	2	3	1	5
		Total building rooftop area	2	3	2	7
Building and Context	Location	Site address	3	4	1	8
		Latitude	2	4	0	6
		Longitude	2	4	0	6
		Alternate or former address	1	4	0	5
		Watershed	2	2	2	6
		Sewer catchment	2	4	1	7
		Drainage basin	2	4	1	7
		Neighbourhood	2	4	1	7
		Zoning district	2	3	0	5
		Zone	1	3	0	3

	Building Specifications	Building materials	1	2	0	3
		Building height	2	3	0	5
		Number of storeys	2	3	0	5
		Passive house	1	4	0	5
		Building intended use	3	3	1	7
		Passive irrigation	1	4	0	5
	Permit	BP Permit ID	2	4	0	6
		DP Permit ID	2	4	0	6
		Acceptance date	3	4	0	7
		Acceptance period	1	4	0	5
		Accepted for occupancy	2	4	0	6
	Stormwater Management Details	Rainwater management plan submitted	3	3	1	7
		Rainwater management plan acceptance date	2	3	0	5
		Rainwater management plan acceptance period	1	3	0	4
		Pre-development runoff	2	4	1	7
		Post-development unmitigated runoff	2	4	1	7

		Post-development controlled runoff	2	4	1	7
		Mitigated flows	2	4	1	7
		Controlled unit release rate	2	4	1	7
		% Tier 1	2	4	1	7
		% Tier 2	2	4	1	7
		% Tier 3	2	4	1	7
		% Not managed	2	4	1	7
		% Tier 1- green roof	3	4	1	8
		% Tier 1- rainwater harvesting	3	4	1	8
		% Tier 1- infiltration	2	4	1	7
		% Tier 2- landscape on slab	1	4	0	5
		% Tier 3- detention storage	2	4	1	7
		Detention tank	2	4	1	7
		Detention tank volume	2	4	1	7
		Pumping of tank	2	4	2	8
		Water quality treatment percent	2	4	1	7
		Water quality unit type	1	4	0	5
		Landscape on slab	1	4	0	5

		Infiltration system	2	4	1	7
		Rainwater harvesting tank with pump	3	4	2	9
		Permeable pavement with infiltration	1	4	1	6
		Permeable pavement area	1	4	1	6
		Sewer type	2	3	2	7
		Drainage area managed	2	4	1	7
		Pre-development impervious area	2	4	1	7
		Post-development impervious area	2	4	1	7
		Impervious area managed	2	4	1	7

Note: Each indicator is assigned points across three ranking categories. The total number of points is tabulated in the final column, with higher point totals equating higher ranking. Indicators scoring 9 or 8 (the first and second highest scores) are highlighted in yellow, with indicators scoring 7 (the third highest score) highlighted in paler yellow.

[1] 3-1 most to least important in comparison to other indicators within that indicator's category.

[2] 4-0 most to least easy. High point values (4-3) are assigned to indicators for which data collection is easy, and low point values (2-0) are assigned to indicators for which data collection would be difficult (2-1) or unrealistic (0).

[3] 7-0 Point value reflects number of City bylaws, guidelines, plans, strategies categories (Biodiversity, Stormwater Management, Amenities, Childcare, Urban Agriculture, Climate Resilience, and Equity) that the indicator is relevant to (e.g. a point value of 3 means that the indicator is relevant to three City strategy categories).

[4] Points from each category are summed to calculate a score by which to rank the indicator (higher scores are equivalent to higher ranking) in order to provide a quantified basis for indicator prioritization recommendations.

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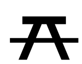
Appendix D

Tracking Co-benefits: Green Roof Indicators Supporting City of Vancouver Goals

CATEGORY	SUBCATEGORY	INDICATOR	BIODIVERSITY	RAINWATER MANAGEMENT	AMENITIES	URBAN AGRICULTURE	CHILDCARE	CLIMATE RESILIENCE	EQUITY
	Dimensions	Area							
		Percentage of total roof area that is green roof							
	Technical Specifications	Type of green roof							
		Green roof category							
		Irrigation							
		Supplemental technologies included							
	Access to Green Roof	Access type							
	Planting Specifications	Number of edible plants							
		Number of trees							
	Stormwater Management	Volume of rainwater diverted from runoff							
	QA/QC, Maintenance, and	Dead or stressed vegetation							

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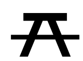
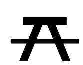
	Performance Assessment	Dry grass or vegetation							
	Green Roof Intended Purpose	Stormwater management							
		Biodiversity support							
Building Roof	Building Roof Intended Purpose	Access restrictions							
		Means of access							
		Enhanced universal access							
		Agriculture							
	Roof Features	Children’s play area							
		Water features							
	Amenity Capacity	Weight limit							
		Number of available garden plots							
	Building Roof Characteristics	Building roof exposure							
		Total building rooftop area							
Building and Context	Location	Site address							
		Sewer catchment							
		Drainage basin							
		Neighbourhood							
	Building Specifications	Building intended use							

	Permit	Acceptance date							
	Stormwater Management Details	Rainwater management plan submitted							
		Pre-development runoff							
		Post-development unmitigated runoff							
		Post-development controlled runoff							
		Mitigated flows							
		Controlled unit release rate							
		% Tier 1							
		% Tier 2							
		% Tier 3							
		% Not managed							
		% Tier 1- green roof							
		% Tier 1- rainwater harvesting							
		% Tier 1- infiltration							
		% Tier 3- detention storage							
		Detention tank							
		Detention tank volume							

		Pumping of tank							
		Water quality treatment percent							
		Infiltration system							
		Rainwater harvesting tank with pump							
		Sewer type							
		Drainage area managed							
		Pre-development impervious area							
		Post-development impervious area							
		Impervious area managed