environments

Technical Note

Implementing Green Roofs in the Private Realm for City-Wide Stormwater Management in Vancouver: Lessons Learned from Toronto and Portland

Junlin Wang [1], Phalguni Mukhopadhyaya [2] and Caterina Valeo [1,*]

[1] Mechanical Engineering, University of Victoria, Victoria, BC V8W 2Y2, Canada; junlin1996@hotmail.com
[2] Civil Engineering, University of Victoria, Victoria, BC V8W 2Y2, Canada; phalguni@uvic.ca
* Correspondence: valeo@uvic.ca; Tel.: +1-250-721-8623

Abstract: Green roofs are an innovative stormwater management technology that has numerous environmental benefits. Citywide implementation is critical to maximizing the benefits of green roofs, especially in terms of jurisdictional encouragement and advancing management programs. The City of Vancouver is interested in developing a rainwater management strategy that supports the widespread implementation of green roofs on private property. Performance control for a green roof on private property requires standards on local natural factors that affect performance; development considerations; supporting legal tools; maintenance and operation responsibilities; equity through the different types of private properties; and finally, cost. Research into the rainwater management strategies for the cities of Toronto and Portland for green roof implementation was conducted to provide insight into the best approaches for such an implementation in Vancouver. Portland and Toronto both have independent green roof standards in addition to separate rainwater management strategies. Portland focuses on a post-occupancy inspection program to monitor a green roof's ongoing performance, while Toronto established the Green Roof Bylaw to encourage the implementation of green roofs. Incentive programs that educate and encourage private owners to take the initiative to construct and effectively operate green roofs are essential to the success of a private green roof program.

Keywords: private green roofs; municipal stormwater bylaws; rainwater management; monitoring green infrastructure

Citation: Wang, J.; Mukhopadhyaya, P.; Valeo, C. Implementing Green Roofs in the Private Realm for City-Wide Stormwater Management in Vancouver: Lessons Learned from Toronto and Portland. *Environments* **2023**, *10*, 102. https://doi.org/10.3390/environments10060102

Academic Editor: Manuel Soto

Received: 18 April 2023
Revised: 7 June 2023
Accepted: 13 June 2023
Published: 15 June 2023

1. Introduction

Rainwater management has been challenging for many jurisdictions, including the City of Vancouver. Water quality in the Vancouver watershed, including False Creek and the Fraser River, already suffers from an aging stormwater drainage system and is worsening due to climate change and population growth. Urban stormwater runoff also increases the risk of flooding and carries pollutants to receiving waters that are known to be toxic to fish and other aquatic species [1]. In addition, more frequent and intense rainstorms are making Vancouver's prevalence of combined sewers and associated combined sewer overflows (CSOs) worse. In response to these issues, the City of Vancouver established the Citywide Integrated Rainwater Management Plan (IRMP) and the Rain City Strategy (RCS) [2,3]. These plans require the city to transform its urban water management strategies. A more comprehensive and integrated approach should be taken to achieve sustainable stormwater management throughout the city with improvements in water quality, resilience, and livability. The RCS recognizes rainwater as a valued resource for local communities and natural ecosystems and manages stormwater using green stormwater infrastructure (GRI), such as green roof systems, water infiltration systems, and water reuse systems, to mimic the natural hydrological cycle. In 2019, RCS required public properties to design a rainwater management plan to capture and clean 48 mm of rainfall per day in streets, public spaces, civil facilities, and parks [3]. The current design standard for private property is to capture a minimum of 24 mm of rainfall per day and clean 48 mm of rainfall per day for high-pollutant surfaces, including roads, driveways, and parking lots. The design standard is applied at the project-, site-, or district-scale whenever rainwater management objectives are included as part of a project scope. Over the coming three decades, the RCS will be the guideline for Vancouver's transition to a water-sensitive city on both public and private properties. Within the RCS, green roof systems have been identified as one of a set of important GRI technologies in Vancouver's rainwater management strategy because of their ability to capture, retain, and treat rainwater on-site at the source [3].

Green roofs can capture rainwater at the source, reducing the volume of rainwater entering the sewer and drainage systems and lowering the possibility of CSO events and their overall volume. Green roof systems consist of, at a minimum, high-quality waterproofing, a root repellent system, a drainage system, filter cloth, a lightweight growing medium, and plants [4]. There are two major types of green roofs: extensive and intensive [5], with the soil layer of an extensive green roof normally being less than six inches, while intensive green roofs have higher expectations in performance and aesthetics (see Figure 1a). Green roofs offer a wide range of public and private benefits in addition to enhancing their aesthetic value. They are intended to collect, retain, and treat rainfall at the source, and precipitation retention is around 90% for small storms and 50% for larger storms [6]. Other studies showed that 85.7% of light rain could be retained and the runoff peak of a heavy rainstorm could be delayed by half an hour—although the runoff could not be fully retained [7]. Long-term performance research has shown that green roofs can retain an average of 82% of rainfall [8] and provide 50.2% cumulative annual rainfall retention [9]. The elements of green roofs, like trees, plants, and, in particular, soil, can play a critical role in absorbing and sequestering carbon dioxide, which is a significant greenhouse gas produced by burning fossil fuels like gasoline, diesel, and natural gas [10]. Green roofs have been reported to improve surrounding air quality [11], as well as reduce heating or cooling energy consumption and the urban heat island (UHI) effect through heat absorption, shading, and evapotranspiration. A safe, natural space can be provided in urban areas for birds, spiders, insects, butterflies, and other invertebrates to live, nest, and have food [12]. Hence, green roofs are considered an ideal form of green infrastructure for on-site infiltration of rainwater in many jurisdictions. However, many factors affect green roof performance, including substrate layer depth, vegetation, local climate, and proper operation and maintenance. The first three factors are considered during design and construction. The operation and maintenance, however, must be continually monitored to determine if performance targets are being met once the green roof is built. Maintenance requirements and operational performance can be determined through monitoring (real-time or intermittently scheduled), which is relatively more manageable for public lands. This can be more challenging, however, on private properties. Regardless, it is evident that a comprehensive monitoring program is essential in private realms to manage and ensure the ongoing performance of onsite green rainwater infrastructure.

General Aspects of Operating and Maintaining Green Roofs

Post-construction inspection, maintenance, and responsibilities are important considerations in meeting green infrastructure-related targets. Rating systems help different jurisdictions with local green roof construction standards ensure that performance goals over short and long periods are being met. In 1998, the Landscape Construction and Development Research Society (FLL) in Germany published a system for rating green roofs (GR) in land-use planning, building permit applications, and construction approval [13]. There are four major categories of GR construction: growing medium water retention capacity, drainage layer water retention capacity, number of plant species (extensive green roofs), and plant biomass or volume (intensive GR). Another well-known performance rating system is the Karlsruhe Performance Rating System, which rates five natural functions of GR. The five functions are assigned a weight in percentage according to their importance [14]: soil type and depth (15%); impact on climate due to evapotranspiration (15%); type and variety of vegetation (30%); impact on zoological biodiversity (30%); and average annual stormwater retention (10%). These well-defined rating systems need to be properly designed and constructed because, without on-site monitoring, performance can be highly uncertain, even if they have been well-designed and constructed. Operation and maintenance (O&M) require a significant human factor in keeping a GR at ideal performance in the long term. Green roofs are complex "living" systems with the same functions as conventional roofs but also containing a vegetation ecological system. Hence, a successful GR requires design, construction, establishment, an O&M plan, and O&M implementation to all work well. Missing any one element will result in the project failing. The purpose of O&M is to provide ideal conditions for all vegetation, find issues in their earliest stages, and prevent structural damage to the roof. A well-performing GR should be self-sustaining with a balance of soil, plantings, and water and minimal O&M needs. The O&M plan should include vegetation care, weed and pest control, proper irrigation (frequency and quantity), and frequent inspection [15]. Ideally, O&M does not require much garden care, such as trimming, edging, or fertilization, but weeding and mulching may be required depending on the planting method. It should only need frequent inspections for vegetation health and coverage. Most plant problems are caused by pests, too much or too little irrigation, fertilization, air vent flow damage, HVAC condensation, or people. The drains are important for any type of roof and should be cleared annually. Erosion is another common concern and needs to be corrected with gravel mulch and sedum cuttings. In addition, an aging GR's rainfall retention can decrease significantly as compared to that at the start of its life [16], primarily due to the organic matter content in the aged roof substrate layer being relatively high and directly increasing the retention capacity. The local climate conditions, mainly temperature and moisture, are major elements affecting rainwater retention. Research has shown that the wettest locations have the highest absolute retention values, and the warmest/driest locations have the highest retention percentage of annual precipitation [17]. The research also found that evapotranspiration was the limiting factor in GR retention capacity in cold and wet locations. However, there had to be relatively large changes in evapotranspiration to affect the retention capacity [17].

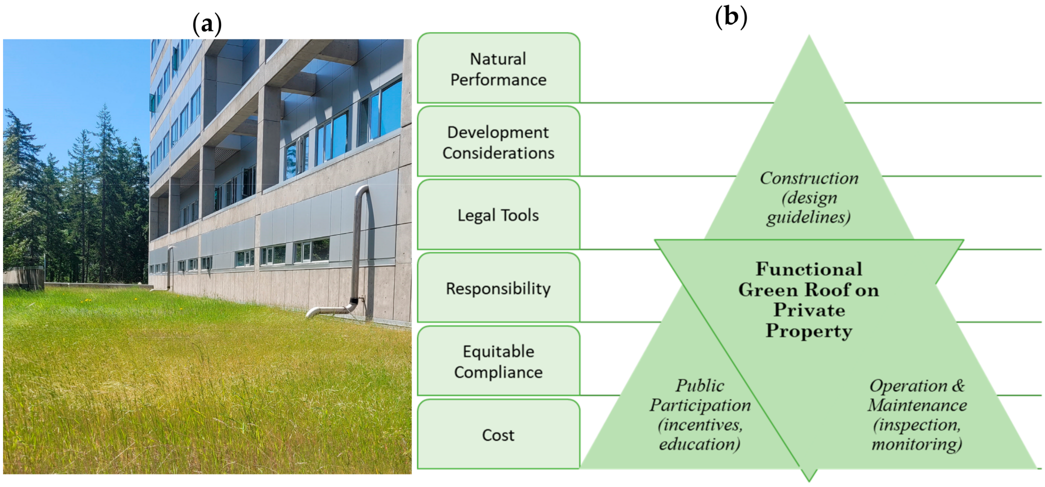

Figure 1. (**a**) Second floor rooftop adjacent to a walkway between two university buildings with a simple grass green roof (in Victoria, BC); (**b**) private green roof implementation mapping for a functional green roof on private property. The six elements at left are necessary components of a quality assurance program leading to optimal green roofs on private properties (the objective shown centrally in the schematic at right). These elements are all factors in each supporting component in the system on the right.

Managing green roofs on private properties involves a number of perspectives. An advanced quality assurance and quality control (QV/QC) program for private property

GR management requires standards on the following topics: natural performance (major natural factors that affect performance), development considerations (how is the program established), supporting legal agreements and tools (the legal agreements, bylaws, or other tools to ensure monitoring in all development phases), maintenance and operation responsibility (constructing, inspecting, and maintaining GRs on private properties), equity (any various compliance mechanisms for different types of private properties), and finally, cost.

The implementation of a city-wide green roof system for private residences is multidimensional and complex. In order to minimize problems moving forward, examining other large cities that have already moved forward on similar strategies can provide valuable insights into best practices. The cities of Toronto, Ontario, and Portland, Oregon, have both implemented, to varying degrees, city-wide strategies for green roofs on private properties. The objective of this research is to study and analyze the systems in Toronto and Portland with the lens of the six considerations noted above and to determine if these systems are feasible in Vancouver given the city's RCS (the general approach shown in Figure 1b). This will help the City of Vancouver avoid any pitfalls of implementing GRs on private properties, as well as provide insight for any other municipalities interested in implementing green roofs on private properties in similar cities. Toronto and Portland were chosen because the former is a Canadian city and the latter has a similar climate to Vancouver. In addition, these two cities made their information easily accessible through the methodology for data collection in this research: phone interviews and online data mining. The minimum criteria for all six considerations are presented, including cost, labor, scale, etc. The research will provide reference points on needed policies and considerations for next steps.

2. Green Roof Implementation in Vancouver, Toronto, and Portland

Each of the three cities is reviewed and compared in terms of some or all of the considerations given in Figure 1b. A review of Vancouver will help provide insight into the progress made thus far by the municipality and illuminate differences between the cities.

2.1. City of Vancouver

2.1.1. Factors Affecting Natural Performance

Vancouver is located on the western half of the Burrard Peninsula, bordered by English Bay and Burrard Inlet to the north and the Fraser River to the south. The City of Vancouver is a coastal seaport city and the largest city in British Columbia. It has 114 km^2 (44 miles^2) of land, serving 631,486 people (according to the 2016 census) (the wider Metro Vancouver population is 2,463,431). With the protection of mountains and warmth from Pacific Ocean currents, Vancouver has a moderate oceanic climate. The wettest months are November and December, with an average precipitation of 182 mm. July and August are normally the driest months, with an average of just 41 mm of precipitation [18]. In 2021, Vancouver's total precipitation was 116 cm [19]. To manage GRI in private properties and ensure ongoing performance, the city established a comprehensive review process to review all development applications.

2.1.2. Development Considerations and Legal Tools

For the private realm, the City of Vancouver has established a rainwater management program focusing on water-sensitive site design and green rainwater infrastructure practices to regulate and guide property owners to treat rainwater in the correct ways. The new or redeveloped sites will enhance on-site rainwater management through pervious surfaces for infiltration, landscape systems for irrigation and evaporation, and the capture and use of rainwater [18]. The city will review applications in the private realm to ensure new and redeveloped projects meet the standards. There are four stages with separate intake streams for starting the rainwater management review process. Each stream will be triggered by different requirements and require submittals. The four stages are: (i) rezoning; (ii) development permit; (iii) building permit; and (iv) occupancy permit.

If a proposed development triggers the Green Building Policy for Rezoning or the Rezoning Policy for Sustainable Large Developments, then the rainwater management requirements, as described in Section 4 of the Zoning and Development Bylaw, will apply, and the review process will begin at the Rezoning stage. If the proposed development does not require rezoning but is located in an area of concern for rainwater management or adequate drainage is unclear or not available according to Section 4 of the Zoning and Development By-law, then the rainwater management requirements will apply and the review process will begin at the Development Permit stage. A Building Permit review will then be necessary for any project that triggers the Vancouver Building Bylaw, and a subsequent Occupancy Permit review is then required for most but not all applicants. The Rainwater Management Bulletin (RMB), published by the city, reiterates Section 4 of the Zoning and Development Bylaw but also provides information on preferred GRI tools (Tier 1, 2, and 3) and the process and submission requirements related to rainwater management throughout the development process.

Rezoning Stage: Sites with CD-1 zoning require a Preliminary Rainwater Management Plan (RWMP) and a Rainwater Management Project Summary Form. The Rainwater Management Plan (RWMP) explains how a proposed rainwater management system meets the requirements of Section 4 of the Zoning and Development By-law in detail, and it is required in all rezoning, development permit, and building permit stages with different standards. The Preliminary RWMP only outlines the proposed rainwater management system and how the project will meet the requirements for volume reduction, rate control, and water quality required in the Rezoning stage in a high-level approach.

Development Permit Stage: Registration of a Rainwater Legal Agreement, acceptable to the General Manager of Engineering Services and the Director of Legal Services, is required prior to the issuance of the development permit. The agreement prevents construction until the final RWM design is accepted, requires that the RWM systems be built as per the accepted design, and requires that these systems be maintained by the owner indefinitely. A Complete RWMP report and Rainwater Management Project Summary Form are also required. The Complete RWMP should outline the near-finalized rainwater management system with some relevant design details, while some information may be missing or need to be confirmed at the building permit stage.

Building Permit Stage: The Building Permit stage is the last stage of the reviewing process prior to construction. The Final RWMP and Rainwater Management Project Summary Form are required at this stage. The Final RWMP needs to outline the final rainwater management system to be constructed, including Best Management Practices located within the building footprint and final internal building mechanical designs. The city will verify if the final design meets the applicable criteria, as the Building Permit is the only stage requiring the final mechanical designs. The Final RWMP can deviate from the accepted Complete RWMP as long as it meets the requirements. A standalone Operation and Maintenance Manual is also required with information on the rainwater management system maintenance program for its future upkeep and performance. The manual should include:

- Site plan descripting proposed conditions in the Final RWMP;
- Phasing considerations, including early-stage requirements immediately following construction and on-going requirements once the site is established;
- A table or schedule showing the optimal work and frequency required to maintain performance for each individual component of the system (additional indications are required if maintenance requires occupancy of the public right-of-way);
- Contact information for any proprietary systems to be located on-site;
- Checklists to assist non-technical persons in assessing operation and maintenance performance and requirements (including pictures where appropriate);
- A description of how access to each of the proposed rainwater management features would be achieved with all necessary maintenance vehicles and equipment; and
- Any additional component that is relevant for the specific application being reviewed.

Occupancy Permit Stage: A sealed letter from a registered professional confirming that the rainwater management system has been constructed in accordance with the accepted Final RWMP is required.

Post-Occupancy Maintenance Reporting: Post-Occupancy is not a stage in the City of Vancouver's Rainwater Management Plan review process. The property owner must submit a report sealed by a professional engineer at the end of the period of time defined in the legal agreement that demonstrates the on-site rainwater management systems have been properly maintained. For most sites, this report requirement is limited to a one-time declaration per the period of time defined in the legal agreement following the Occupancy Permit issuance date.

2.2. City of Portland

2.2.1. Factors Affecting Natural Performance

Portland is a large port city located in northwest Oregon, US, with a population of 641,162. Similar to Vancouver, the City of Portland is also in a moderate climate zone, generally warm and temperate, and well known for its rainy weather, with 1220 mm of average annual precipitation and higher amounts in the winter [20]. Portland has five major watersheds: Columbia Slough, Fanno Creek, Johnson Creek, Tryon Creek, and the Willamette River, which are part of two larger drainage basins: the Willamette River Basin and the Columbia River Basin [21]. Many species of birds, salmon, and other wildlife species are found in the ecosystems of the Columbia and Willamette Rivers.

Portland's stormwater infrastructure is a complex network of engineered and natural assets. In addition to hundreds of miles of pipes and ditches, Portland works with property owners and community organizations to tackle urban challenges with green street planters, trees, and natural area restoration [22]. The city's stormwater management program promotes the use of green infrastructure, including green roofs, rain gardens, sustainable street designs, and infiltration planters, through education, funding, and incentive programs [23]. As with many cities, Portland has a history of pollution and a desire to repair local ecosystems, which became the motivation to develop its stormwater strategies. The overflows from the city's combined sewer system are one of Portland's ecological concerns as they cause industrial and urban pollution in the Willamette River.

2.2.2. Development Considerations and Legal Tools

In 1999, Portland adopted its first Stormwater Management Manual (SWMM) to protect watershed resources and infrastructure investments in both the public and private realms. The manual has been updated regularly and contains retention, water quality, and flow control design standards for stormwater management facilities [24]. It sets stormwater management requirements for new development or redevelopment projects involving 500 ft^2 or more of impervious area. The requirement prioritizes on-site infiltration using vegetation as the most beneficial standard to maximize environmental and urban design benefits, but it would be impossible for some sites because of technical issues or competing requirements. Thus, SWMM established the Infiltration and Discharge Hierarchy, which ranks discharge systems in three levels. Level 1 requires full on-site infiltration of the 10-year design storm with design infiltration rates of 2 in/hr or more. The only exception is for a project with a green roof covering 60% or more of the roof area and conforming to the latest SWMM manual design standards. Level 1 is always prioritized, and levels 2 and 3 (offsite discharge) can be applied only if full on-site infiltration is not feasible. Level 2 requires the project to use surface water systems or separated storm systems that ultimately drain to surface waters as the primary disposal and conveyance for stormwater receiving systems. Level 2 contains water quality treatment standards for all projects and flow control standards in most situations. Level 3 requires projects discharging offsite to combined sewers that convey water to the wastewater treatment plant with flow control standards. All Infiltration and Discharge Hierarchy applications need to be reviewed and approved by the city on a site-by-site basis. If the project cannot meet any levels because of technical issues, the project designer can submit a Special Circumstances Request and pay the Offsite Stormwater Management Fee instead of designing stormwater management facilities. The amount of fee charged depends on the total area of unmanaged impervious area, and the unit price is calculated according to the city's construction costs for installing stormwater management facilities through retrofitting existing impervious areas.

2.2.3. Responsibility—Operation and Maintenance

Stormwater infrastructure and facilities require regular maintenance to ensure performance and limit environmental impacts. In Portland, property owners, or the designated responsible party, are responsible for the operation and maintenance of their own facilities. The owner includes all current and future owners of the property. The current owners are responsible for informing the city to update the responsible party whenever it changes. The O&M Plan and O&M Form submitted in the review stage will be the standards for inspection and enforcement. The standard O&M Plan and O&M Form are available on the City of Portland websites. They are categorized into infrastructure types, including green roofs, permeable pavement, rain gardens, basins, planters, filter strips, drywells and soakage trenches, and surface sand filters.

2.2.4. Equity

An interview with Portland Bureau of Environmental Services (BES) staff revealed that they implemented inspections based on stormwater facility categories, previous inspection time, and private property type. Due to limited staff resources, single-family units are no longer on the inspection list as they are considered low-risk. Instead, letters are sent annually to single-family units explaining the importance and benefits of operation and maintenance. Single-family units make up around 60% of Portland's total private properties. For new developments, BES will try to inspect them in the first year after the project is finished. The following inspection depends on the previous inspection date and stormwater management facility type. The green roof is prioritized because of the system complexity and the large cost associated with failure; thus, the inspection time is set within two years after the previous inspection. Enforcement will be triggered if the property owners or the designated responsible party do not comply with the operation or maintenance of the stormwater management facility based on the O&M Plan. Enforcement is not fully triggered right after an inspection. The city will give property owners a certain amount of time to fix the issue and then apply smaller bills until the full amount is issued. Based on the BES Enforcement Program Administrative Rules, civil penalties can be up to $10,000 per day per violation.

2.2.5. Cost

The BES is responsible for Portland's wastewater and stormwater infrastructure so that it protects the environment and residents' health. The bureau's funding is primarily from retail sewer and stormwater charges, wholesale contract revenues from surrounding jurisdictions, system development charges, permit-related fees, and reimbursements for services provided to other bureaus [25]. From 2020 to 2021, the bureau had a $351.8 million (US) budget for operating and capital expenditures. The operation portion was $181.2 million. A certain portion of this funding comes from residents. In 2020–2021, a typical residential family's sewer and stormwater bill was anticipated to increase by $2.16 per month (2.85%) to support the bureaus' budget and the long-term forecast.

2.3. City of Toronto

2.3.1. Factors Affecting Natural Performance

Toronto has a very high population density, with 3 million people living within 640 km^2 of land, which is supported by extensive sewer infrastructure networks [26]. Toronto is in a different climate zone than Vancouver or Portland, and the weather is more extreme compared to Vancouver. The warmest months are July and August, averaging over 20 °C and frequently rising above 30 °C in the daytime. In winter, Toronto has snowfall, and the temperatures fall below −25 °C in January and February [27]. The average annual precipitation in Toronto is around 762 mm, and the average snowfall is approximately 100 mm [28]. The city's complex sewer system includes 4500 km of storm sewers with more than 2600 outfalls and 1300 km of combined sewers with 79 CSOs [29]. In its long history, Toronto has had serious water pollution issues impacting Lake Ontario and its tributaries, which motivated the city to improve stormwater management. Thus, the City's council approved the Wet Weather Flow Master Plan (WWFMP), which is a 25-year plan costing $1.03 billion that uses both traditional and green stormwater methods to improve surface water quality and quantity, solve sewage overflow issues, and protect habitat and wildlife by prioritizing rainwater management at or near the source (location of rainfall) [23].

2.3.2. Development Considerations and Legal Tools

In 2010, Toronto adopted the Toronto Green Standard (TGS) in its policy framework to standardize new private and city-owned development projects' performance and sustainable design. TGS has four tiers, and only tier 1 is mandatory and needs to be applied for through the planning approval process. The targeted projects are categorized by building type: low-rise residential buildings, mid- to high-rise residential and non-residential buildings, city agencies, and corporation- and division-owned facilities. Under the water quality and efficiency section, TGS requires private properties, including both low-residential and mid-to-high-residential buildings, to have water balance, quality, and quantity control with priority on on-site green infrastructure as a Tier 1 standard. Tier 2 encourages private properties to reduce potable water consumption for building and irrigation.

Toronto has investigated the benefits of GRs since 1990 and has been at the forefront of promoting green roofs in the city's developments to address environmental challenges. In 2003, the city formed a Green Roof Task Force to investigate and promote the benefits of green roofs. Two years later, the city, in partnership with Ontario Centres of Excellence—Earth and Environmental Technologies (OCE-ETech), collaborated with the Toronto Metropolitan University to conduct research into the potential environmental benefits and costs of green roof technology for Toronto [14]. The research included a study of available GR technology, the measurable benefits of GRs to Toronto's environment, and thresholds that provide reference to any incentives or programs. The research simulated the characteristics and distributions of the city's rooftops in 2005 using landscape features (buildings, streets, and stormwater infrastructure) and watershed spatial information. It determined the benefits based on the aggregation of building distribution and land use in various scenarios. The green roof area in the study was based on 100% of the available roof area being GR, but with restrictions in design, construction, operation, and maintenance. The research set four requirements for simulating GRs on rooftops: (i) the rooftop must have less than 2% slope; (ii) the area of the rooftop must be larger than 350 m^2; (iii) the GR has to be larger or equal to 75% of the roof footprint when constructed on a building; and (iv) greenery over underground parking garages and non-conditioned enclosed spaces at grade level are not included in green roof statistics. The total estimated Toronto land area is 631.75 km^2, and 21% (134.78 km^2) of the total land area is building roof area. With the boundary set, only 49.85 km^2 (37% of the building roof area) can be constructed as a green roof. With the land data, the research team applied monetary analysis to estimate the basic cost of green roofs, then compared it with the estimated municipal-level savings in stormwater management and improvements to air quality, building energy, and the urban heat island effect. Compared to a traditional roof, a GR has a higher cost for construction and maintenance, which are primarily private property owners' responsibilities. The major cost at the municipal level will be establishing programs to promote GRs, like incentive programs, educational programs, etc. [14]. The study estimated that cost savings from pollutant reduction were approximately $14 million, erosion control would save $25 million, and CSO reduction that would minimize beach closures would save $750,000 annually. Savings are also expected from an increase in air pollution quality (afforded by the rooftop vegetation) as well as heating and cooling energy loads in the building. This would have indirect savings in CO_2 emissions [14]. The total cost savings of green roof implementation in Toronto are estimated to be $313.1 million initially and $37.13 million annually.

2.3.3. Responsibility, Equity, and Costs

In 2006, Toronto City Council adopted Toronto's Green Roof Strategy, "Making Green Roofs Happen", in its policy framework and developed incentive programs, public education programs, and development approval processes to encourage the city and private property owners to build GRs. As part of the Green Roof Strategy, the Green Roof Pilot Program was created for private property owners. In 2006, the pilot incentive program offered $10/m^2 to homeowners for implementing a GR; this was funded by Toronto Water. The program was very successful after its establishment and prompted the construction of 3000 m^2 of GRs with 16 rewarded applications just in 2006. The green roof incentive program still exists but is now called the Eco-Roof Incentive Program, which raised incentives to $100/m^2 and included cool roofs in incentive categories [30]. In 2009, City Council adopted the Green Roof Bylaw, which makes Toronto the first city in North America to have a bylaw requiring and governing the construction of green roofs. The bylaw sets 20–60% of the available roof space of a building with a minimum gross floor area of 2000 m^2, except residential buildings that are less than six storeys or 20 m in height, to have a GR [31]. The available roof space is defined by the bylaw, and it excludes areas that are designated for renewable energy, residential private terraces, residential outdoor amenity space, which is less than 2 m^2 per unit, and the tower roof on a building with a floor plate less than 750 m^2. The GR area is defined in the bylaw as well.

While computer models exist for modeling performance in a GR, ensuring performance often requires on-site monitoring. Monitored systems have been extensively researched in the literature and require a combination of sensors to monitor water input (precipitation), soil moisture, water outflow, the surrounding environment, and irrigation (if applicable). By analyzing the collected data, a simulated green roof water flow model can be used to calculate the water retention capacity under different weather conditions. The common issue in GR monitoring in the post-construction stage is the inability to access downspouts, which restricts the type and variety of flow monitoring equipment. Some studies used flumes to monitor the outflow from the GR; however, the flume has the potential to backup water onto the roof and is inaccurate at very low flows (0.1 gpm or less), which might cause a tendency to overestimate retention and underestimate runoff [32]. An ultrasonic depth sensor can be placed in a runoff chamber as a drainage pipe weir device with an outlet weir to measure runoff volumes. This sensor detects the rising water and adjusts its output voltage accordingly. It can be used between 0 and 70 °C and is applicable in saturated substrate conditions based on the drainage area (normally 50 mm/hr of rainfall) [33]. Flow meters are another option, which use a magnetic field to generate and channel liquid flow through a pipe. There are studies showing that the flow meter will not work properly for water flow lower than 1.5 gallons per minute and requires a tipping bucket flow meter to present accurate results. A tipping bucket flow meter can be combined with electromagnetic flow meters to monitor flow in all ranges. A unit is currently on the order of $2000 to $3000, depending on the pipe size [34]. Table 1 provides a summary of flow meters for use in GR systems and their advantages and disadvantages.

Table 1. Flow meter summary.

Category	Ultrasonic Type Sensor	Electromagnetic Flow Meter
Price	<$1000	Two to three times more expensive.
Green Roof Requirement	N/A	Easy access to the leader flow pipe.
Maintenance	Might require more maintenance.	Less maintenance.
Monitoring Flow	All flow-range monitoring.	Combine with a bucket flow meter.
Limitation	Maximum flow depends on the drainage pipe size.	No restriction.
Installation	Need a construction team to install and require high-knowledge people to initialize devices before installation.	Need a construction team to install.
Monitoring Set	One unit per drainage pipe. One green roof might require multiple units to monitor the total flow.	One unit per leader pipe. Normally, one green roof requires only one unit.

3. Discussion

As a well-known and beneficial tool, the GR brings many more benefits besides rainwater management. All three cities prioritize on-site infiltration by green rainwater infrastructure in their rainwater management strategies and policies, although their approaches and requirements may differ. Portland and Toronto both have an independent GR standard in addition to their rainwater management strategies. Table 2 shows a comparison of various factors related to the discussion of GRs for all three cities considered in this work.

Table 2. Case study comparison table.

Categories	Vancouver	Portland	Toronto
Population	631,486	641,162	2,956,024
Location	Coastal seaport city on the southwest coast of Canada.	Northwest Oregon, US	In south-central Canada, near the east coast.
Average Precipitation	116 cm	122 cm	76.2 cm
Motivation	Aging sewer system; population growth; climate change; water quality; CSO[1].	Watershed pollution; damage to the ecology of plants and animals; MS4 permit compliance; CSO; system capacity.	Population growth; CSO; system capacity; economic benefits; aging sewer system; water quality.
GRI Reviewing Authorization (Private Realm)	City of Vancouver	City of Portland, Bureau of Environmental Service.	City of Toronto, environmental planning, and Toronto Water.
Central Policy Document	Rain City Strategy; Zoning and Development By-law.	Stormwater Management Manual.	Wet Weather Flow Management Guidelines.
Private Realm Rainwater Management Objective	Capture 24 mm of rainfall in 24 h from all areas. The first 24 mm of rainfall from all pervious and impervious surfaces shall be treated to remove 80% TSS[2] by mass prior to discharge from the site. For impervious surfaces with high pollutant loads, including roads, driveways, and parking lots, the rainfall to be treated increases to the first 48 mm of rainfall.	Full Onsite Infiltration (fully infiltrate the 10-year design storm), Offsite Discharge to the Separated Stormwater System with pollution reduction and flow control requirements, or Offsite Discharge to the Combined Sewer System with only flow control requirements.	Mandatory: Retain a minimum of 50% of the total average annual rainfall volume; remove 80% of TSS on an annual loading basis from runoff; apply peak flow control following; and apply on-site green infrastructure. Voluntary: Water-Efficient Fixtures and Efficient Irrigation.

Table 2. *Cont.*

Categories	Vancouver	Portland	Toronto
Applicable Site	New and redeveloped projects located in the CD-1 rezoning area that require Rezoning Permits, and new and redeveloped projects requiring Development Permits and located in the area of concern. The current areas of concern are the Broadway Corridor and the Cambie Corridor.	New development or redevelopment projects involving 500 square feet or more of impervious area (green roofs have an exception).	New and redeveloped projects.
Rainwater Management Requirement	Rainwater Management Plan (preliminary, complete, and final version); registration of Rainwater Legal Agreement; Rainwater Management Project Summary Form; Operation and Maintenance Manual; a sealed letter from a registered professional; an ongoing report proving GRI [3] performance.	Site Plan; Landscape Plan; Operation and Maintenance Plan; Operation and Maintenance Form; Hierarchy Level Justification; SIM (Simplified Approach) Form.	N/A
Operation and Maintenance Responsibilities	Current private owner's or property manager's responsibilities.	Current private owner's or property manager's responsibilities.	Current private owner's or property manager's responsibilities
Monitoring	A sealed letter from a registered professional confirming ongoing GRI performance is required at a pre-determined date after the issuance of Occupancy.	The BES [4] oversees post-construction inspections of stormwater facilities and drainage reserves on private property. Enforcement will be triggered if the property owners or the designated responsible party do not comply with the operation or maintenance of the stormwater management facility based on the O&M [5] Plan.	The city monitors the sewer system in the end area. The bylaw allows the city to track back to origin area if pollution is found.
Operation and Maintenance Cost	The property owner pays for the operation and maintenance of GRI tools. If the GRI tools needs to be replaced, it is also the private owner's responsibility.	The property owner pays for the operation and maintenance of GRI tools. If the GRI tools need to be replaced, it is also the private owner's responsibility. If the rainwater management fails, civil penalties can be up to $10,000 per day per violation based on the BES Enforcement Program Administrative Rules.	The property owner pays for the operation and maintenance of GRI tools. If the GRI tools needs to be replaced, it is also the private owner's responsibility.
GRI Encouragement	Education sectors through public documents.	Incentive programs; public education; mails to single-family owners.	Mandatory Downspout Disconnection; intensive research on green roof; Green roof GIS [6] simulating model.

[1] combined sewer overflow; [2] total suspended solids; [3] green rainwater infrastructure; [4] Bureau of Environmental Service department in the City of Portland; [5] operation and maintenance; [6] Geographic Information System.

Differences found in Portland and Toronto from Vancouver's strategy include the fact that Portland exempts buildings with a GR from the mandatory level 1 full on-site infiltration requirement as long as the GR is qualified by the Stormwater Management Manual (which is continuously updated every several years). It gives property owners a clear and full understanding of the necessity of GRI and minimum efforts to plan their projects. In Portland's post-occupancy inspection program, the GR is also prioritized, and most will be inspected less than every two years. Toronto uses the Green Roof Bylaw adopted in 2009, which makes it the first city in North America to have a bylaw requiring GRs. The bylaw was motivated by published research demonstrating the potential environmental benefits and costs of GR technology and evidence from existing GR systems with standards established in Europe.

While all three cities examined in this work prioritized GRI in their rainwater management strategies, they did so with different standards and approaches to ensuring proper performance. In Toronto, extensive research played a significant role in persuading stakeholders and the city council to adopt the Green Roof bylaw, enhancing GRI implementation. The research and analyses conducted there can be used by the City of Vancouver to estimate incentive programs, provide education, and encourage private owners to take the initiative to construct green roofs. With foundational research, jurisdictions can develop realistic strategies in the long term and prove their further estimated achievements, particularly at the planning stages where public buy-in is important. Zhang and He [35] found in a review of barriers and drivers to green roof implementation that drivers included policy and market pressures as well as technological advances and innovation, while barriers included a lack of government policies, a lack of rigor or data for understanding the technology and/or economic benefits, as well as reluctance on the part of the building owner. They propose an approach that combines policy, technical, economic, and social aspects in combination with stakeholder involvement to enable wide-scale implementation of green roofs. Chen et al. [36] identified barriers as maintenance costs, design and construction costs, ineffective use of green roofs, and a lack of incentives. A policy that improves building and construction codes related to green roofs was recommended. Hui et al. [37] noted that the more proactive a city was in promoting green roofs, the better informed the communities were and the greater their willingness to accept this technology. Public perceptions were affected by socio-demographics, living environments, and general attitudes toward "greening", all of which were also city-dependent. Mahdiyar et al. [38] found that the savings on energy-related costs had the most influence on the value of a green roof in the private realm and that installation could be financially feasible (return of initial costs) only if all private benefits were realized (for their study area). They suggested that an incentive for a private owner could be one that involved governments bearing the initial costs. Ziogou et al. [39] observed that implementing green roofs did not prove to be cost-effective in residential buildings in general and that the large environmental benefits were always difficult to monetize. In general, the literature supports the understanding that public buy-in through incentives and education, feasible capital costs, and effective operation and management are essential to the development of a functioning green roof program in the private realm.

The City of Vancouver has a specific rainwater management requirement to capture and treat certain amounts of rainfall in a certain period, depending on the surface. However, the rainwater management requirements of Portland and Toronto are dealt with in a much more complex system. Portland applies a hierarchy-level ranking system to projects in the private realm and sites that cannot comply with any levels and need to pay offsite stormwater management fees. Similarly, Toronto has tier performance standards in their board policy, the Toronto Green Standard. Tier 1 is mandatory, and tiers 2–4 are voluntary. Sites that comply with Tier 2 may have rewards or incentives from the city (Development Charge Refund Program). There are also different requirements depending on the building type and number of stories. Although the Toronto Green Standard Version 4, published in May 2022, has the same rainwater management standards for various types of buildings, the incentives for different building types are important. The best rainwater management requirements from research contain basic standards, voluntary standards with rewarding programs, and monetary solutions for impossible conditions. Both Portland and Toronto noted the value of incentive programs, which have greatly encouraged the growth of GR implementation in their respective cities. Currently, both cities still have multiple incentive programs and prioritize them in their strategies.

The required documents in permit applications (supporting legal tools) are similar in all cities. The core documents include a site plan, a rainwater management plan, a legal agreement, and an operation and maintenance plan. The City of Vancouver requires an on-time GRI report after construction, as defined in the legal agreement, and does not limit or differ in GRI varieties. Portland is similar, and it contains an additional portion of the standard O&M plan categorized by GRI type submission requirements. The policy framework is the foundation for the rainwater management program. A bylaw may be established first to explore the possibility of new programs in the post-occupancy stage. In addition to supporting programs, bylaws could also be used to encourage a specific type of GRI tool implementation. Given the similarities in jurisdictions between Toronto and Vancouver, Toronto's bylaws, legal tools, and support systems are reasonable measures for Vancouver.

For Toronto, the post-occupancy inspection and enforcement are supported by City Code 17.38. The Toronto Sewer Bylaw also defines Toronto's water quality monitoring in the sewer system. The City of Vancouver requires property owners to declare GRI status after construction and to monitor GRI performance. Post-occupancy inspections and maintenance are the responsibility of the property owner through legal requirements established in registered Rainwater Legal Agreements. Portland's City Code 17.38.043 gives BES the right of entry to enter all private premises at any time to inspect any potential violations with proper protocols. The inspectors are authorized to take samples, test them, record examinations, install devices, and make photographic documentation. From interviews with Portland BES, the inspection program is considered an effective way to ensure GRI's ongoing performance in the long-term period after construction. However, due to limited resources, BES is not able to inspect all sites at the ideal time, and other means, such as mailed letters to owners, are used to help maintain compliance. Inspection standards are also different depending on the GRI type, and the more complex GRIs, i.e., those with a higher risk of failure or a greater cost to fix, receive priority for inspection.

4. Conclusions and Recommendations

The efficacy of a green roof is affected by numerous factors, but the single most important and complicated factor is the operation and maintenance program that constitutes an ongoing relationship between the local government and the private building owner. Complete on-site monitoring can help ensure efficacy in operations and maintenance requirements. While this is possible in some cases, it may not be practical or even possible to conduct this over city-scale jurisdictions. Portland, Toronto, and Vancouver encourage on-site infiltration by green rainwater infrastructure in their rainwater management strategies and policies, but their approaches and management program focuses are different. Portland focuses on a post-occupancy inspection program to ensure green roof O&M and ongoing performance, which applies equally to all private property rainwater infrastructures. Toronto uses a Green Roof Bylaw to encourage the implementation of green roofs in the program development stage. The research is limited by the fact that only two other cities were examined for insight into Vancouver's developing strategy. While all of them are of comparable size, the similar weather between Portland and Vancouver may be outweighed by the differing political climates. Toronto's climate is affected by a significantly colder winter that requires different green roof functionality. Thus, greater research to determine the efficacy of year-round operation and maintenance in both Toronto and Portland would be helpful for Vancouver and similar municipalities moving forward. In addition, greater research is needed into each program's outcomes, including the level of uptake by the public, a thorough assessment of each individual system, any problems, systemic or otherwise, encountered in both cities, an assessment of the costs and effectiveness of the incentive programs and the public education programs (including continual assessments of public perceptions and attitudes as well as tangible metrics that measure the effectiveness of incentive programs based on the existing programs), and additional research into other cities to widen the breadth of data, especially given the costs associated with inspection, operation, and maintenance. In addition, if a jurisdiction considers green roofs the primary component of a city-wide green rainwater infrastructure, a specific and local construction standard needs to be provided.

For the City of Vancouver:

- A cursory perspective suggests that Toronto's legal tools and support appear to be reasonable measures for Vancouver.

- Further research into proper operation and maintenance procedures for private owners at the building scale will be beneficial for the City of Vancouver moving forward.
- While Vancouver has supporting legal agreements and tools to support their comprehensive procedure for developing reviews in the initial stages, a blend of approaches used by Toronto and Portland could facilitate efficient O&M in the private realm.

Author Contributions: Conceptualization, C.V. and P.M.; methodology, J.W., P.M. and C.V.; investigation, J.W.; resources, C.V. and P.M.; data curation, J.W.; writing—original draft preparation, J.W.; writing—review and editing, J.W., P.M. and C.V.; supervision, P.M. and C.V.; project administration, C.V. All authors have read and agreed to the published version of the manuscript.

Funding: MITACS Accelerate: IT23656 and City of Vancouver.

Data Availability Statement: No new data was created in this work. All reviewed material is available online in the references.

Acknowledgments: The authors would like to thank the many personnel at the municipalities of Vancouver, British Columbia; Toronto, Ontario; and Portland, Oregon who provided valuable insight and knowledge. The authors would also like to thank the reviewers for their time and many helpful suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. City of Vancouver. 2023. Foundations for a Healthy Waters Plan. Summary of Phase 1 Work and Next Steps. January 2023. 77p. Available online: https://vancouver.ca/files/cov/csa-foundations-summary-report.pdf (accessed on 11 May 2023).
2. City of Vancouver. City Wide Integrated Stormwater Management Plan. Available online: https://vancouver.ca/home-property-development/city-wide-integrated-stormwater-management-plan.aspx (accessed on 13 February 2023).
3. City of Vancouver. 2019. Rain City Strategy. 5 November 2019. Available online: https://vancouver.ca/files/cov/rain-city-strategy.pdf (accessed on 27 September 2021).
4. "About Green Roofs," Green Roofs for Healthy Cities. Available online: https://greenroofs.org/about-green-roofs (accessed on 13 February 2023).
5. Joyce, A.; Dunnett, N.; Kingsbury, N. *Planting Green Roofs and Living Walls*; Booklist; American Library Association: Chicago, IL, USA, 2004.
6. Carter, T.L.; Rasmussen, T.C. Hydrologic Behavior of Vegetated Roofs. *J. Am. Water Resour. Assoc.* **2006**, *42*, 1261–1274. [CrossRef]
7. Teemusk, A.; Mander, Ü. Rainwater Runoff Quantity and Quality Performance from a Greenroof: The Effects of Short-Term Events. *Ecol. Eng.* **2007**, *30*, 271–277. [CrossRef]
8. Voyde, E.; Fassman, E.; Simcock, R.; Wells, J. Quantifying Evapotranspiration Rates for New Zealand Green Roofs. *J. Hydrol. Eng.* **2010**, *15*, 395–403. [CrossRef]
9. Stovin, V.; Vesuviano, G.; Kasmin, H. The Hydrological Performance of a Green Roof Test Bed Under UK Climatic Conditions. *J. Hydrol.* **2012**, *414*, 148–161. [CrossRef]
10. Satzewich, J.; Straker, D. Biodiversity-Led Green Infrastructure in a Changing Climate. Retrieved. February 2020. Available online: https://act-adapt.org/wp-content/uploads/2019/06/BD_GI_concept_v3.pdf (accessed on 14 June 2019).
11. Tan, P.Y.; Angelia, S. *A Selection of Plants for Green Roofs in Singapore*, 2nd ed.; National Parks Board: Singapore, 2008.
12. Brenneisen, S. The Benefits of Biodiversity from Green Roofs—Key Design Consequences. In Proceedings of the Greening Rooftops for Sustainable Communities, First North American Green Roof Infrastructure Conference, Chicago, IL, USA, 29–30 May 2003.
13. Ngan, G. Green Roof Policies: Tools for Encouraging Sustainable Design. December 2004. Available online: https://commons.bcit.ca/greenroof/files/2019/01/Ngan_2004_Policy-report-Final.pdf (accessed on 1 December 2021).
14. Missios, P.; Banting, D.; Doshi, H.; Li, J.; Au, A.; Currie, B.; Verrati, M. *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto*; Toronto Metropolitan University: Toronto, ON, Canada, 2005; 88p.
15. Environmental Services. *Ecoroof Handbook 2009*; City of Portland: Portland, OR, USA, 2009.
16. Speak, A.F.; Rothwell, J.J.; Lindley, S.J.; Smith, C.L. Rainwater Runoff Retention on an Aged Intensive Green Roof. *Sci. Total Environ.* **2013**, *461–462*, 28–38. [CrossRef] [PubMed]
17. Johannessen, B.G.; Hanslin, H.M.; Muthanna, T.M. Green Roof Performance Potential in Cold and Wet Regions. *Ecol. Eng.* **2017**, *106*, 436–447. [CrossRef]
18. City of Vancouver. Private Realm Rainwater Management. Available online: https://vancouver.ca/home-property-development/private-realm-rainwater-management.aspx (accessed on 1 December 2022).
19. "Total Precipitation—Annual Data for Vancouver," Amateur Weather Statistics for Vancouver, British Columbia. Available online: https://vancouver.weatherstats.ca/charts/precipitation-yearly.html (accessed on 1 December 2022).

20. City of Portland HYDRA Rainfall Network. 2022. Available online: https://or.water.usgs.gov/precip/ (accessed on 3 January 2023).
21. Portland's Watersheds | Portland.gov. 2022. Available online: https://www.portland.gov/bes/protecting-rivers-streams/portlands-watersheds (accessed on 3 January 2023).
22. How We Manage Stormwater | Portland.gov. Available online: https://www.portland.gov/bes/stormwater/how-we-manage-stormwater#toc-what-does-environmental-services-do-about-all-that-rain- (accessed on 3 January 2023).
23. Garrison, N.; Hobbs, K. *Rooftops to Rivers II: Green Strategies for Controlling Stormwater and Combined Sewer Overflows*; The Natural Resources Defense Council: New York, NY, USA, 2011.
24. Bureau of Environment Service. *City of Portland 2020 Stormwater Management Manual*; City of Portland: Portland, OR, USA, 2020; 480p. Available online: www.portland.gov/bes/stormwater/swmm#toc-the-2020-stormwater-management-manual (accessed on 27 September 2021).
25. City of Portland. *City of Portland, Oregon Adopted Budget Fiscal Year 2020–2021, Volume 1, City Wide Summaries and Bureau Budgets*; City Budget Office, City of Portland: Portland, OR, USA, 2019; 572p. Available online: www.portlandoregon.gov/cbo/article/764227 (accessed on 1 December 2022).
26. S. C. Government of Canada. Profile Table, Census Profile, 2021 Census of Population—Toronto, City (C) [Census Subdivision], Ontario. 9 February 2022. Available online: https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E (accessed on 3 January 2023).
27. City of Toronto, "About Toronto," City of Toronto. 8 December 2017. Available online: https://www.toronto.ca/community-people/moving-to-toronto/about-toronto/ (accessed on 3 January 2023).
28. Snowfall—Annual Data for Toronto, Amateur Weather Statistics for Toronto, Ontario. Available online: https://toronto.weatherstats.ca/charts/snow-yearly.html (accessed on 3 January 2023).
29. Kloss, C.; Calarusse, C. *Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows*; Natural Resources Defense Council: New York, NY, USA, 2006.
30. City of Toronto. Eco-Roof Incentive Program. City of Toronto. 17 November 2017. Available online: https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives/green-your-roof/ (accessed on 3 January 2023).
31. City of Toronto. *Toronto Municipal Code Chapter 492, Green Roofs*; City of Toronto Bylaw: Toronto, ON, Canada, 2021. 17p. Available online: www.toronto.ca/legdocs/municode/1184_492.pdf (accessed on 30 April 2022).
32. Cardno TEC Inc. *Final Green Roof Performance Study*; Seattle Public Utilities: Seattle, WA, USA, 2012.
33. Kok, K.H.; Lariyah, M.S.; Ming, F.C.; Mohamed, R.Z.A.; Hidayah, B.; Gasim, H. Evaluation of Green Roof Performances for Urban Stormwater Quantity and Quality Controls. *Int. J. River Basin Manag.* **2016**, *14*, 1–7. [CrossRef]
34. Tipping Bucket Flow Gauge 6506. 25 December 2021. Available online: http://streamlinemeasurement.net/wp-content/uploads/2015/03/Tipping-Bucket-Flow-Gauge-6506.pdf (accessed on 30 April 2022).
35. Zhang, G.; He, B.-J. Towards green roof implementation: Drivers, motivations, barriers and recommendations. *Urban For. Urban Green.* **2021**, *58*, 126992. [CrossRef]
36. Chen, X.; Shuai, C.; Chen, Z.; Zhang, Y. What are the root causes hindering the implementation of green roofs in urban China? *Sci. Total Environ.* **2019**, *654*, 742–750. [CrossRef] [PubMed]
37. Hui, L.C.; Jim, C.Y.; Tian, Y. Public views on green roofs and green walls in two major Asian cities and implications for promotion policy. *Urban For. Urban Green.* **2022**, *70*, 127546. [CrossRef]
38. Mahdiyar, A.; Tabatabaee, S.; Yahya, K.; Mohandes, S.R. A probabilistic financial feasibility study on green roof installation from the private and social perspectives. *Urban For. Urban Green.* **2021**, *58*, 126893. [CrossRef]
39. Ziogou, I.; Michopoulos, A.; Voulgari, V.; Zachariadis, T. Implementation of green roof technology in residential buildings and neighborhoods of Cyprus. *Sustain. Cities Soc.* **2018**, *40*, 233–243. [CrossRef]