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Greenroof Study: Final Report, an Assessment of Greenroof Design and Maintenance in Portland, Oregon: 2011 – 2013

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Greenroof Study: Final Report
An Assessment of Greenroof Design and Maintenance in Portland, Oregon: 2011 – 2013

by
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requirements for the degree of

Master of Environmental Management

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Portland State University
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Abstract

In 1999 the City of Portland (City) began to require that stormwater management facilities (SMF) be built when private property is newly developed or redeveloped (City Code Chapter 17.38). Proper maintenance and upkeep of SMFs is essential to ensuring they function appropriately. The City's Maintenance Inspection Program (MIP) is tasked with inspecting stormwater management facilities on private properties in order to ensure that they are being properly operated and maintained and to meet provisions of the City's NPDES Municipal Separated Storm Sewer System (MS4) permit.

Greenroofs are one type of SMF that are installed to satisfy this requirement. Understanding the long-term maintenance needs of a greenroof is essential to reaching MIP goals established by City Code and the MS4 permit. Data collection occurred between November 2011 and May 2013 at private properties in Portland, Oregon during routine maintenance inspections of stormwater management facilities for the City's Maintenance Inspection Program (MIP).

The objectives of this study are to:

- Provide a summary of the type and frequency of greenroofs inspected in Portland as well as common issues, concerns from the property owners, and other information gained from greenroof inspections. This will also address questions such as
    - What does a typical Portland greenroof look like?
    - How deep is the growing media?
    - What types of plants are used?
    - What stressors act on the greenroofs?
    - Does replanting a greenroof eliminate stressors?

- Inform property managers, architects, engineers, and maintenance personnel about some design techniques that may ease long-term maintenance input and expense. This study also aims to further scientific and systematic evaluation of greenroofs as an amenity and stormwater management facility.

Based on inspection results of greenroof plant communities, soil depth, stressor frequency, and replanting and replacing soil events; maintenance and design concerns are identified and recommendations are provided. Using the data collected, the typical greenroof has 1 to 7 inches of soil and an extensive design; it is most frequently vegetated by succulents and drains to either the CSO or the MS4. Most greenroofs are installed with growing media seven inches thick or less. Succulent plants are used most often both as a monoculture and in combination with other vegetation. Biological stressors act on greenroofs more often than any other type of stressor. Replanting does not eliminate stressors.

Acknowledgements

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Table of Contents Page Number

List of Tables

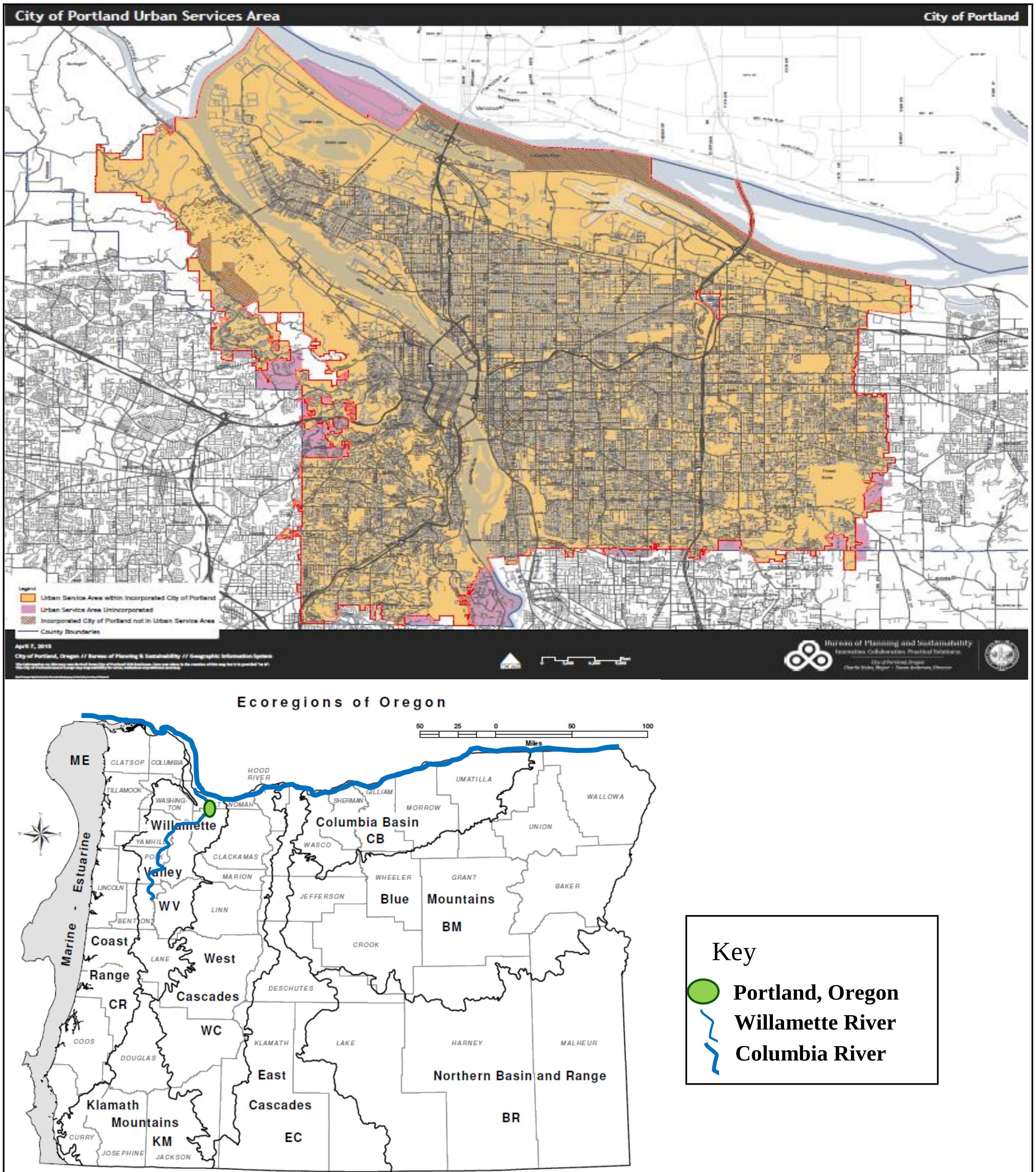
List of Figures

Introduction

Background

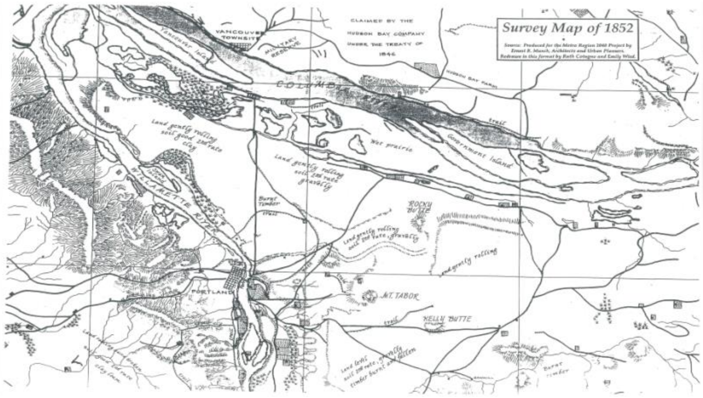
The Portland, Oregon metropolitan area lies at the intersection of the Willamette and Columbia rivers along the northwestern edge of Oregon. Portland is the largest city in Oregon and has a long history of utilizing the nearby waterways. The hydrology of the area is characterized by seasonal flooding to lowlands surrounding the rivers. This hilly terrain was once entirely covered by forests, streams, wetlands, and estuaries that drain and filter stormwater that falls on the area. On average Portland receives 37 inches of rainfall a year (City, 2004). Drainage districts were officially established and levees began to be built beginning in 1917. This was done to decrease seasonal flooding on valuable agriculture land. Channels and subsurface drainage followed and were direct ways to move both sewage and rainwater away from the increasing population and the impervious surface area that resulted from the increased population. Wetlands and agricultural land was next drained, filled and converted to make way for commercial, industrial and residential housing again increasing impervious surface area and directing more sewage and stormwater into pipes and directly to the river. By 2005 54% of the watershed was covered by impervious surfaces (Figure 1 and Figure 2) (City, 2005).

Figure 1. City of Portland Urban Services Area and Location within the State of Oregon

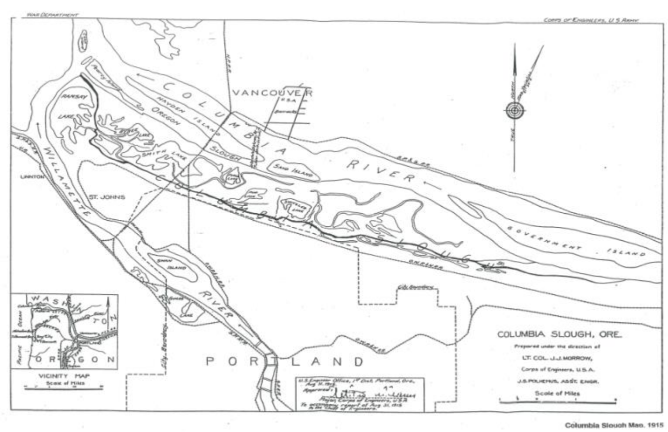


Ecoregions of Oregon. Portland lies along the north edge of the Willamette Valley ecoregion. The Willamette and Columbia rivers intersect along the northern edge of the WV Ecoregion ((ORBIC, 2010), edited by

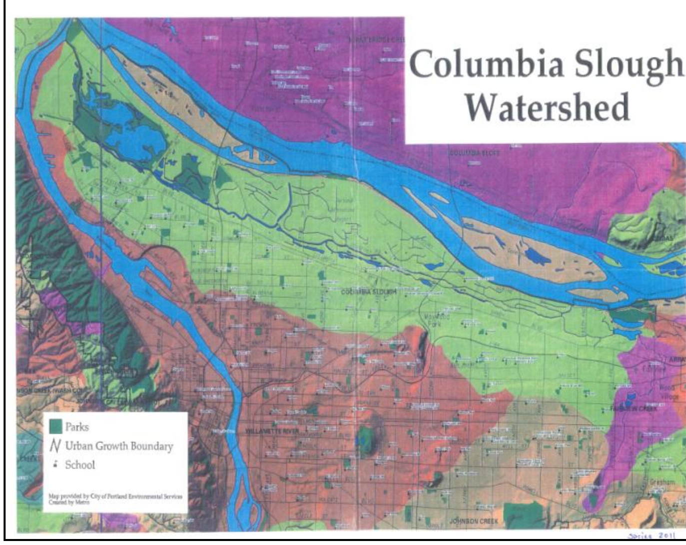
Figure 2. Three Maps of the Intersection of the Columbia and Willamette Rivers; Top image circa 1852, Middle image circa 1915, Bottom image circa 2011. Images courtesy of the Columbia Slough Watershed Council's Slough School Spring 2011. Maps show increasing development near water bodies over time. See notes below.



1852: The western edge of the Columbia Slough is home to Smith and Bybee Lakes. A wet prairie, meandering streams and small ponds extend to the east from the lakes. Swan Island (along the Willamette river) and Ross Island (to the south of Swan Island) are relatively undisturbed habitat.



From 1852 – 1915: Dikes and channels were constructed along the southern edge of the slough, from the Smith and Bybee lakes travelling east through the slough and wet prairie. Historical records indicate the slough waterway had been turned into a dumping ground. Everything from slaughterhouse waste to home and industrial waste was disposed of in this waterway.

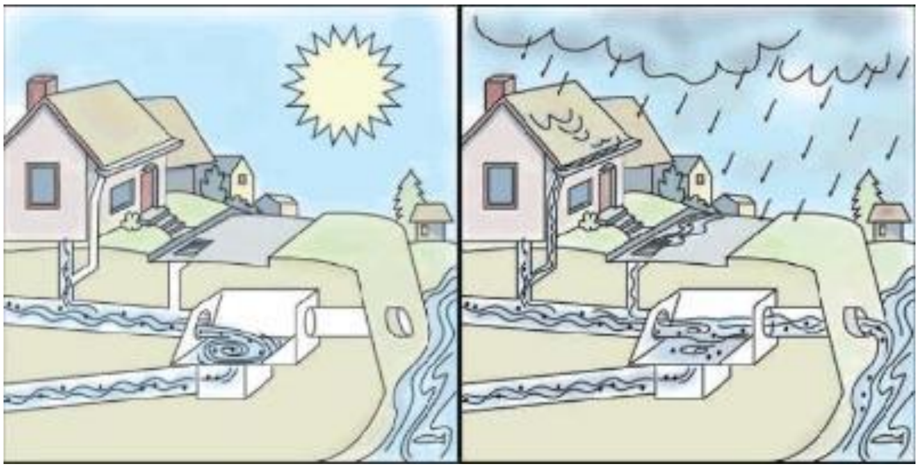


From 1915 - 2011: Creation of dikes and channels in the slough and along the Willamette River has increased. The wet prairie has been filled in and converted to an Airport. Swan island has been filled in and industrialized (this is the location of many ports and shipyards). Much of Ross Island's land mass has been removed.

In the early 1900s Portland's water quality had deteriorated with industrial pollutant and sewage effluent and citizens called for a change. Portland's first sewer treatment facility went on line in 1952 and a marked increase in water quality was quickly noticed. The sewer design directed both sanitary sewage and stormwater into the same pipes (Figure 3). During rain events, the capacity of the system was frequently surpassed and it overflowed a combination of stormwater and sanitary sewage to the river and/or slough (Combined Sewer Overflow (CSO)). Over the last 60 years, implementation of environmental acts and requirements[1] has led to improvements in the water quality of the Willamette River, Columbia River and the Columbia Slough. As time went on more of the city was developed creating more impervious area; this new impervious area directed stormwater to the CSO, exacerbating overflows in both frequency and amount. In 1991 the Oregon DEQ ordered the governing body of Portland, the City of Portland (City), to control the CSO's (City, 2012) (City, 2011).

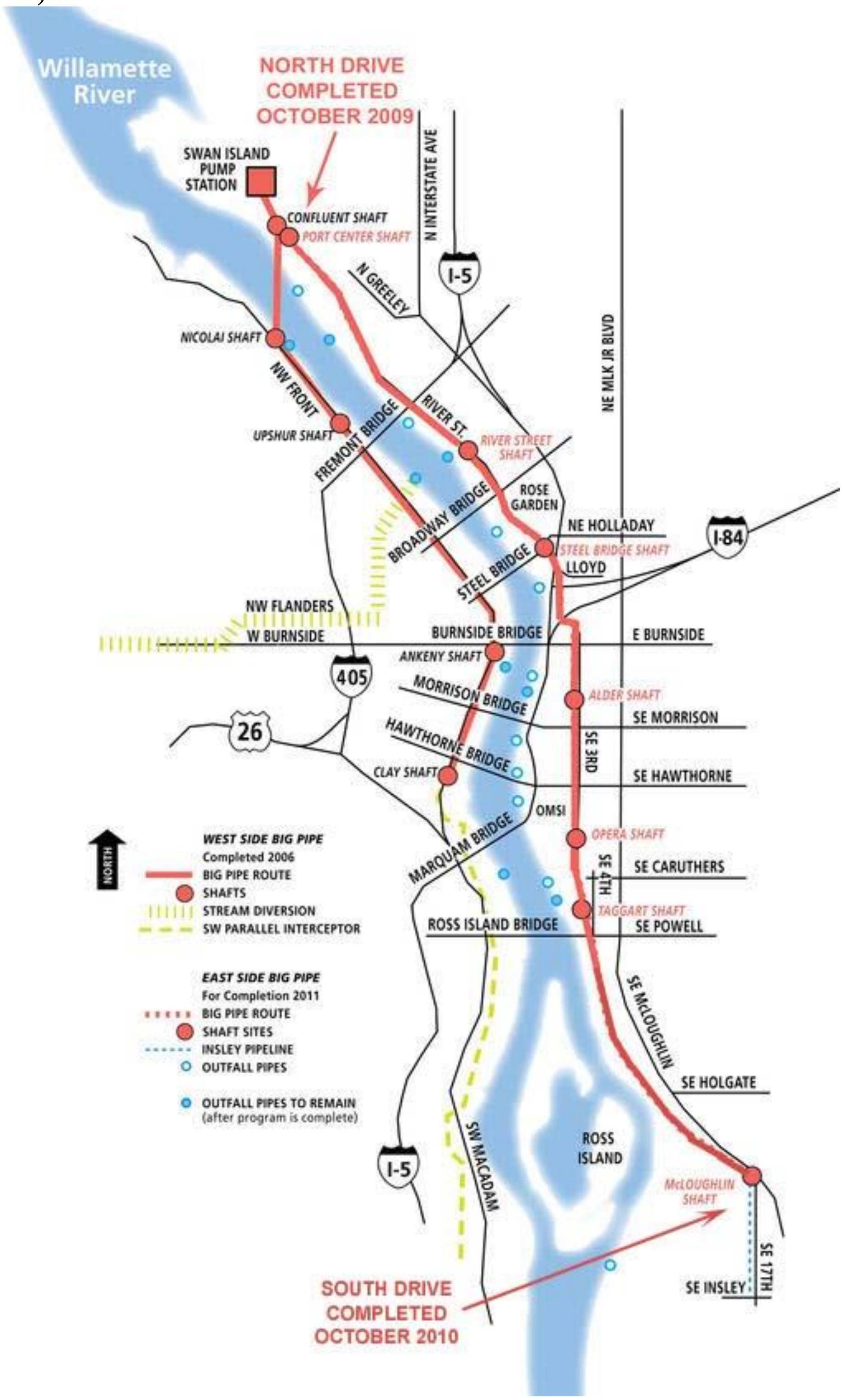
[1] Environmental acts and requirements that have led to increased water quality in the United States include: Clean Water Act; Comprehensive Environmental Response, Compensation and Liability Act (Superfund); Endangered Species Act; EO 12898: Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations; EO 13045: Protection of Children From Environmental Health Risks and Safety Risks, Federal Insecticide, Fungicide, and Rodenticide Act; Marine Protection, Research, and Sanctuaries Act; National Environmental Policy Act; Oil Pollution Act; Pollution Prevention Act; Resource Conservation and Recovery Act; Safe Drinking Water Act; Toxic Substances Control Act

Figure 3. Combined Sewer System Flow Diagram. Combined Sewer System during normal functioning (left) and storm events (right), before the initiation of the CSO program. During normal functioning sanitary sewage from homes and businesses is carried to the sewer treatment facility through the sewer pipes. During storm events the sanitary sewage and stormwater is directed to the sewer treatment facility through sewer pipes; if the capacity of the sewer system is reached a combination of sanitary sewage and storm water overflows the system and is discharged to the nearest approved waterway. These overflow events that that occur in the combined sewer system are called combined sewer overflows (CSO) (City, 2012).



To comply with the DEQ's order the City began a 20-year, multifaceted project that centered on removing stormwater from the combined sewer system. The goal of the project was to reduce the number of CSO's to the Columbia Slough by 99% and to the Willamette River by 94% by December 2011. The plan included the installation of street sumps and sedimentation manholes, disconnection of downspouts from the sewer system, removal of underground streams from the sewer system (e.g., Tanner Creek in southwest Portland), construction of larger combined sewer pipes (in three areas- along the Columbia Slough and along the east and west banks of the Willamette River), construction of separated storm sewer systems for some neighborhoods and advancements to sewage treatment facilities (City, 2012). This project was completed on time and under budget (Figure 4).

Figure 4. Portland's Combined Sewer Overflow: Willamette River Big Pipe Projects and Outfalls (City, 2011)



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In 1999 the City began to require that stormwater management facilities be built when private property is newly developed or redeveloped (City Code Chapter 17.38) (City, 1999). This code is part of a larger plan that manages Portland's sewage. As development occurs, there is increased strain on the sewer facilities.

City Code Chapter 17.38 aims "to maintain or increase water quality within the watercourse and water bodies within the City of Portland." This is accomplished by managing stormwater as close to the site of development as practicable using treatment systems to remove pollutants of concern[2] from stormwater thereby reducing the amount and increasing the quality of water flowing to the sewer systems (and the rivers) during storm events. The code also aims to recharge groundwater and reduce peak hydrographs of runoff during storm events. There are multiple stormwater management facilities (SMFs) and many of them function to settle out sediment (which many of the pollutants of concern adsorb to) and remove oil and grease, while others reduce the amount and/or rate of stormwater flowing into the sewers. Often, a combination of SMFs will provide both treatment of pollutants and flow control. These facilities are structural or vegetative. The City required projects to incorporate green infrastructure when feasible. These included bioswales, pervious pavement, infiltration ponds, landscape infiltration areas, stormwater planters, planting trees, water gardens, vegetative filters and greenroofs (Appendix A). These green facilities function as stormwater filtration, detention, and infiltration systems before runoff reaches the sewer system. Additionally these facilities provide added benefits such as stormwater retention, reduced demand for energy for heating and cooling, reduced negative health impacts from extreme heat events, air quality improvement, CO_2 reductions, carbon sequestration, reduced greenhouse gas emissions, urban heat island mitigation, noise reduction, biodiversity and habitat (Wise, 2010).

Properties that are required to treat stormwater are also required to complete an Operation and Maintenance (O&M) Plan. The O&M Plan is intended to document the SMFs on site and clarify

[2] Pollutants of Concern: a list of EPA defined chemicals that inhibit water body health and intended use by humans or ecosystems.

general maintenance requirements. These documents are tied to the title of the property so that current and future property owners are aware of maintenance needs of the SMFs on a site.

Proper maintenance and upkeep of stormwater management facilities is essential to ensuring they function appropriately (City, 2014). The Stormwater Maintenance Inspection Program (MIP) is tasked with inspecting stormwater management facilities on private properties in order to ensure they are being operated and maintained. The MIP is part of the NPDES MS4 permit to manage stormwater discharges.

Greenroofs[3] are one option property owners may select to assist with stormwater management on a property. Rooftops are harsh environments; greenroofs are exposed to extremes and rapid temperature fluctuations, fluctuations in seasonal water availability (leading to flood or drought unless irrigated), and shallow soil substrate (unless deep soils are used) which limits availability of water and temperature control (Monterusso, 2005). Climate impacts the vegetative selections recommended for installation. Precipitation events over a 24-hour period were studied; on average 81% of Portland's annual rainfall occurs in small storm events that occur 145 days a year (Liptan, 2002). This leaves over 200 days for the other 21% of the annual rainfall to fall. Greenroofs must be able to survive drought conditions or be irrigated. Shallow soils fluctuate in temperature more dramatically than deeper soils. A study in Canada found that some vegetation in soils two inches or less had increased cold damage when compared to the same vegetation in four to six inches of soil depth (Boivin, 2001).

Studies on greenroofs included explorations of the effects of greenroofs on indoor temperature regulation, mitigation of urban heat stress, hydrological restoration in urban areas, green building rating systems, runoff measurements, commercial viability, aggregate soil performance, vegetative performance, arthropods, influence on outflow rainwater to the sewer system.

[3] Greenroof: vegetated rooftop system that may function as a stormwater management facility.

In arid and semi-arid areas of the world greenroofs may be a cost effective way to reducing runoff but irrigation needs may limit use where water is scarce (Jiang, 2015). A study of the most urbanized catchment in Singapore found that the mix of greenroofs and stormwater basins are effective at reducing peak discharge during storm events (Trinh, 2013). An assessment of greenroofs using different green building rating systems was conducted comparing Taiwan's green building rating system Ecology, Energy, Waste and Health and the United States Leadership in Energy and Environment Design. Both rating systems evaluate greenroofs based on sustainable site selection, stormwater control, energy savings, and water resource conservation. The rating systems utilize different criteria to evaluate these categories; the major difference is the level of roof area coverage is equal to different amounts of credits between the two systems. The Taiwan system provides more credits for less greenroof coverage than the LEED system (Liaw, 2015). Greenroofs reduce stormwater runoff from the roofs they are installed upon (Sobczyk, 2016). Heat transfer rates vary based on the soil composition more than presence or absence of vegetation when comparing sand to silty clay soil. All soil compositions (sand and silt clay soil), with and without vegetation, reduced heat transfer compared to conventional roofs (Issa, 2015). A diverse mix of grass, forbs and sedums enhances cooling and stormwater retention at a higher rate than greenroofs with monocultures or soil media only. Not all combinations of grasses, forbs and sedums are equally effective; it is best to test mixes before installation in the region of interest to ensure effectiveness (Lundholm, 2010).

Looking at survivorship, sedums species were found to be more resilient to drought conditions than natives, forbs, and grasses (these plants would require irrigation during a drought) (Carter, 2008). Lichens are not intentionally planted on greenroofs but do volunteer and provide benefits to the greenroofs. Lichens provide cryptogenic crusts in arid environments holding in soil moisture, and these and other mat-forming plants may enhance survival of non-succulent plants during droughts (Heim, 2014). Several articles evaluated vegetation in various ways. Fungal richness was evaluated and found to be higher in parks than greenroofs. A literature review found studies that manipulated plant diversity found a mixture of grasses and forbs is ideal with relation to temperature reduction and water capture (McGuire, 2013). Pit fall traps and soil arthropod samples were evaluated on greenroofs with differing vegetation. Plant type, height and area of greenroof had no discernable effect though the presence of vegetative cover was positively correlated to the number of insect families found in greenroofs (Bracha y. Schnideler, 2011). Greenroofs are one location to utilize greenspace for habitat for wildlife and native vegetation. London uses greenroofs for bird habitat; the initiative followed the destruction of bird habitat that occurred during rebuilding efforts after World War II. Researchers in Switzerland have found protected arthropods and arachnids on greenroofs (Trzaskowska, 2011). These vegetated rooftop systems can be habitat for wildlife including sensitive, rare, and endangered species.

These studies provide valuable insight in to the validity of installing and utilizing greenroofs for energy and stormwater discharge reductions as well as for the value of greenroofs as habitat. No study located during this review categorizes the stressors or catalogs the design (area, soil depth, vegetative composition, or stressors impacting them) of greenroofs across a city. Understanding the long-term maintenance needs of a greenroof is essential to reaching MIP goals established by City Code, City groups (Clean River Rewards, Sustainable Stormwater, and Floor to Area Ratio Programs, Pollution Prevention Services), property owners, and federal/state regulators (Environmental Protection Agency and DEQ). Gathering, collating and analyzing greenroof design features and common stressors will increase the base of information that can be used to assess the current status of greenroofs in Portland and inform City staff, property owners and maintenance personnel of trends in maintenance and irrigation of greenroofs in Portland. By looking at a large and diverse proportion of greenroofs that have been built in Portland, how they were built, and how they are maintained, this study is providing details not previously gathered, categorized or analyzed. . This study looks at greenroofs in Portland, Oregon through the lens of maintenance and stormwater management.

Objectives

The objectives of this study are to:

- Provide a summary of the type and frequency of greenroofs installed in Portland as well as common issues, concerns from the property owners, and other information gained from greenroof inspections. This will also address questions such as
    - What does a typical Portland greenroof look like?
    - How deep is the growing media?
    - What types of plants are used?
    - What stressors act on the greenroofs?
    - Does replanting a greenroof eliminate stressors?
- Inform property managers, architects, engineers, and maintenance personnel about some design techniques that may ease long-term maintenance input and expense. This study also aims to further the systematic evaluation of greenroofs as a stormwater management facility and as an amenity.

Data Collection Methods

As discussed in the background factors influencing greenroofs are diverse. In order to catalog greenroofs in Portland, Oregon as many variables as quantifiable were collected. A conceptual model of factors influencing greenroof maintenance and irrigation helps to visualize these factors (Figure 5). Many things interact to impact a greenroof's maintenance and irrigation needs. The complexity and variation in design and time limitations for data collection required a direct and simplistic approach to experimental design. Six variables were selected to be assessed, these variables include:

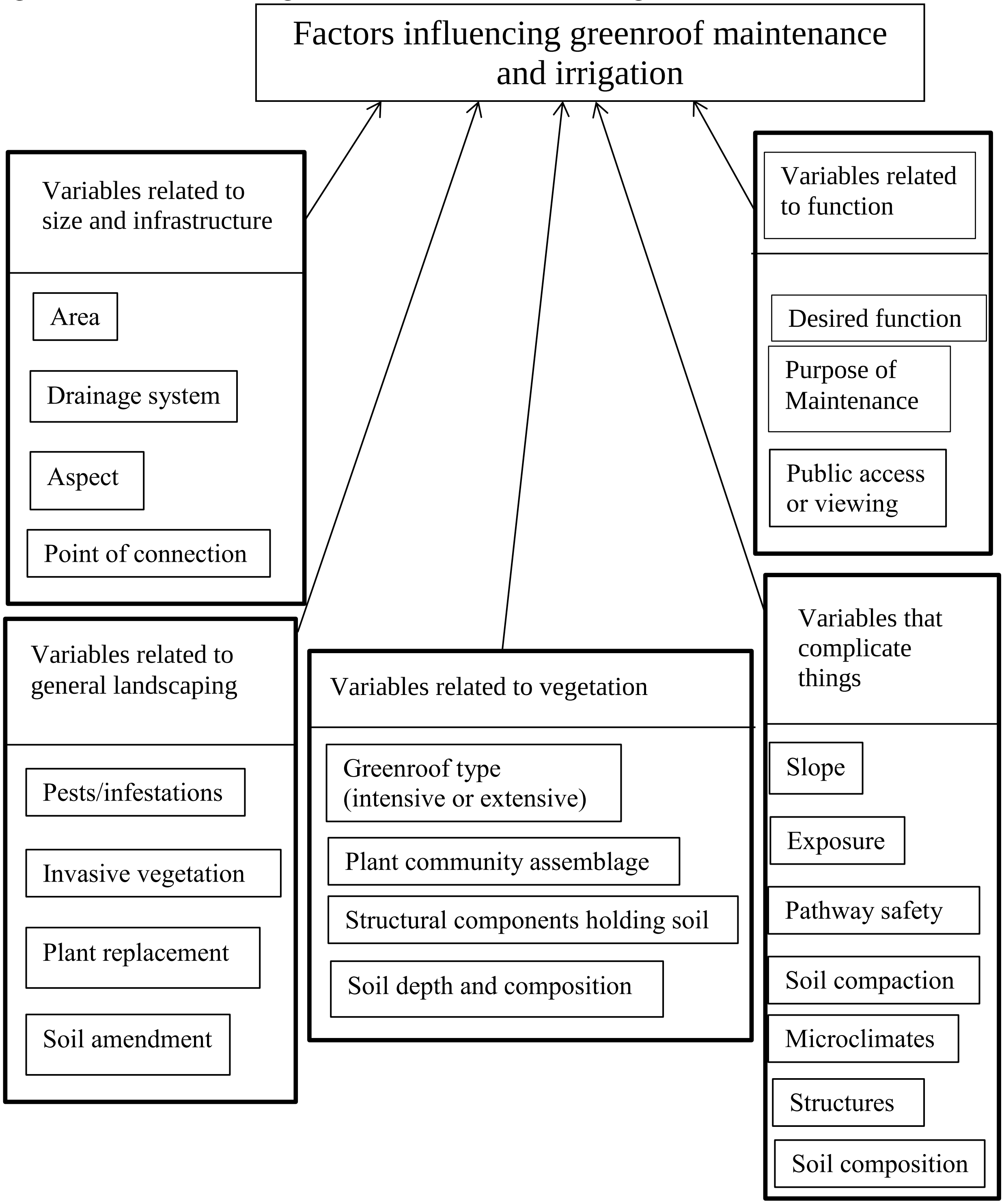
- Soil depth
- Aspect
- Plant species
- Point of connection
- Area of greenroof
- Stress

Other variables that likely impact maintenance and irrigation include:

- Soil composition
- Soil compaction
- Slope
- Microclimates
- Structures on the roof
- Pathway location and material
- Public access or access to view the greenroof

These variables are more difficult to quantify and measure and due to limited time and resources were not assessed in this study.

Figure 5. Factors Influencing Greenroof Maintenance and Irrigation



Data were gathered through visual inspection, soil depth measurements, records research and verbal interviews with property owners and managers. Records research included review of building permits, blue prints, sewer maps, greenroof Operations and Maintenance plan, and any other relevant documents located in the City archives. Data collection occurred between November 2011 and May 2013 at private properties in Portland, Oregon during routine maintenance inspections of stormwater management facilities for the City's MIP.

At the time of the study there were approximately 258 properties in Portland with greenroofs. 55 of those properties are included in this study. This list of greenroofs was generated using database queries in the MIP and by requesting information from other city programs (Clean River Rewards, Floor to Area Ratio, and Sustainable Stormwater). Greenroofs were selected for inspection based upon a property zoning designation other than single-family residential (such as: multifamily residential, industrial, commercial, etc.), a minimum of one year since installation (establishment period), an absence of inspections for the previous two years, a required re-inspection due to noncompliance or inadequate facility function, a City Code or Policy requirement for the completion of an O&M Plan for the greenroof, and the ability to contact property owners or managers to arrange access to the greenroofs on the property. Only greenroofs inspected for the MIP were included in the study. Access to greenroofs was limited and the MIP required access that could not have been gained otherwise.

In addition to the inspection of the roofs property contacts were interviewed, when possible. The property contacts were asked:

Has the greenroof been replanted? If so, what area was replanted?

Are pests a problem on the greenroof? If so, what pests and what area? What is done to combat these pests?

Has the greenroof soil been replaced? If so, what area was replaced?

Variables of Interest

During the MIP inspection information was collected about greenroof design (soil depth and point of discharge) and vegetative cover. This information included soil depth, plant species, and stressors (such as wind erosion, invasive vegetation, burnt plants, pest infestation and other unexpected stressors). Photos were taken and interviews with the property contacts were conducted. The perimeter of each greenroof was walked and soil depth measurements were taken at two or more locations on the greenroof. At least one measurement was collected adjacent to the edge and other samples were taken within the greenroof center. Access limited the number of samples collected and the distribution of sample locations. Soil depth measurements were collected using a thin sturdy tool with a pointed end and half inch marks (similar to a chopstick or knitting needle with ruler marks on it). As stressors were identified by visual assessment, estimates of the size of the area impacted were gathered by estimating the percentage of the greenroof impacted and calculating the square footage based on the total size of the greenroof (if access was limited) or by counting off the size of the area by steps (each step is equal to approximately 3 feet). The type of stressor was documented and included wind erosion, pest infestation, invasive vegetation, burnt plants and other unexpected stressors (Table 1). Interviews with property contacts conducted regarding replanting and soil replacement frequencies. Photographs representing the greenroof design and plant communities were taken along with images of damage or evidence of stress. All photos and complete data sets are property of the City.

The MIP reports units in the Imperial System and that system is used in this report for this reason. After data collection was completed, soil depth was divided into two different categories: 7 inches or less in soil depth and greater than 7 inches in depth. This was done to categorize data for analysis and follows general greenroof categorization practices. Greenroofs are often divided into two categories; intensive and extensive designs. Intensive designs often have deeper soils, plants that require more maintenance and irrigation and a building with greater structural capacity than extensive designs. Extensive designs refer to greenroofs with shallow soils (usually 6 inches or less), with plants that are known to be low maintenance, and which can be installed on buildings with limited structural capacity (Kohlur, 2006) (Brenneisen, 2006). Review of data in this study found that the majority of greenroofs with 7 inches or less of soil were planted with extensive designs and were categorized as extensive for this reason.

The analysis was conducted using Microsoft Excel 2010 and R for Windows 3.3.1 (http://ftp.osuosl.org/pub/cran/). Due to the categorical nature of the data, counts of variables and percentages were used to compare frequencies (Ramsey, 1997). Pivot Tables were used to compare the frequency of structural and design components to the number of stressors and whether a greenroof was replanted or not. A Chi-square test was used to test for independence between two variables (R, 2016) as and testing for equality of proportions between two groups.

Pearson's Chi-square test assesses categorical variables for independence. Fisher's test for exact count data was also used to compare categorical variables. These tests were used to evaluate the data from this study because the majority of the variables are categorical rather than numerical; for example the presence or absence of a specific type of vegetation or the type of greenroof (intensive or extensive). The null hypothesis of these tests is that any variability in the data is due to randomness or measurement error. If the p-value of a test is less than 0.05, the null hypothesis is rejected and the variables are not independent; variability is not due to randomness (Zar, 1999) (Ramsey, 1997). If the null hypothesis is not rejected it means that there is no relationship between the two variables. When the null hypothesis is rejected it means the variables are related and may provide insight into effective design, maintenance, plant community assemblage, etc.

Yates correction for continuity was used on some tests. The Yates' correction is used to prevent overestimation but may lead to overly conservative results. The tests were also run without the Yates' correction and the results were compared.

Table 1. Predictor, Response, and Other Variables for Greenroof Stress	
Predictor Variable	Definition
Soil depth	Inches from base to surface of substrate
Vegetation type	Succulents; Graminoids; Forbs; Ferns; Shrubs; Trees; others
Response Variable	Definition
Replant	Percent of the greenroof area that underwent plant replacement
Soil replacement	Percent of the greenroof area that had the soil removed and replaced
Number of Stressors	Quantity of observations indicating stress observed on a greenroof
Design Variable	Definition
Point of discharge	Drainage location and connection to outlet. Point of connection to sewer, ground
Greenroofs installed per property	Number of distinct and hydrologically isolated greenroofs installed throughout the roof on a property
Greenroof type	Category of greenroof system relating to soil depth, plant type, and maintenance demands of vegetated system. Types: 1) Intensive[4] 2) Extensive[5]
Stressors	Definition
Wind erosion	Loss of soil due to wind.
Pest infestation	Presence of bird, mammal, insect or other wild life that causes damage to the greenroof.
Invasive vegetation[6]	Weedy, undesirable plant species present on greenroof.
Burnt plants	Vegetation shows withered appearance or evidence of sunburn leading to poor plant health.
Other stressors	Any other stressor identified during the inspection and interview that was indicated to cause or be a sign of damage on the greenroof.

[4] Intensive greenroof: A vegetated system installed on the roof of a structure with soils that are deeper than six inches and vegetation that requires routine maintenance and irrigation.
[5] Extensive greenroof: A vegetated system installed on the roof of a structure. Soils are typically shallow (six inches or less deep) and vegetation typically requires minimal maintenance and irrigation. This study categorizes greenroofs with 7 inches and less of soil as extensive
[6] Invasive Vegetation: Weedy undesirable plants. Weedy plants tend to be present only during certain parts of the year. Undesirable plants tend to require additional maintenance and watering adding to the expense and work required to maintain these facilities. Greenroof plants are selected to hold the soil in place year round, uptake water during the rainy season, require minimal irrigation during the dry season, and require minimal annual maintenance (mowing, weeding, trimming, etc.).

Results

Property Types

Of the 258 properties with greenroofs in Portland, Oregon, this study evaluated 55 properties which represent a subset of approximately 20.0% of all properties with greenroofs. A total of 125 greenroofs were installed on these 55 inspected properties; the number of greenroofs on a property varied from 1 to 14**.** The smallest greenroof is 37.0 ft^2, the largest is 31600.0 ft^2, the mean is 3321.9 ft^2, and the median is 1025.0 ft^2.

An extensive design was used on 97 greenroofs. An intensive design was used on 28 greenroofs. A mixed design utilizing both intensive and extensive greenroof styles was utilized on several properties though the greenroofs were categorized by the system that was most representative of the rooftop as a whole**.** Greenroofs in the study were most commonly installed during new construction (109/125 or 87.2% of greenroofs), however, 16/125 greenroofs (13.0% of greenroofs) were installed on existing structures.

Greenroof Vegetation Information

Greenroofs are installed with monocultures[7] as well as with a diverse mix of plant types (Table 2). Monocultures are utilized on 48/125 systems representing 38.4% of the greenroofs. Approximately 61.6% (77/125 greenroofs) are vegetated with multiple plant types.

Of the 48 greenroofs vegetated by one plant type, that plant type is commonly succulent plants[6] (used on about 93.3% or 42 of the 48 greenroofs with only one plant type). One greenroof was planted exclusively with forbs[8], two additional greenroofs were planted with graminoids[9] only, and three greenroofs were planted with only other plant types (mosses and mushrooms).

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[7] Monocultures: An area vegetated with one species of plant.
[8] Forbs: Herbaceous broadleaf vegetation not within the graminoid category (USDA, 2016).
[9] Graminoids: Grass and grass-like plants including sedges and rushes (USDA, 2016).

Succulent[10] plants were installed on 76.0% of all greenroofs, by far the most commonly used plant type in the study. Greenroofs were at least partially vegetated by forbs, 45.6% of the time. Graminoids were installed on 29.6% of the greenroofs. Shrubs are installed on 23.2% of all greenroofs. Trees are included on 8.8% of the facilities. Ferns at least partially vegetate 8.0% of all greenroofs. Other plants that do not fit into the categories were installed on 16.8% of all greenroofs. Other plants include bamboo, cacti, edibles, vines, moss and mushrooms. Since these data include all plants on all the greenroofs and multiple plants make up an individual greenroof, when added together the combined total is over 100% used.

Table 2. Plant Type and Frequency of Use on Portland Greenroofs

Plant Type	Number used as only plant type on greenroof	Percent used as only plant type on total greenroofs	Number used in combination with other vegetation	Percent used in combination with other vegetation	Number total use	Percent total use
Succulents	42	33.6	53	42.4	95	76.0
Ferns	0	0.0	10	8.0	10	8.0
Graminoids	2	1.6	35	28.0	37	29.6
Forbs	1	0.8	56	44.8	57	45.6
Shrubs	0	0.0	29	23.2	29	23.2
Trees	0	0.0	11	8.8	11	8.8
Other Plants	3	2.4	18	14.4	21	16.8
Total	48	38.4	--	--	--	--

Note: Percentages were calculated by dividing number of greenroofs where a particular plant is found by total greenroofs (125).

Soil Depth

Soil depth varies dramatically on greenroofs with depths ranging between 1.5 and 24.0 inches. Some systems have a range of growing media depths throughout the roof and others are one consistent and unchanging depth. To examine the soil depth, the mean soil depth was calculated from two or more measurements taken on each greenroof (Table 3).

Mean soil depth was categorized into two distinct groups 1.5 to 7.0 inches of soil depth and 7.1 to 24.0 or more inches of soil depth. Shallow soils (1.5 to 7.0 inches) are often found on extensive greenroofs while deep soils (7.1 to 24.0 inches) are often found on intensive

[10] Succulent plants: Plants with "modified morphology adapted to conserving water" these species are often found in arid environments and include Crassulacea, Didieraceae, Euphorbiacea and other families (SIU, 2016).

greenroofs. Two greenroofs with shallow soils were found to support intensive plant systems (Table 3). Review of data from this study found more greenroofs with a soil depth of 7 inches or less to be planted with low maintenance plants and require infrequent maintenance and irrigation; these greenroofs were categorized as extensive greenroofs. The greenroofs with soil depths of 7 inches or more were planted with high-maintenance plants that require regular and frequent irrigation and maintenance; these greenroofs were categorized as intensive greenroofs. Several City studies classify extensive designs as 6 inches of soil or less. Additional review of these data is available by using the data-set supplied in this report as Supplemental file B: Greenroof Data Set 2011 – 2013.

Table 3. Mean Soil Depth and Extensive v Intensive Greenroofs in Portland, Oregon.

	Shallow Soil 1.5 – 7”	Deep Soil 7.1 - 24+”	Total	Extensive Greenroof	Intensive Greenroof	Total
Number of Greenroofs	97	28	125	99	26	125
Percentage of Greenroofs	77.6	22.4	100	79.2	20.8	100

Greenroof Point of Discharge Information

A discharge location is required for all greenroofs so that when a storm event produces more rain than the capacity of the greenroof an appropriate overflow connection is in place. Stormwater may be discharged to the City’s sewer systems (CSO or MS4), a private sewer systems that outfalls to the river, vegetated infiltration facilities, landscaping, or underground injection control facilities (UICs)[11]. Greenroofs drain to various discharge locations (Table 4). There may be a series of stormwater facilities that receive rainwater from the greenroof before the final discharge location. Occasionally UICs are required to have overflow connections to a separate location when soils, space, and building safety may limit the amount of stormwater that will infiltrate into the soils.

[11] Underground injection facilities (UIC): Subsurface stormwater management facility designed to facilitate stormwater discharge through infiltration into the native soils adjacent to the facility.

Of the greenroofs in the study, 29.6% of greenroofs discharge to the Municipally Separated Storm Sewer System. In contrast, 32.0% of the greenroofs discharge to the combined sewer system. The remaining 38.4% of the greenroofs discharge to vegetated areas, UICs or private outfalls and do not connect to the City's sewer systems thereby providing a reduction in stormwater flowing into the sewer system.

Table 4. Final Discharge Locations for Greenroofs in Portland, Oregon.

Discharge location	Number of greenroofs	Percentage of greenroofs
Vegetated area	11	8.8
Combined Sewer System (CSO)	40	32.0
Municipally Separated Sewer System (MS4)	37	29.6
Private outfall	19	15.2
Underground Injection Control System (UIC)	18	14.4
Total	125	100

Indicators of Stressors Observed on the Greenroofs

The stress indicators observed on the greenroofs included wind erosion, burnt plants, invasive plants, and pest infestations. Other indicators not included in these categories were also identified. Other stressors include annual rooftop equipment tests, heat vents, construction damage, over irrigation, lack of irrigation, litter, plants do not thrive, shade, roots have not broken through mat backing and shallow soil. The total number of greenroofs that had an indication of stress was 69 of 125 or 55.2%. A total of 56 greenroofs (44.8%) did not show any signs of stress (Table 5). Multiple indicators of stress were observed on individual greenroofs and each indicator was categorized. Ninety-two individual stressors were observed on the greenroofs in the study (Table 5). Each stressor type is addressed below in the order it appears in Table 5.

Table 5. Number of Stressors and Stress Indicators Observed on Greenroofs		
Total stressors per greenroof	Number of greenroofs	Percentage of greenroofs
1	46	36.8
2	23	18.4
Total greenroofs with 1-2 stressors	69	55.2
Total greenroofs with 0 stressors	56	44.8
Total	125	100
Evidence of stress or maintenance need	Number of greenroofs	Percent of all greenroofs
Wind erosion	3	2.4
Burnt plants	13	10.4
Pest infestation	13	10.4
Invasive vegetation	26	20.8
Other stressors	37	29.6
Total	92	n/a
Note: Multiple stressors and stress indicators were observed on individual greenroofs.		

Wind Erosion

Three greenroofs were identified to have been impacted by wind erosion (Table 5). The entire area of these greenroofs had been impacted by wind and evidence of this was observed as soil movement away from vegetated areas onto pathways or other areas of the rooftop not intended to harbor growing media (where other dispersal pathways were not observed such as: bird damage nor evidence it was caused by water-induced erosion).

Burnt Plants

Burnt plants were identified on 13 (10.4%) greenroofs; however, the majority of the time only a small portion of the greenroof was impacted (Table 6). On two greenroofs with burnt plants, it appears that reflections from windows may have caused the damage.

Table 6. Percent of Greenroof Area Observed with Burnt Plants		
Percent of burnt area	Number greenroofs	Percentage of greenroofs
0%	112	89.6
0.1% to 9.9%	5	4.0
10%	1	0.8
25%	1	0.8
30%	1	0.8
100%	5	4.0
Total	125	100

Pests

A total of 13 (10.4%) greenroofs were identified to have issues with pests. Pests observed include ants, aphids, bees, birds, and cats. Birds caused concern for property owners and managers on nine greenroofs, were the most prevalent pest, and were a stressor on 7.2% of greenroofs. Pest management techniques includes routine removal of animal droppings (from domestic cats), and releasing ladybugs on the greenroof to manage aphids. Some pests were not a significant concern and no actions were taken to manage them. Bird X and other bird dispersal products were planned for use on two greenroofs (but it is unknown if they were used); one residential condominium replaced soil media and plants to vary soil depth and increase biodiversity in order to provide more food so the birds will not be inclined to pick up and toss the vegetation to find food (Table 7).

Table 7. Pest Prevalence on Greenroofs

Pest	Number of greenroofs	Percentage of greenroofs	Removal techniques
Ants	1	0.8	In home control
Aphids	1	0.8	Ladybugs
Bees	1	0.8	Nothing
Birds	9	7.2	Replace displaced sedum (5) Nothing (4; one greenroof will utilize Bird X in future)
Cats	1	0.8	Scoop poop during routine maintenance
None	112	89.6	Nothing
Total	125	100	

Invasive Vegetation and Other Stressors

Invasive vegetation impacted 26 of the 125 greenroofs in the study. The invasive vegetation encroaching upon greenroofs include: trees, bamboo, butterfly bush, clover, dandelions, grasses, and other aggressive annual plant species. Other indicators of stress were observed on nearly one-third of the greenroofs in the study, more than any identified stressor (Table 8).

Individually these other stressors are: annual machine tests that burn plants (these are machine tests conducted on roof-top equipment such as heating, ventilating and air-conditioning systems); plants do not thrive for no observed reason - further study needed; construction that damages plants and compacts soil; heat vents that burn or damage plants; over irrigation that causes root rot; lack of irrigation during hot weather that leads to plant death; litter from humans; mats of plants that have minimal root development, roots have not broken through to growing media and plants are not established after a two-year period; dense shade that limits plant establishment; extended sun exposure that limits plant establishment; and lastly soil holds moisture longer than desired which leads to root rot and poor plant establishment (composition is suspected to be overly organic). Two greenroofs were identified with soil approximately 1.5 inches; these greenroofs were categorized as stressed due to shallow soils. Soil depth was not the only reason these greenroofs were categorized as stressed; soil erosion was also observed on these greenroofs.

A week-long infestation of insects that occurs annually (small flying insects that are more of a nuisance to humans then a stress to the success of the greenroof) occurred on two greenroofs. This was not counted as a stress to the greenroofs.

Table 8. Frequency of Other Stressors Observed on Portland Greenroofs

Other stressor category	Number of greenroofs	Percentage of greenroofs
Annual machine tests	1	0.8
Construction damage	8	6.4
Heat vents	1	0.8
Over irrigation	1	0.8
Lack of irrigation during hot weather	6	4.8
Litter	1	0.8
Plants do not thrive	6	4.8
Roots have not broken through mat backing	2	1.6
Shade	9	7.2
Shallow soil	2	1.6
Total other stressors identified	37	29.6
No other stressor identified	88	70.4
Total	125	100

<u>Replacement of Plants and Soil Media</u>

Replacement of plants and soil data were gathered through verbal interviews with property contacts. Three (2.4%) greenroofs have undergone soil replacement while 36 (28.8%) greenroofs have been replanted (Table 9). Only greenroofs that had been replanted at the time of the inspection were counted as being replanted. No future plans to replant were counted in order to avoid overstating the number of greenroofs replanted. Of the greenroofs where soil was replaced, the plants were also replaced.

Table 9. Greenroofs That Have Undergone Replanting Events or Soil Replacement.

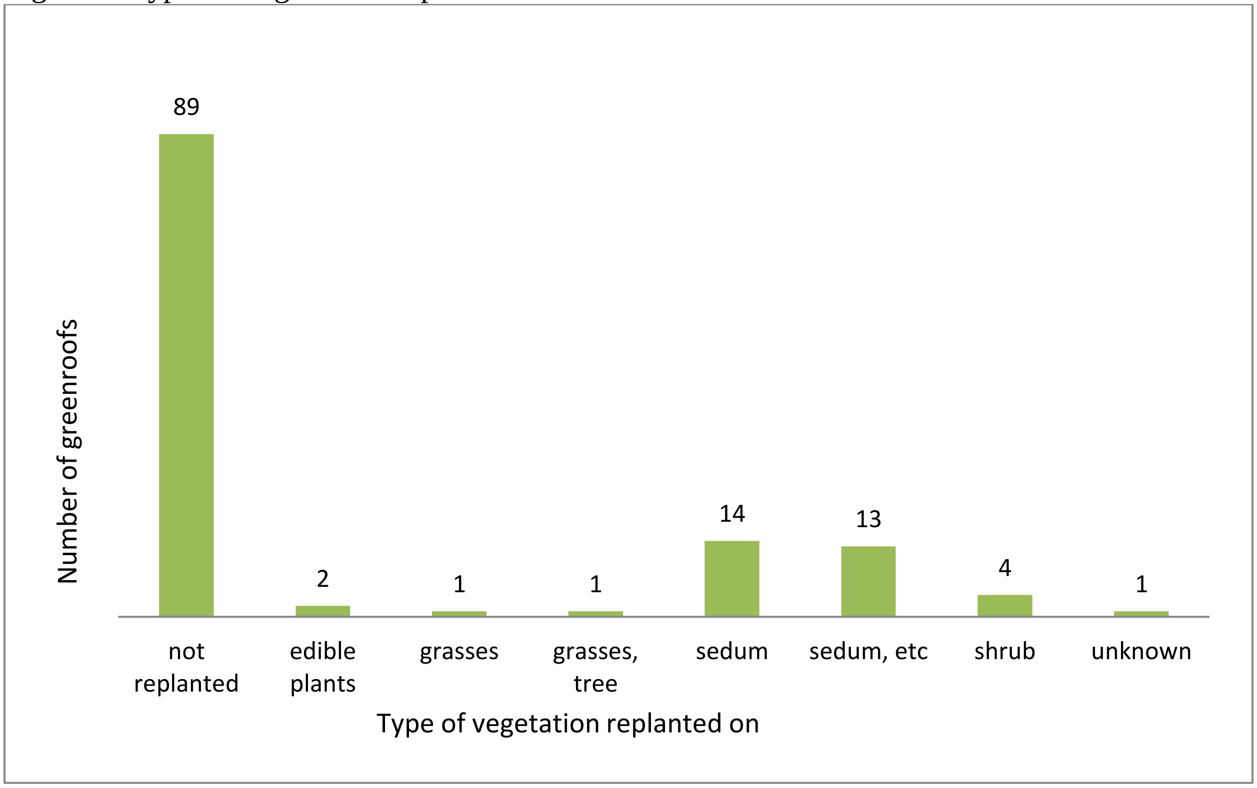
Maintenance needed beyond routine	Number of greenroofs	Percent of greenroofs
Replant vegetation	36	28.8
Replace soil	3	2.4
Total	39	n/a - Those properties that replaced soil also replaced plants

The vegetation replanted varied from edible plants to graminoids, ground cover, succulent plants, shrubs and trees. Succulent plants are the most common plant type that was utilized when replanting a greenroof. Whether replanted exclusively with succulents or in combination with other vegetation types, 22.6% of replanted greenroofs were replanted with succulents (Table 10, Figure 6). Due to lack of information about original planting design, the type of plants that needed to be replaced was not collected.

Table 10. Type of Vegetation Replanted on Greenroofs in Portland, Oregon.

Vegetation installed during replant	Number of greenroofs	Percentage of greenroofs	Percentage of replanted greenroofs
Edible plants	2	1.6	5.5
Graminolds	1	0.8	2.78
Graminoid and trees	1	0.8	2.78
Succulent plants	14	11.2	38.88
Succulent plants and other vegetation	13	10.4	36.11
Shrubs	4	3.2	11.11
Unknown plant type	1	0.8	2.78
Total greenroofs replanted	36	28.8	100
Total greenroofs NOT replanted	89	71.2	0
Total	125	100	100

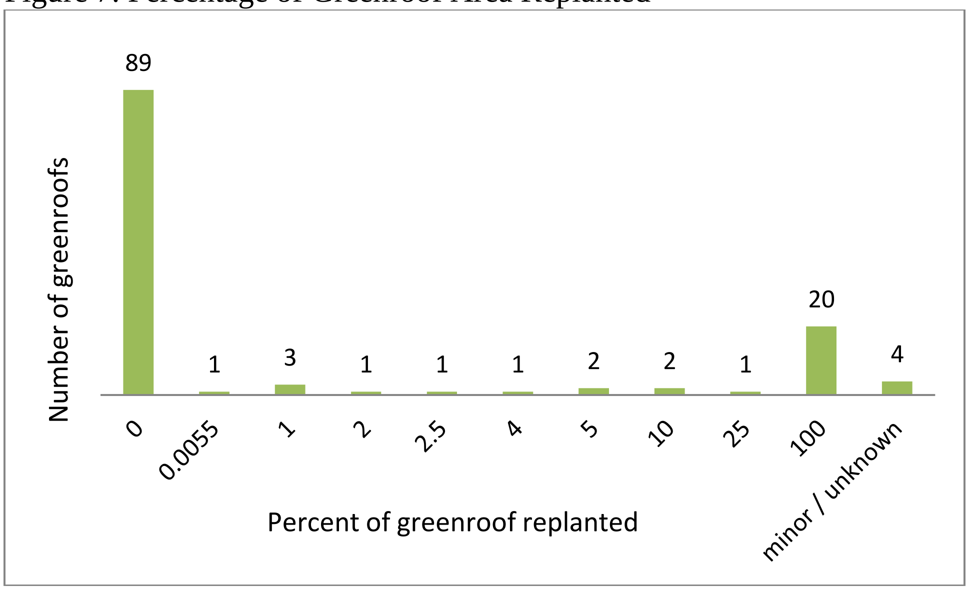
Figure 6. Type of Vegetation Replanted on Greenroofs



Twenty (16%) of the greenroofs replanted the entire facility area. Twelve (10.4%) replanted .005 to 25% of the greenroof and four of the greenroofs were replanted but the size of the area was described as minor or unknown (Table 11, Figure 7).

Table 11. Percentage of Greenroof Area Replanted		
Percentage of greenroof area replanted	Number of greenroofs	Percentage of greenroofs
0	89	71.2
0.0055	1	0.8
1	3	2.4
2	1	0.8
2.5	1	0.8
4	1	0.8
5	2	1.6
10	2	1.6
25	1	0.8
100	20	16
Minor/unknown	4	3.2
Total	125	100

Figure 7. Percentage of Greenroof Area Replanted



Analysis

Soil Depth

Of the greenroofs with shallow soils (97), 30 were replanted, accounting for 30.9% of the greenroofs with shallow soils. Of the greenroofs that were replanted (36), 30 had shallow soils, accounting for 83.3% of all replanted greenroofs (Table 12). Of the greenroofs with deep soils (28), 6 were replanted; this accounts for approximately 21.4% of the greenroofs with deep soils and 16.7% of all replanted greenroofs.

Table 12. Greenroofs Replanted v Soil Depth Category

Soil Category	Total Greenroof	Replanted	Percentage of those replanted	Percentage of greenroof with like soil depth
Shallow Soils (1.5 – 7”)	97	30	83.3	30.9
Deep Soils (7.5 – 24”)	28	6	16.7	21.4
Total	125	36	100	89

Of the greenroofs with shallow soils (97), 55 were observed to have one or more stressors accounting for approximately 56.7% of greenroofs with shallow soils. Of the greenroofs with deep soils (28), 14 were found to show evidence of one or more stressors accounting for 50.0% of greenroofs with deep soils (Table 13).

Table 13. Number of Stressors per Greenroof v Soil Depth

Total stressors per greenroof	Shallow soil (1.5-7”)	Deep soil (7.1-24”)	Total
0	42	14	56
1	35	11	46
2	20	3	23
1 or more	55	14	69
Total	97	28	125

Intensive v Extensive and New Construction v Retrofit

Of the greenroofs categorized as intensive (26), 14 had one or more stressors observed accounting for 53.8% of the intensive greenroofs. Of the extensive greenroofs (99), 55 had one or more stressors observed accounting for 55.6% of the extensive greenroofs. Of the greenroofs installed on new construction (109), 60 showed one or more stressors making up approximately

55.0% of greenroofs installed on new construction. Of the greenroofs installed on retrofits (16), 9 exhibited one or more stressors making up 56.3% of greenroofs installed on retrofits. Of all greenroofs in the study (125), 69 were observed with one or more stressors, 55.2% of all greenroofs (Table 14).

Table 14. Number of Stressors per Greenroof v Intensive/Extensive and New Construction v Retrofit

Total stressors per greenroof	Number of new construction	Number of retrofit	Number of intensive greenroofs	Number of extensive greenroofs	Total
0	49	7	12	44	56
1	40	6	9	37	46
2	20	3	5	18	23
1 or more	60	9	14	55	69
Total	109	16	26	99	125

Vegetation

Of the 125 greenroofs in this study, succulents were planted most often as either a monoculture or a mixed planting. Of all the greenroofs in the study, 28.8% were replanted at the time of data collection. Succulent plants were used most often when replanting greenroofs, either as monoculture or in combination with other vegetation (Table 10). Of the greenroofs that were not replanted (89), 40 were found to show evidence of one or more stressor making up approximately 45% of greenroofs not replanted. Of the greenroofs that were replanted (36), 29 were found to show evidence of one or more stressors making up 80.5% of replanted greenroofs (Table 15).

Table 15. Number and Percentage of Replanted and Not Replanted and the Number of Stressors

Number of stressors	Greenroofs not replanted	Percentage of greenroofs not replanted	Greenroofs replanted	Percent of greenroofs planted
No stressors	49	55	7	19.5
One stressor	29	32.6	17	47.2
Two stressor	11	12.4	12	33.3
One or more	40	45	29	80.5
Total	89	100	36	100

Of the greenroofs installed with monocultures (49), 23 showed one or more stressors making up 46.9% of greenroofs with only one type of plant installed. Of the greenroofs installed with diverse vegetation (76), 46 were observed to have one or more stressors making up 60.5% of greenroofs with mixed plantings (Table 16). As replanting efforts were completed with the aim of restoring a greenroof to health and alleviating stressors, the results of those greenroofs replanted were further assessed.

Table 16. Number of Stressors per Greenroof v Monoculture/Mixed Planting

Total stressors per greenroof	Number of greenroofs with monoculture	Number of greenroofs with mixed plantings	Total
0 Stressors	26	30	56
1 Stressor	15	31	46
2 Stressors	8	15	23
1 or More Stressors	23	46	69
Total	49	76	125

A breakdown of the vegetation type and the number of stressors observed identifies that greenroofs with graminoids and other plants (that do not fit into the identified categories) were found on greenroofs that showed evidence of stress more often than the average greenroof (zero stressors were observed 4.8% and 37.8% of the time, respectively). Ferns and trees were observed on greenroofs that showed evidence of stress least often (this may be due to their infrequent use on greenroofs as a whole). Of all the vegetation types used on greenroofs, 41.1% of plants were observed on greenroofs that showed no evidence of stressors. Of the greenroofs installed with multiple plant species 39.5% were found to have zero stressors. This percentage is relatively close to the average greenroof that was found with zero stressors (41.1%) (Table 17).

Table 17. Number of Greenroofs Planted with Vegetative Type v Number of Stressors						
Vegetation type	0 Stressors	1 Stressor	2 Stressors	1 or More	Total	Percentage of zero stressors
Other plant types	1	17	3	20	21	4.8
Succulent	43	36	16	52	95	45.3
Fern	6	2	2	4	10	60
Graminoid	14	14	9	23	37	37.8
Other forb	25	19	13	32	57	43.8
Shrub	12	14	3	17	29	41.4
Tree	6	5	0	5	11	54.5
Total	107	107	46	153	260	41.1
Percentage	41.1	41.1	17.8	n/a	100	n/a
Multiple species	30	31	15	46	76	39.5

The Chi Square analysis was conducted with and without the Yates continuity correction (Table 18).

Table 18. Pearson's Chi-square test with and without the Yates' continuity correction								
Variables tested		Yates' continuity correction used			Yates' continuity correction not used			Warning message
Variable 1	Variable 2	X-squared value	Degrees of freedom	P-value	X-squared value	Degrees of freedom	P-value	
Soil (shallow or deep)	Greenroof type (intensive or extensive)	31.843	1	1.672e-08	34.895	1	3.48e-09	No
Soil (shallow or deep)	Replant (yes or no)	0.549	1	0.458	0.956	1	0.328	No
Stress observed (yes or no)	Soil (shallow or deep)	5.261e-31	1	1	0.0386	1	0.844	No
Stress observed (yes or no)	Greenroof type (intensive or extensive)	0.00430	1	0.947	0.0824	1	0.774	No
Stress observed (yes or no)	New or reroof (yes or no)	1.478	2	0.477	0.20063	1	0.654	No
Stress observed (yes or no)	Soil (shallow or deep)	5.261e-31	1	1	0.0386	1	0.844	
Stress	Replant	14.624	1	0.000131	16.183	1	5.752	No

observed (yes or no)	(yes or no)						e-05	
Stress observed (yes or no)	Multiple plant types (yes or no)	0.881	1	0.347	1.261	1	0.261	No
Stress observed (yes or no)	Succulent (yes or no)	0.156	1	0.692	0.367	1	0.544	No
Stress observed (yes or no)	Fern (yes or no)	0.457	1	0.498	1.015	1	0.313	chi squared approximation may be incorrect – maybe due to small sample size – error present with and without yates correction – 10 observations with ferns present
Stress observed (yes or no)	Graminoid (yes or no)	0.179	1	0.671	0.385	1	0.534	No
Stress observed (yes or no)	Forb (yes or no)	0.139	1	0.708	0.307	1	0.579	No
Stress observed (yes or no)	Shrub (yes or no)	0.404	1	0.524	0.720	1	0.396	No
Stress observed (yes or no)	Tree (yes or no)	2.5184e-31	1	1	0.002089	1	0.963	chi squared approximation may be incorrect – maybe due to small sample size – error present with and without yates correction - 11 observations with trees present
Stress observed (yes or no)	Other plant (yes or no)	14.474	1	0.000142	16.362	1	5.233 e-05	No

Irrelevant of whether the Yates' continuity correction was applied or not three tests were found to reject the null hypothesis:

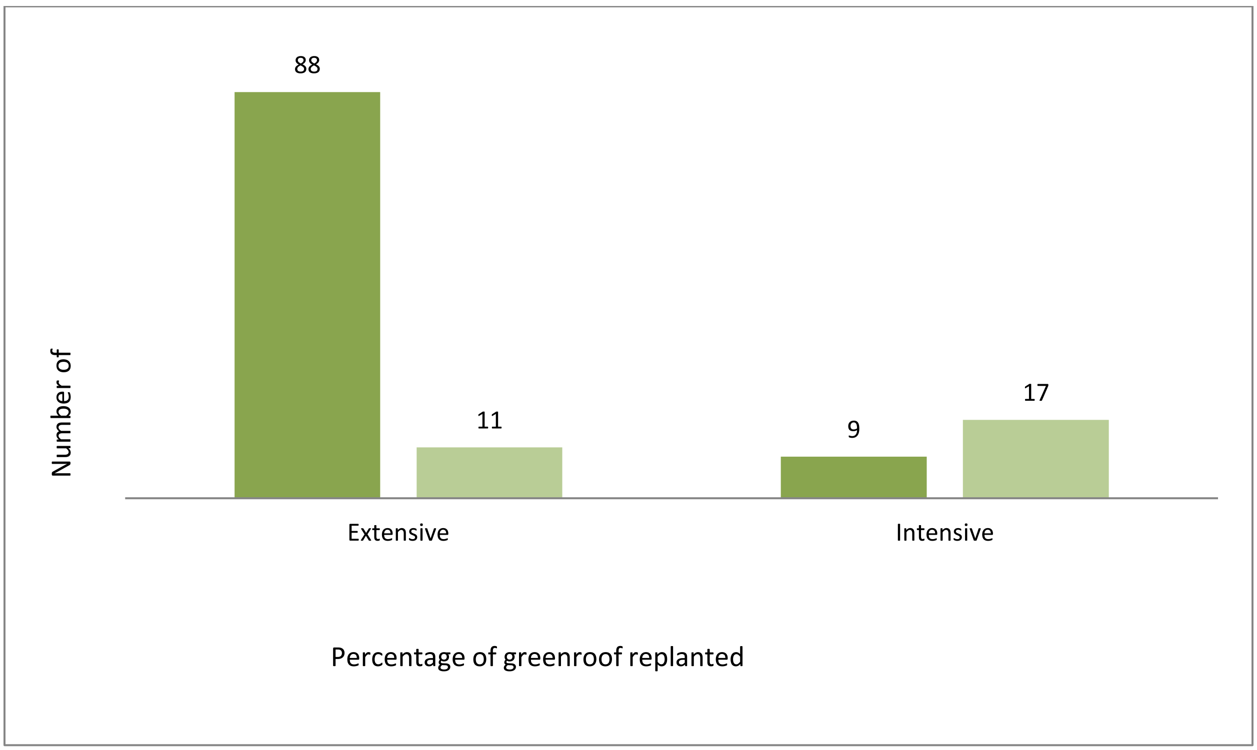
soil category v greenroof type

stress observed v replant

stress observed v other plant

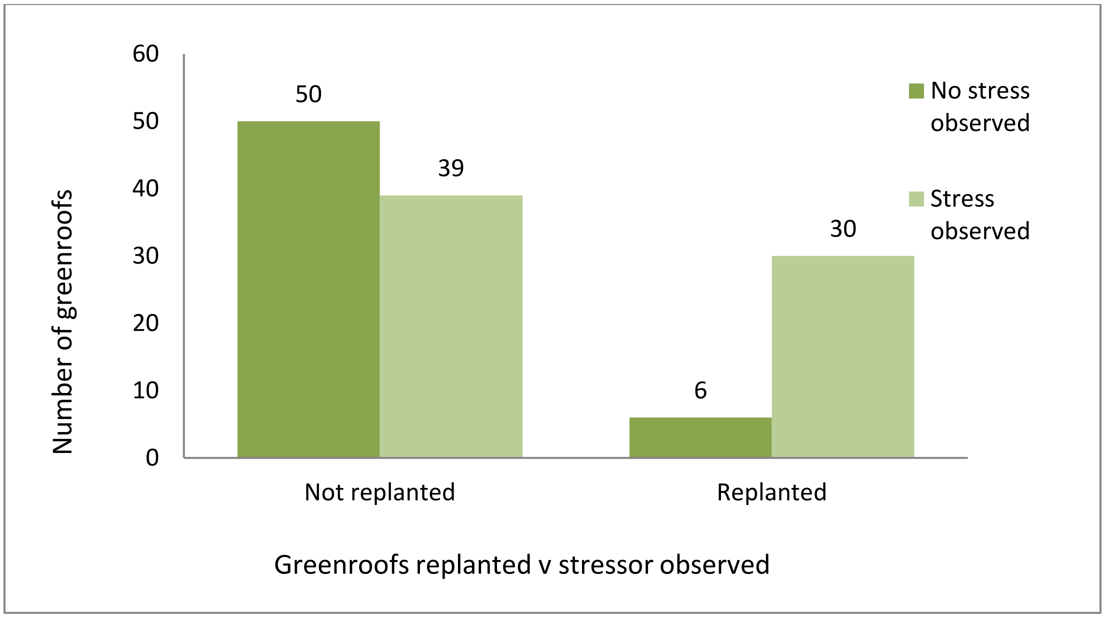
Soil category v greenroof type was tested to evaluate if the categorization scheme used in this report grouped greenroofs correctly. The null hypothesis was rejected and the variability in the data cannot be attributed to randomness or measurement error, these variables are not independent. Review of the data and the analysis results confirm that the grouping of 7 inches or less of soil media as an extensive greenroof and 7 inches or more of soil media as an intensive greenroof is valid for this project (Table 3, Figure 8).

Figure 8. Greenroof Type v Soil Category



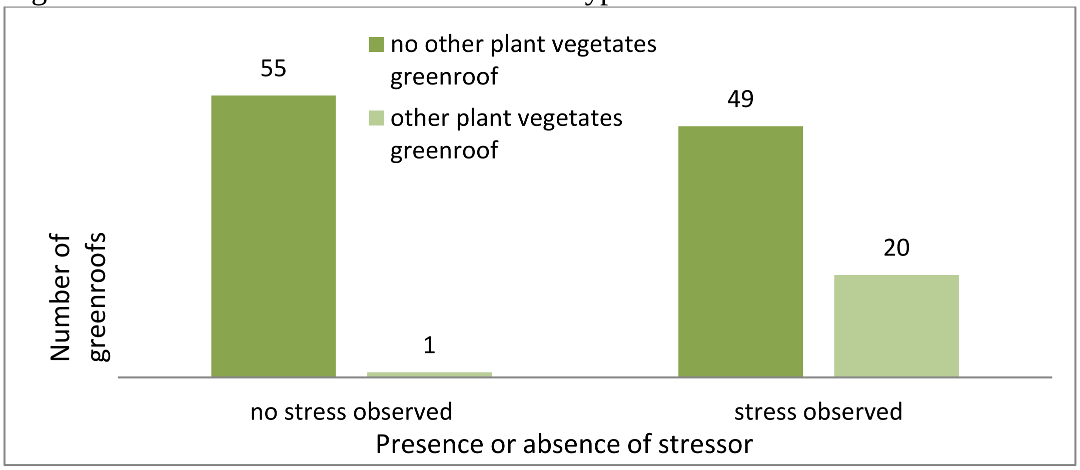
Stress observed v replant was tested to evaluate if replanting a greenroof impacted the number of stressors. The null hypothesis was rejected and the variability in the data cannot be attributed to randomness or measurement error, these variables are not independent. Review of the data and the analysis results identify that replanted greenroofs were observed with one or more stressors more often than would be expected if there was no relationship (Table 15). This means that replanting does not eliminate stress on greenroofs.

Figure 9. Stressor Observed v Replant



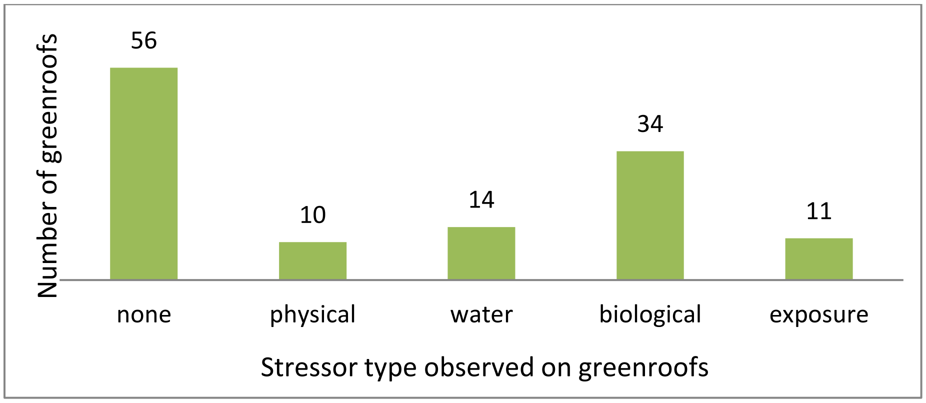
Stress observed v other plant (as well as every other plant type category) was tested to evaluate if any plant type showed a relationship to stress on a greenroof. The null hypothesis was rejected and the variability in the data cannot be attributed to randomness or measurement error, these variables are not independent. Review of the data and the analysis results identify that greenroofs with other plant types installed were observed with stress more often than if there was no relationship (Table 17). As most plants installed on greenroofs are recommended or approved by City regulators use of other plants is thinking outside the box and trying something new. It is common to fail more often when trying something new, and there is something to be learned from the failures as well as the successes. Identified which of the other plants were found on greenroofs with no stressors had fewer stressors. Or maybe stressors are growing on greenroofs with stressful design features such as heavy shade and the other plants are growing in these challenging locations

Figure 10. Stressor Observed v Other Plant Types



Stressors were grouped into four categories to further analyze data. Type of stressor impacting greenroof was categorized as biological, physical, water, or exposure. Biological includes vegetative and pest issues. Water includes irrigation concerns, burnt plants and plants too wet. Exposure includes wind and shade. Physical stressor includes construction damage or damage due to annual machine tests or litter. Biological stressors impact greenroofs more than any other stressor type (Figure 11). Stressor type was compared to the presence of multiple plant types, the presence of other plant types, and whether a greenroof was replanted or not (Figure 12).

Figure11. Stressor Types Observed on Greenroofs



Additional tests were run to evaluate the relationship between the variables and the stressor type. Both Fisher's and Chi-squared tests were used. It was found that greenroof type, diverse planting mixture, use of other plants, and replanting events had a statistically significant relationship with the stressor type. It was also found that soil category (shallow or deep) and installation on a new building or a retrofit on an existing structure had no impact on the stressor type impacting it.

Table 19. Fisher's Exact Test for Count Data and Chi-squared Test for stressor type				
Statistical Test	Fisher's Exact Test for Count Data	Chi-squared Test		
	Stressor Type	Stressor Type		
Variable of interest	p-value	x-squared value	Degrees of freedom	p-value
Diverse plant mixture	0.00415	15.324	4	0.004074
Other plant types used	1.361e-05	24.983	4	5.07e-05
New roof or reroof	0.928	1.3274	4	0.857
Soil category (shallow v deep)	0.176	6.693	4	0.153
Greenroof type (intensive v extensive)	0.0146	12.776	4	0.0124
Replant	1.822e-05	26.966	4	2.019e-05

Stressors that impact greenroofs vegetated with multiple plant types experience biological and water stressors at high numbers (top Figure 12). Greenroofs with other types of plants vegetating them experience all types of stressors at a high frequency, only one greenroof installed with other plants was found to be free of stressors (middle Figure 12). Stressor types that impact greenroofs is not related to if the greenroof was installed on new construction or as a retrofit on an existing structure (bottom Figure 12). Exposure, physical, and water stress types impacted only three of the greenroofs planted with deep soils (top Figure 13). Physical and exposure stress types did not impact extensive greenroofs while every stress type was found to impact extensive greenroofs (middle Figure 13). The occurrence of replanting events, the use of other plants, or use of multiple plant types does not seem related to stressor type. It appears biological issues follow replanting events more than other stressor types (bottom Figure 13).

Figure 12. Stressor Type Compared to Multiple Plant Types, Other Plants, and New or Reroof

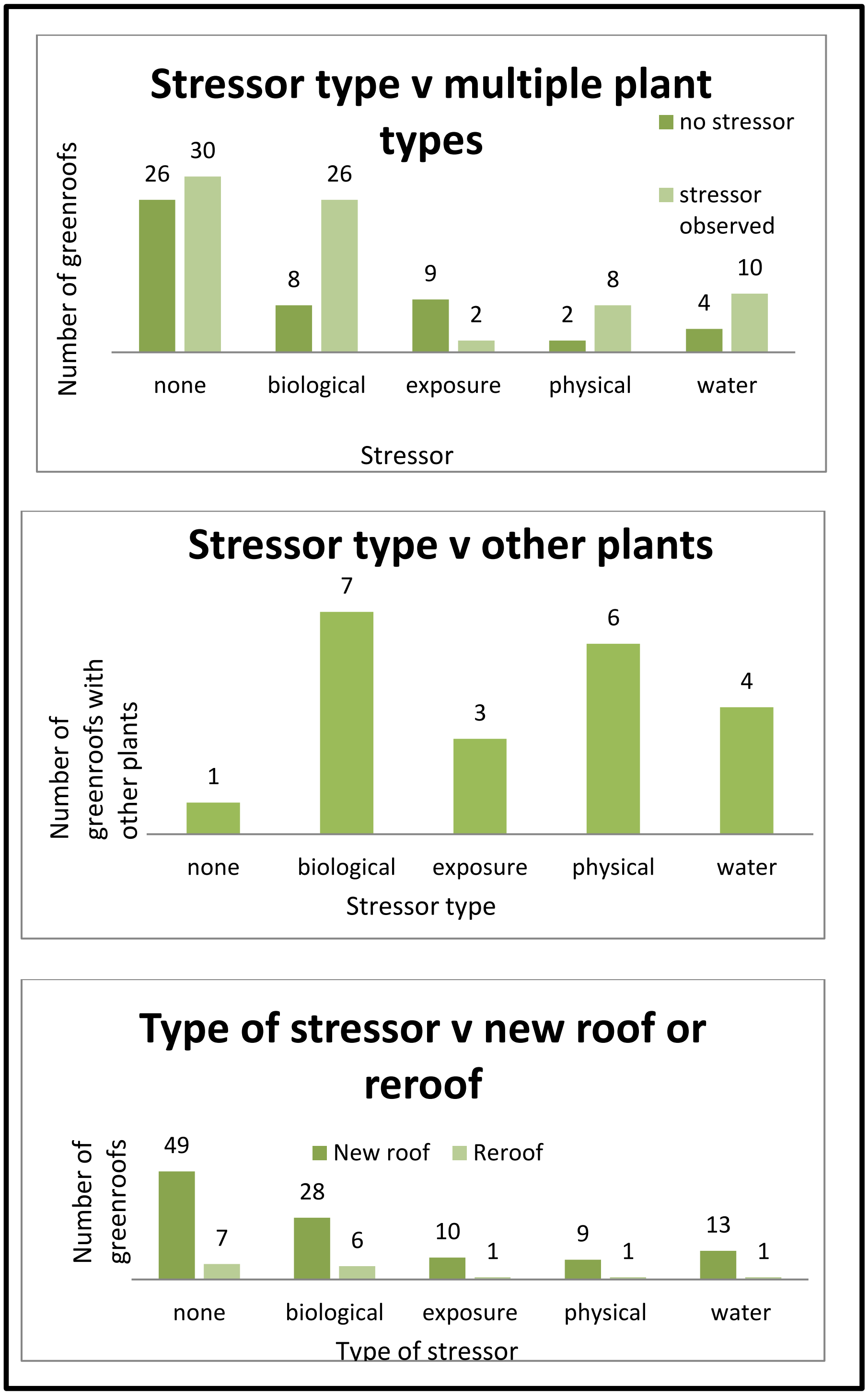
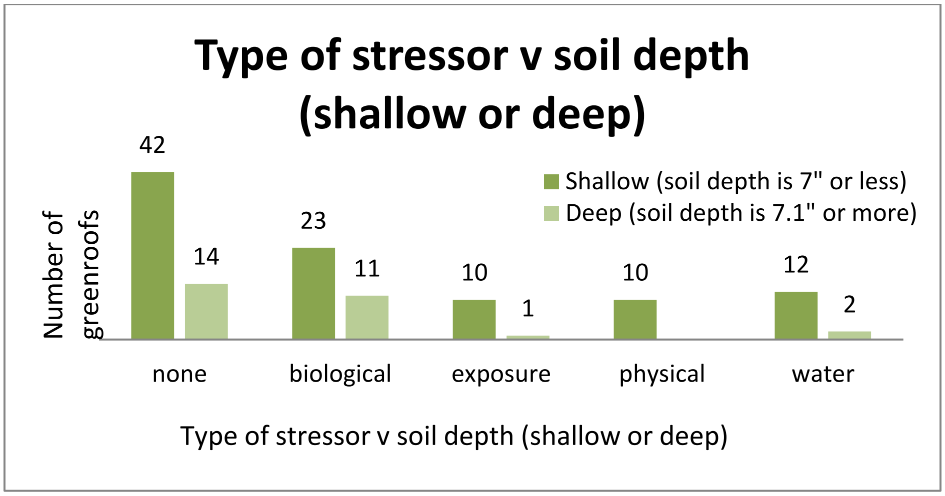
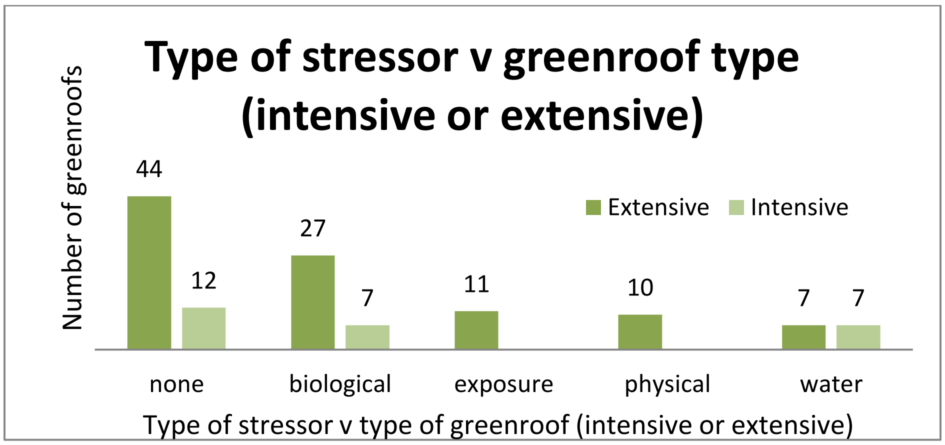
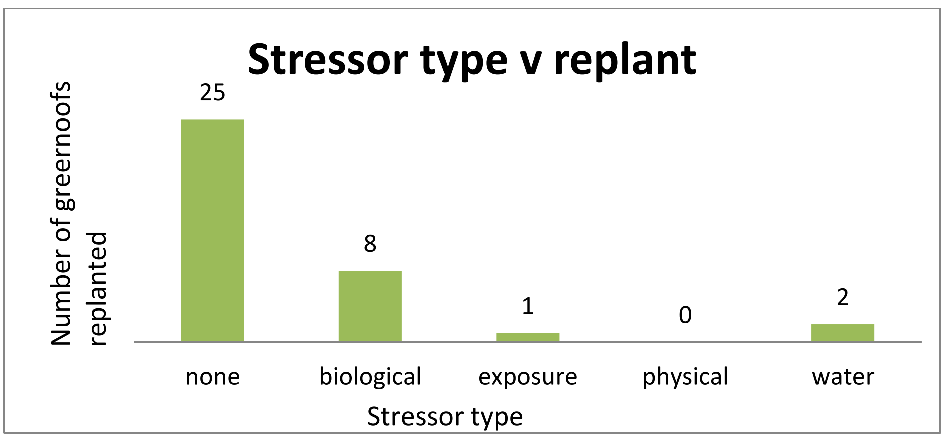


Figure 13. Stressor Type Compared to Soil Category, Greenroof Type and Replant







Conclusions

At the time of this study there were 258 properties with greenroofs known to the City. This report studied 55 of those properties (a total of 21.6% of the greenroofs). On the 55 properties, 125 greenroofs were installed for an average of 2.3 greenroofs per property. The typical greenroof has 1 to 7 inches of soil and an extensive design; it is most frequently vegetated by succulents and drains to either the CSO or the MS4.

Types of Greenroofs

Greenroofs are most often installed when a new building is being constructed rather than during a reroofing project; this may be related to the structural capacity and design limitations of the existing buildings, cost of greenroof installation post construction, and lack of information about greenroofs. Because of the added weight of water-saturated soil, older buildings may require major structural modifications which may be cost prohibitive. Much of the city has already been developed with designs that limit structural loading[12] therefore; greenroofs may be more applicable to redevelopment projects.

Maintenance Concerns

Consideration of maintenance and access needs that will occur on a greenroof property will better inform architects and engineers about design considerations that would help limit damage to the vegetation.

1. Greenroofs may be utilized to stage equipment for exterior maintenance and remodeling projects.
2. Heat vents damage plants below.
3. Some grass species dry out in the summer and may present a fire hazard.

[12] Structural loading: The weight that a building and its support structures must bear and its distribution across a property.

4. Many greenroofs lack access for maintenance. Inspections were occasionally conducted through windows or by passing through private residences in multi-family residential properties.
5. Many greenroofs lack pathways for maintenance; therefore, vegetation is damaged when stepped on.
6. Some greenroofs lack safety barriers and may require safety equipment.

Vegetation

Greenroof conditions may be harsh and can impact plant success. Vegetation type appears to influence the number of stressors found on a greenroof. Greenroofs with grasses and other plants were found to have one or more stressors more frequently than greenroofs with other categories of plants. This may be related to the increased water needs of perennial plants (Heim, 2014). Awareness of the increased water demand should prompt property managers to irrigate during drought condition. Monocultures appear to be replanted less frequently. Diverse planting designs appear to be replanted more frequently. Replanting did not eliminate stressors.

Although not planted, some volunteer vegetation was identified on greenroofs as desirable; these plants are not considered invasive and they provide sufficient vegetative cover to protect the soils from erosion. Some unexpected, though desirable, vegetation identified on greenroofs includes mushrooms, mosses, native forbs and vines. Any non-invasive vegetation that thrives on a greenroof, provides vegetative cover, prevents erosion, and does not risk damage to the structure serves a purpose from a stormwater management perspective and should be considered beneficial.

Soil Depth

Soil depth is partially influenced by structural capacity of the building. Some buildings are designed to hold more weight than others and the depth of the soil influences how much water will be retained adding to the amount of weight that the building must be designed to support. At least three considerations influence final soil depth: structural capacity, design and plant selection. Additionally, the plants that are able to survive on greenroofs are influenced by soil depth (large trees and shrubs require more soil than shallow-rooted succulents, graminoids, forbs and ferns). Soil depth does not appear to influence the number of stressors or the frequency of replanting events.

Greenroof Stressors

Wind erosion impacted less than one percent of the greenroofs in the study and does not appear to present a significant maintenance concern for Portland greenroofs; however, soil depth and successful plant establishment may play an important role in areas where wind erosion is a larger concern (such as areas without windbreaks).

Burnt plants impact nearly 10% of the facilities. Proximity to windows and brick (or other heat-radiating materials) that reflect the sun onto sections of the greenroof was observed frequently when burnt plants were present and may present a larger impact than sun exposure.

Pests impact over 11% of the facilities. Birds present the most common pest issue observed in the course of the study, impacting 7.2% of greenroofs. Some adaptive management techniques were observed during the study and included include routine removal of animal droppings (from domestic cats), and releasing ladybugs on the greenroof to manage aphids. Some pests were not a significant concern and no actions were taken to manage them. Bird dispersal products were planned for use on two greenroofs; one property replaced soil media and plants to vary soil depth and increase biodiversity in order to provide more food so the birds will be less likely to upturn vegetation in search of food (Table 7).

Invasive vegetation impacts 20% of the greenroofs in the study (26 of the 125 greenroofs). Some species of invasive vegetation can grow large enough with strong and penetrating root systems that can damage the building over time. These invasive plant types include; trees, bamboo, and butterfly bush (or other aggressive shrubs). Other invasive vegetation may act beneficially covering the soil to prevent erosion (dandelions, grasses and annual plants) or fixing nutrients so they are more readily available for uptake by other plants (clover acts as a nitrogen fixer). Removing large undesirable vegetation is critical to maintaining the integrity of the greenroof system and building; as the plants grow, the added weight may exceed structural capacity and root systems may penetrate the waterproof lining.

Other stressor indicators were observed on nearly one-third of the greenroofs in the study, more than any identified stressor; in combination, they impact more greenroofs than any identified stressor (Table 8).

Stressors that impact greenroofs vegetated with multiple plant types experience biological and water stressors at high numbers (top Figure 12). Biological stress may be related to their increase habitat value leading to additional colonization by damage causing insects and birds, some acceptance of this may be necessary in order for greenroof to function as habitat (Bracha y. Schnideler, 2011) (Trzaskowska, 2011) . Water stress may be related to the higher water requirements need by perennials than succulents (McGuire, 2013) (Carter, 2008).

Greenroofs with other plant types vegetating them experience all types of stressors at a high frequency, only one greenroof installed with other plants was found to be free of stressors (middle Figure 12). The lists of plants recommended for greenroof installation has been researched and tested using vegetation outside of this list is recommended at the owners risk, the harsh environment on greenroofs requires tough plants (Monterusso, 2005).

Stressor types that impact greenroofs is not related to if the greenroof was installed on new construction or as a retrofit on an existing structure (bottom Figure 12). This is useful to know both new construction and retrofits on existing structures have sound design and installation practices and no significant difference has been found on the occurrence of stressors on either type of greenroof construction.

Exposure, physical, and water stress types impacted only three of the greenroofs planted with deep soils (top Figure 13). Physical and exposure stress types did not impact extensive greenroofs while every stress type was found to impact extensive greenroofs (middle Figure 13). Deeper soils insulate plants and provide additional reservoirs for water storage during drought conditions. Deep soil on greenroofs may limit stress types present on greenroofs.

Replanting and Stressors

Nearly 29% of greenroofs in the study were replanted; of those greenroofs that were replanted, nearly 75% used succulent plants when revegetating. Only 2.4% of greenroofs had soil replaced. Over half of the greenroofs in the study had some type of stressor affecting them; the most common stressor was invasive vegetation impacting 20.8% of greenroofs. Wind erosion impacted very few greenroofs (only 2.4%). Of the greenroofs that had been replanted (36), 29 were found to show evidence of one or more stressors making up 80.6% of replanted greenroofs. This indicates that replanting did not resolve stressors.

Recommendations

Encouraging innovative ways to install low-cost and low-maintenance greenroofs on existing buildings may increase interest and use throughout the City. Several City projects and assessments have been carried out that provide guidance and information about greenroof designs with shallow soils and vegetation that requires little to no maintenance (City of Portland Ecoroofs Online Website). This is an excellent step in expanding the installation of greenroof systems. Further efforts to distribute information to property owners about the benefits of greenroofs and low-cost, low-maintenance options may increase installation.

The following design considerations should be reviewed during the planning stage of a greenroof project:

1. Windows reflect sunlight onto greenroofs and can intensify the sun's rays, and brick walls act as heat sinks and radiate heat long after the sunsets. Considering elements of the building that may create stressors on the greenroof is critical during the design and installation of the project. This will allow adjustments to be made that may limit or avoid undue maintenance and repair costs.
2. Greenroofs are utilized to stage equipment for exterior maintenance and remodeling projects. Installing walkways and staging areas may limit the amount of stress the vegetation undergoes during these projects.
3. Heat vents damage plants located below the vent. Leave a perimeter around the exhaust of any heat vents.
4. Grasses that dry out in the summertime must be mowed to ensure they are not fire hazards. Ensure that routine maintenance includes annual summer-time mowing.
5. Many greenroofs lack access for maintenance. Inspections were occasionally conducted through windows or by passing through private residences in multi-family residential properties. Design and install easy access for maintenance.
6. Many greenroofs lack pathways for maintenance; therefore, vegetation is damaged when stepped on during maintenance and inspection. Install maintenance pathways to prevent

damage to vegetation or accept some plant damage when the greenroof is accessed (any plants will bounce back if healthy and damage is minimal).

7. Some greenroofs lack safety barriers and maintenance personnel must be hyper vigilant when working in this windy elevated area. Always post caution signs at access points, install safety barriers as needed, and/or make safety equipment available.
8. Although wind erosion is not a significant maintenance concern for Portland greenroofs; soil depth and successful plant establishment may play an important role in areas where wind erosion is a concern (such as areas without windbreaks).
9. Monocultures appear to be replanted less frequently. Diverse planting designs appear to be replanted more frequently. This does not mean that diverse plantings should be used less frequently. When using any vegetation some die off may occur. Finding the right plant for each location on the greenroof may take some trial and error. Selecting the plant based upon the conditions of the area being planted or replanted will help ensure success (as with all plantings, select vegetation that will tolerate the number of hours of sun and anticipated soil depth and saturation conditions of the area).
10. Soil depth does not appear to influence the number of stressors or the frequency of replanting events. Physical, exposure, and water stressor types are less frequent on greenroofs with deep soils. Continue installing both intensive and extensive greenroofs. A greenroof with shallow soils compared to a greenroof with deep soils provide adequate conditions for different plants and allows for unique designs and planting communities.
11. Allow for stressors to be present on greenroofs. Greenroofs are dynamic changing environments, they will experience stress depending on the conditions they are under, a healthy greenroof (like most environments) can tolerate some stress and recover from it. The area impacted and the intensity of the stressor should be evaluated before any corrective actions are taken.
12. Replanting greenroofs does not eliminate stressors. The underlying cause of the stress must be identified to alleviate the need for maintenance, repair and replacement efforts.

13. Continue to practice adaptive management and replace plants, amend soil, remove litter, and adjust irrigation as needed. Continuing this upkeep is essential to the overall success of Portland greenroofs.
14. Before routine invasive plant removal is conducted careful review of the status and type of the invasive plants on each greenroof should be completed. Assess if the invasive vegetation is causing concerns such as: annual loss of vegetation (leaving soils exposed to erosion) during any portion of the year, drainage impairment, damage to waterproof membrane, or exceeding the structural capacity of the building. If vegetation causes no concerns and assists in the function of the greenroof, removal may be unnecessary. This assessment may alleviate some annual maintenance on some greenroofs.

Recommended Additional Research

This was a cursory look at greenroofs in Portland; more research is needed to get a full picture of greenroof maintenance and design in Portland, Oregon. Additional research evaluating greenroofs should include irrigation practices and the relationship between stressors and recommended corrective actions.

Disclaimers

Biases of the study include the restricted study area (within Portland city limits); site selection (limited due to the need to inspect properties new to the MIP program, properties that had not been inspected in two or more years, properties that may need to be included in MIP, and also limited to private properties); limitations of verbal interviews (some loss of knowledge over time or due to employee turnover; misunderstanding of facilities design or misinterpretation of answers by interviewer, etc.); and time limitations that restricted the number of properties that could be inspected.

Site selection was non-random and therefore conclusions from this study may not be representative of all Portland greenroofs (Ramsey, 6). Data was gathered at all times of the year and some vegetation present in the summer would not have been observed if the inspection took place during the winter; therefore vegetative communities outlined in this report may not include all vegetation types present on every greenroof.

Because this was a monitoring study with data collected when a greenroof was selected for inspection only after it met minimum criteria (discussed in the Data Collection Methods section) and access was gained via permission from the property owners, the results may not be representative of all greenroofs in Portland. It is a starting point and will give some insight into stressors affecting greenroofs in Portland. All findings in this study are of those 125 greenroofs and care must be used when extrapolating to represent all greenroofs in the city because the sample selection was not random. Permit requirements and limited resources required prioritization of the inspections as discussed during the Data Collection Methods section.

Soil depth measurements are limited by:

- Access: Some greenroofs were unsafe to access and safety harnesses were not available. At those locations, soil measurements and vegetative observations were collected at one or at very restricted locations. More than one greenroof was observed through a window and soil depth was estimated from design specifications and observed (or lack of) evidence of erosion or compaction.

- Excessive soil depth: Greenroofs with soil depths that exceeded the depth of the measurement tool were estimated from design specifications or verbal interviews with property managers. If no other method was available, the maximum depth of the measurement was used as the maximum soil depth. For those greenroofs with complex designs and varying soil depths, mean soil depth does not accurately reflect the average soil depth or the greenroof design’s complexity.

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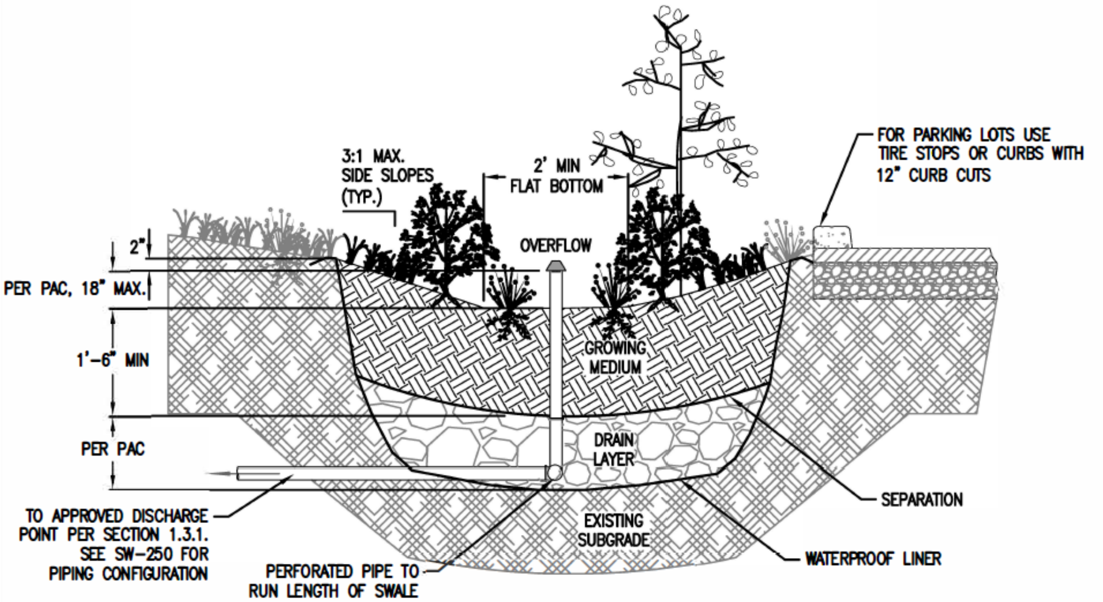
Appendix A: Stormwater Management Facility Designs

Below is a collection of some of the stormwater management facility design typicals that can be installed to manage stormwater. The facility designs are from the 2016 City of Portland Stormwater Management Manual. This represents the majority of approved smfs but other designs and variations are allowed. This list includes an example of most major facility designs but does not include all design variations (such as lined and unlined). This appendix does include:

unlined swale
unlined planter
lined basin
overflow configuration
filter strip
soakage trench
drywell
sand filter
subsurface sand filter
ecoroof
habitat ecoroof

Swale - Lined



NOTES:

1. Detail intended as an example. Detail must match PAC assumptions and/or design report.
2. Dimensions:
   Width of swale: 6'-6" minimum
   Depth of swale (from top of growing medium to overflow elevation): per PAC
   Longitudinal slope of swale: 6.0% or less.
   Flat bottom width: 2' minimum.
   Side slopes of swale: per PAC, 3:1 maximum.
3. Setbacks:
   None required.
4. Overflow:
   Swales must connect to approved discharge point according to SWMM Section 1.3.1.
   Inlet elevation must allow for 2" of freeboard, minimum.
   Protect from debris and sediment with strainer or grate.
5. Piping must be ABS Sch.40, cast iron, or PVS Sch.40. 3" pipe required for facilities draining up to 1500 s.f., otherwise 4" min. pipe. Piping must have 1% grade and follow the Uniform Plumbing Code.
6. Drain Layer:
   Determined by designer. Options include, but are not limited to drain mat, 3/4" washed round rock, or other approved system.
   Separation between drain and growing medium:
   Use appropriate filter fabric or a gravel lens (3/4 - 1/4 inch washed, rock 2 to 3 inches deep), or as per approved design.
7. Growing Medium:
   18" minimum depth. Use sand/loam/compost 3-way mix, or approved mix that will support healthy plants.
   24" minimum depth is required if the lined facility is also meeting BDS landscape requirements.
8. Vegetation: Follow landscape plans otherwise refer to plant list in SWMM, Section 2.4.1. Minimum container size is #1 container. # of plantings per 100sf of facility area:
   Zone A (wet): 80 herbaceous plants OR 72 herbaceous plants and 4 small shrubs.
   Zone B (moderate to dry): 7 large or small shrubs AND 70 groundcover plants.
   The delineation between Zone A and B must be either at the outlet elevation or the check dam elevation, whichever is lowest.
   If project area is over 200 sf consider adding a tree.
9. Check Dams: Must be placed per PAC and be equal to the width of the swale.
10. Waterproof Liner: 30 mil EPDM, HDPE or approved equivalent.
11. Splash Block: Install 4-6" washed river rock or splash pad for erosion control at inlets and downspout.
12. Inspections: Call BDS IVR Inspection Line, (503) 823-7000, request 487. 3 inspections required.

- DRAWING NOT TO SCALE -

STORMWATER MANAGEMENT TYPICAL DETAILS

- Presumptive and Performance Design Approach -

Swale - lined

NUMBER SW-220

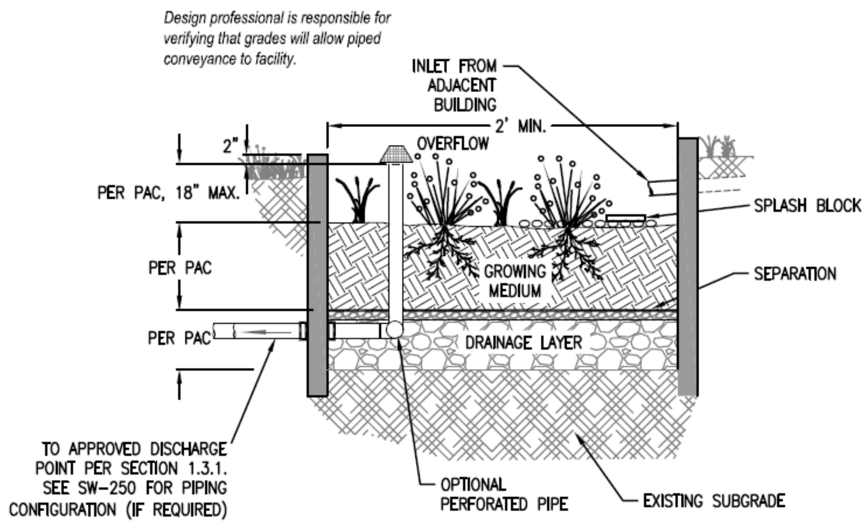
7-1-16

Bureau of Environmental Services

(City, 2016)

Planter - Unlined

ADJACENT TO LANDSCAPING



1. Detail intended as an example. Detail must match PAC assumptions and/or design report.
2. Provide protection from all vehicle traffic, equipment staging, and foot traffic in proposed infiltration areas prior to, during, and after construction.
3. Dimensions:
   Width of planter: 24" minimum.
   Depth of planter (from top of growing medium to overflow elevation): per PAC calculations.
   Longitudinal slope of planter: 0.5% or less.
4. Setbacks:
   Planters must be 5–feet from property line and 10–feet from building foundations.
5. Planter Walls:
   Material must be concrete, unless otherwise approved.
6. Piping must be ABS Sch.40, cast iron, or PVS Sch.40. 3" pipe required for facilities draining up to 1500 s.f., otherwise 4" min. pipe. Piping must have 1% grade and follow the Uniform Plumbing Code.
7. Drain Layer:
   Per PAC calculations. Options include, but are not limited to drain mat, 3/4" washed rock, or other approved system.
   Separation between drain and growing medium:
   Use appropriate filter fabric or a gravel lens (3/4 – 1/4 inch washed, crushed rock 2 to 3 inches deep), or as per approved design.
8. Overflow:
   Inlet elevation must allow for 2" of freeboard, minimum.
   Protect from debris and sediment with strainer or grate.
9. Growing Medium:
   Use sand/loam/compost 3–way mix, or approved mix that will support healthy plants. 18" minimum depth if there is a drainage layer. If soils are well draining and there is not a drainage layer depth may be reduced as approved.
10. Vegetation: Refer to plant list in SWMM, Section 2.4.1. Minimum container size is #1 container. # of plantings per 100sf of facility area:
    80 herbaceous plants OR;
    72 herbaceous plants and 4 small shrubs.
11. Splash Block: Install 4–6" washed river rock or splash pad for erosion control at inlets and downspout.
12. Inspections: Call BDS IVR Inspection Line, (503) 823–7000, request 487. 3 inspections required.

– DRAWING NOT TO SCALE –

STORMWATER MANAGEMENT TYPICAL DETAILS

– Presumptive and Performance Design Approach –

Planter – unlined

Bureau of Environmental Services

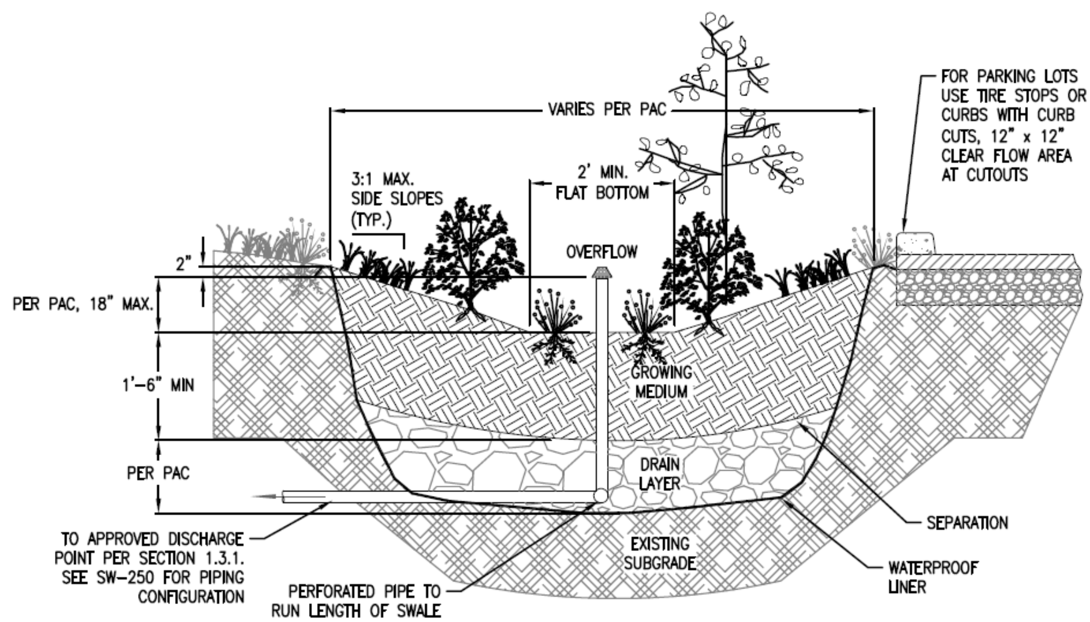
NUMBER

SW–231

7–1–16

(City, 2016)

Basin - Lined



1. Detail intended as an example. Detail must match PAC assumptions and/or design report.
2. Dimensions:
   Width of basin: 5' minimum
   Depth of basin (from top of growing medium to overflow elevation): per PAC
   Flat bottom width: 2' minimum.
   Side slopes of swale: Per PAC, 3:1 maximum.
3. Setbacks: None required.
4. Overflow:
   Basins must connect to approved discharge point according to SWMM Section 1.3.
   Inlet elevation must allow for 2" of freeboard, minimum.
   Protect from debris and sediment with strainer or grate.
5. Piping must be ABS Sch.40, cast iron, or PVS Sch.40. 3" pipe required for facilities draining up to 1500 s.f., otherwise 4" min. pipe. Piping must have 1% grade and follow the Uniform Plumbing Code.
6. Drain Layer:
   Determined by designer. Options include, but are not limited to drain mat, 3/4" washed round rock, or other approved system.
7. Separation between drain and growing medium:
   Use appropriate filter fabric or a gravel lens (3/4 – 1/4 inch washed, crushed rock 2 to 3 inches deep), or as per approved design.
8. Growing Medium:
   18" minimum depth. Use sand/loam/compost 3–way mix, or approved mix that will support healthy plants.
   24" minimum depth is required if the lined facility is also meeting BDS landscape requirements.
9. Vegetation: Follow landscape plans otherwise refer to plant list in SWMM Section 2.4.1. Minimum container size is #1 container. # of plantings per 100sf of facility area:
   Zone A (wet): 80 herbaceous plants OR 72 herbaceous plants and 4 small shrubs.
   Zone B (moderate to dry): 7 large or small shrubs AND 70 groundcover plants.
   The delineation between Zone A and B shall be either at the outlet elevation or the check dam elevation, whichever is lowest.
   If project area is over 200sf consider adding a tree.
10. Waterproof Liner: 30 mil EPDM, HDPE or approved equivalent.
11. Splash Block: Install 4–6" washed river rock or splash pad for erosion control at inlets and downspout.
12. Inspections: Call BDS IVR Inspection Line, (503) 823–7000, request 487. 3 inspections required.

– DRAWING NOT TO SCALE –

STORMWATER MANAGEMENT TYPICAL DETAILS

– Presumptive and Performance Design Approach –

Basin – lined

NUMBER

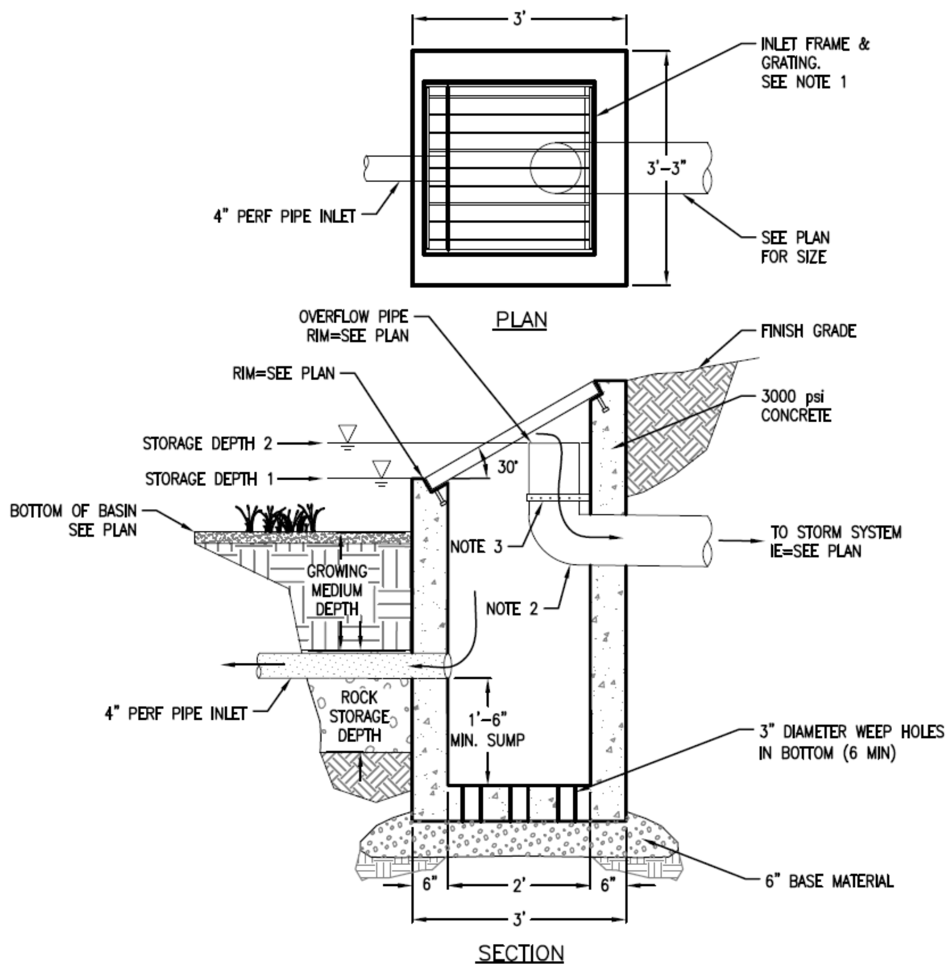
SW–240

7–1–16

Bureau of Environmental Services

(City, 2016)

Facility Overflow Configuration E



1. Grating and frame must be galvanized steel medium duty.
2. 8" dia. outlet pipe with upturned elbow.
3. Secure outlet pipe with s/s band embedded 2" in wall.

– DRAWING NOT TO SCALE –

STORMWATER MANAGEMENT TYPICAL DETAILS

– Presumptive Design Approach –

Facility Overflow Configuration E

Bureau of Environmental Services

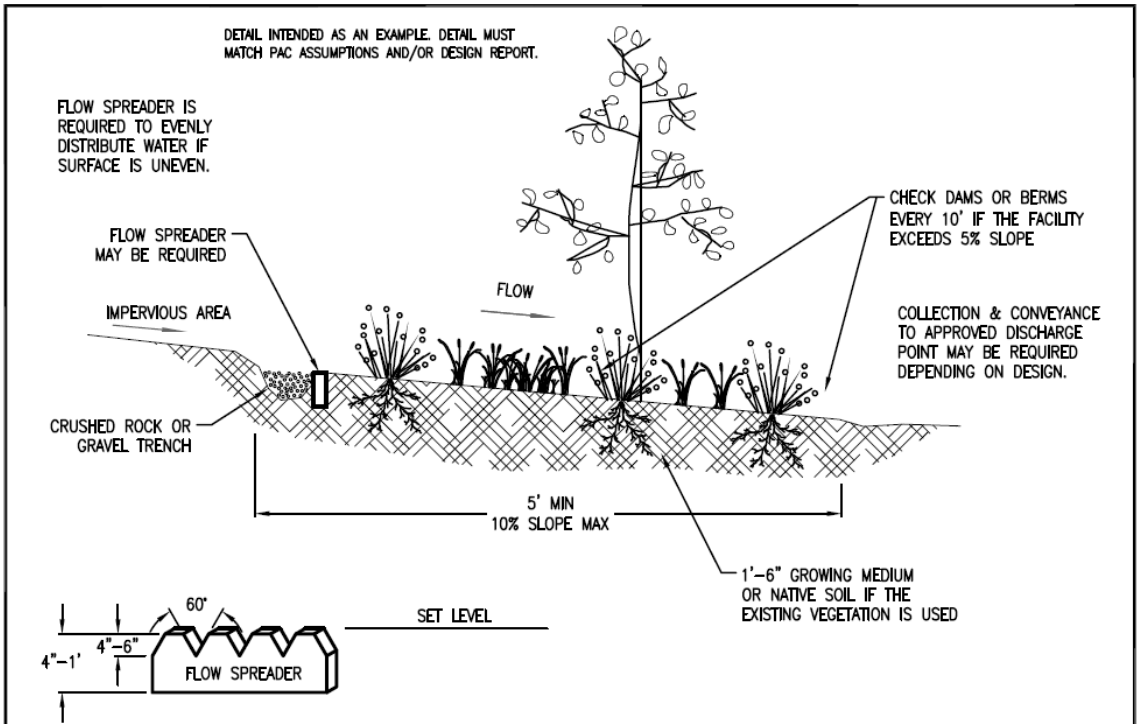
NUMBER

SW–251

7–1–16

(City, 2016)

Filter Strip



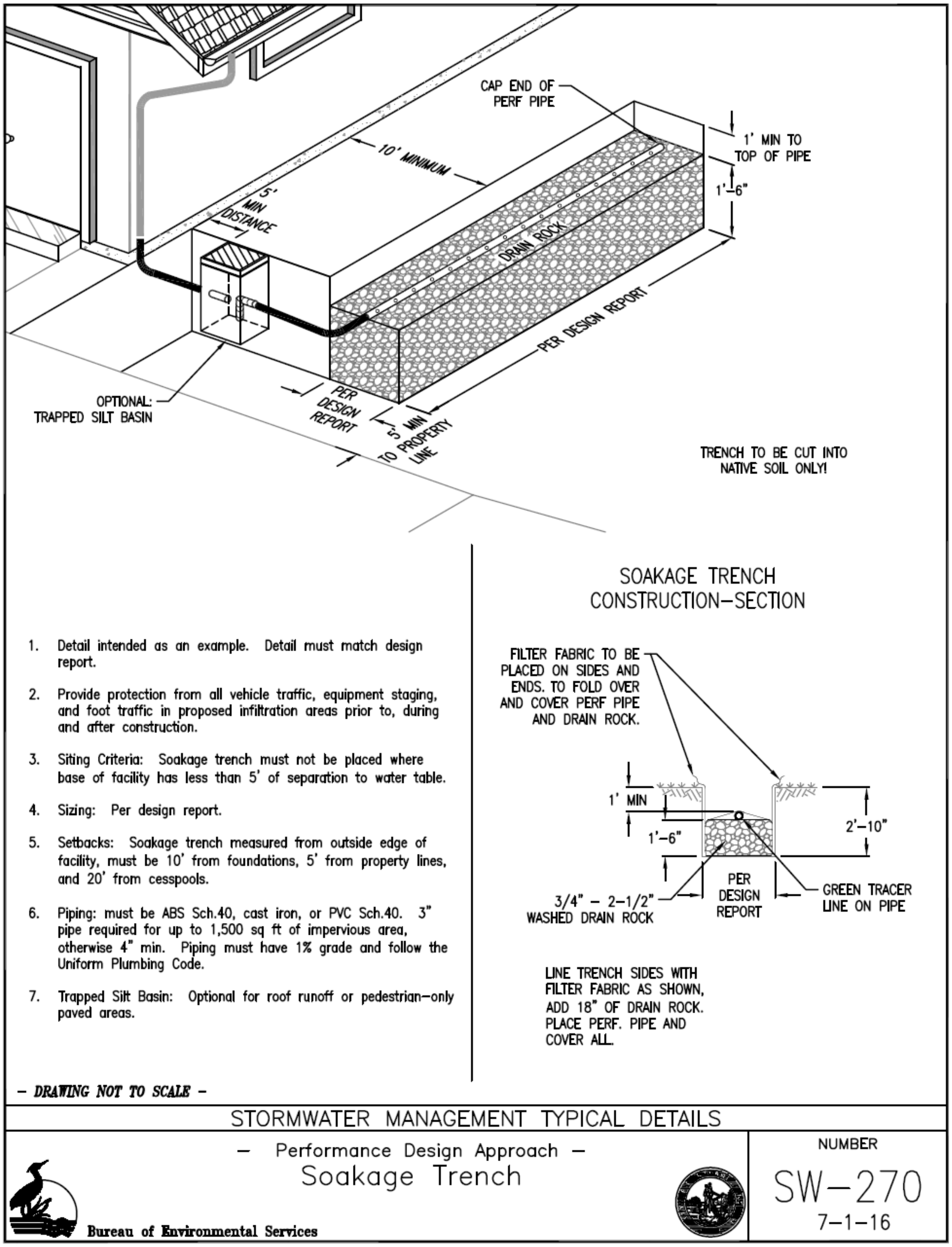
1. Detail intended as an example. Detail must match PAC assumptions and/or design report.
2. Provide protection from all vehicle traffic, equipment staging, as well as foot traffic for proposed infiltration areas prior to and during construction.
3. Dimensions:
   a. Flow line length: 5' minimum.
   b. Slopes: 0.5 – 10%
4. Setbacks (from beginning of facility):
   a. 5' from property line
   b. 10ft from buildings
   c. 50ft from wetlands, rivers, streams, and creeks where required.
5. Overflow: Collection from filter strip must be specified on plans to approved discharge point according to SWMM Section 1.3.
6. Growing Medium: Unless existing vegetated areas are used for the filter strip, growing medium must be used within the top 18" (Or approved mix. Use sand/loam/compost 3-way mix).
7. Vegetation: The entire filter strip must have 100% coverage by native grasses, native wildflower blends, native ground covers, or any combination thereof.
8. Flow Spreaders: A grade board or sand/gravel trench may be required to disperse the runoff evenly across the filter strip to prevent a point of discharge. The top of the level spreader must be horizontal and at an appropriate height to provide sheetflow directly to the soil without scour. Level spreaders must not hold a permanent volume of runoff. Grade boards can be made of any material that will withstand weather and solar degradation. Trenches used as level spreaders can be filled with washed crushed rock, pea gravel, or sand
9. Check Dams: must be placed according to facility design otherwise:
   a. Equal to the width of the filter
   b. 3 to 5" in height
   c. Every 10' where slope exceeds 5%.
9. Inspections: call BDS IVR Inspection Line, (503) 823-7000, for appropriate inspections.

– DRAWING NOT TO SCALE –

STORMWATER MANAGEMENT TYPICAL DETAILS	
– Performance Design Approach – Filter Strip Bureau of Environmental Services	NUMBER SW–260 7–1–16

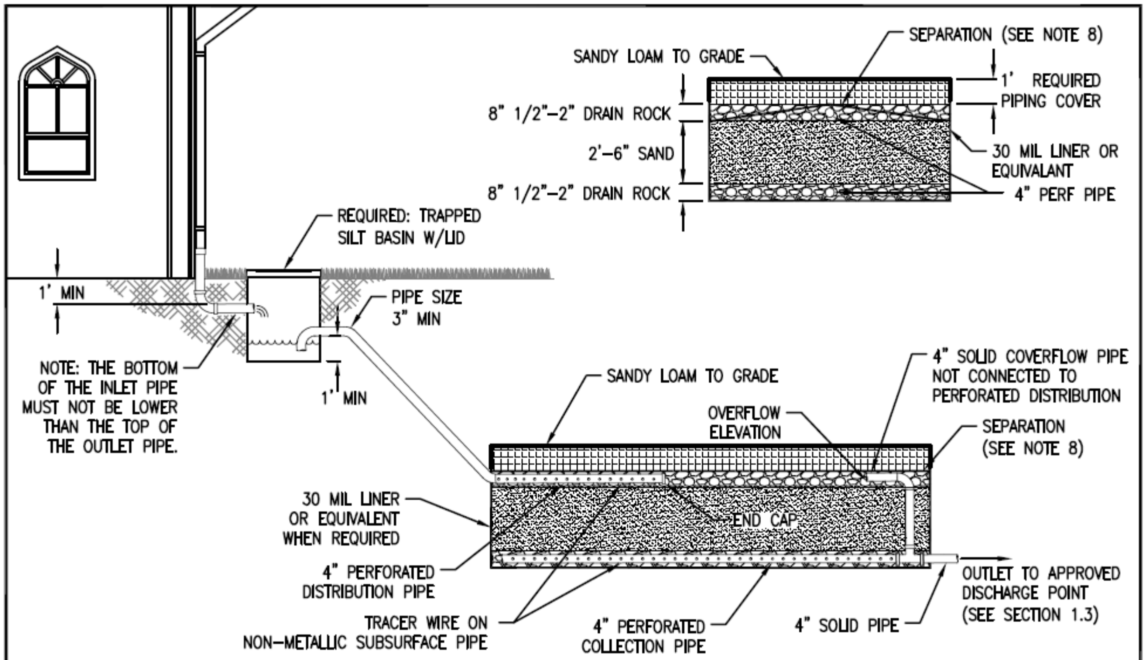
(City, 2016)

Soakage Trench



(City, 2016)

Subsurface Sand Filter



1. Provide protection from all vehicle traffic, equipment staging, and foot traffic in proposed infiltration areas prior to and during construction.

2. Dimensions:
   a. Height of subsurface sandfilter: 46" from base.
   b. Depth of excavation: 58" Min. (to accommodate 12"of cover).

3. Setbacks (from edge of facility):
   a. Infiltration facilities must be 10' from foundations and 5' from property lines.
   b. Lined facilities may be within 10' of foundation and within 5' of property line if properly lined.

4. Trapped silt basin required prior to inlet to subsurface sand filter.

5. Overflow: perforated collection pipe within top gravel layer connected to approved discharge point according to Section 1.3.

6. Piping must be ABS Sch40, cast iron, or PVC Sch40. 3" pipe must be used for up to 1500sf of impervious area, otherwise 4" minimum. Piping must have 1% grade and must follow current Uniform Plumbing Code.
   a. Underdrain piping system must consist of minimum 4" diameter collector manifold with perforated lateral branch lines.
   b. Underdrain laterals must be placed with minimum 1% positive gravity drainage to the collector manifold.
   c. The collector manifold must have a minimum 1% grade toward the discharge joint.
   d. Lateral spacing of collection or distribution pipes must not exceed 10'.
   e. All laterals and collector manifolds must have cleanouts installed, accessible from the surface without removing or disturbing filter media.
   f. Outlet to approved discharge point must be protected from soil, gravel, or sand displacement with filter fabric or equivalent.

7. Drain Rock and Sand Depth:
   a. 8" of 3/4" washed drain rock as base.
   b. 30" of washed sand per chapter 2.
   c. 8" top layer of 3/4" washed drain rock over sand.

8. Separation between drain rock and sand: Use filter fabric or a gravel lens (3/4 – 1/4 inch washed, crushed rock 2 to 3 inches deep) or approved equivalent.

9. Waterproof Liner: Must be 30 mil EPDM, HDPE or equivalent for facilities when lining is required.

10. Inspections: Call BDS IVR Inspection Line, (503) 823–7000, for appropriate inspections.

– DRAWING NOT TO SCALE –

STORMWATER MANAGEMENT TYPICAL DETAILS

– Performance Design Approach –

Subsurface Sand Filter

Bureau of Environmental Services

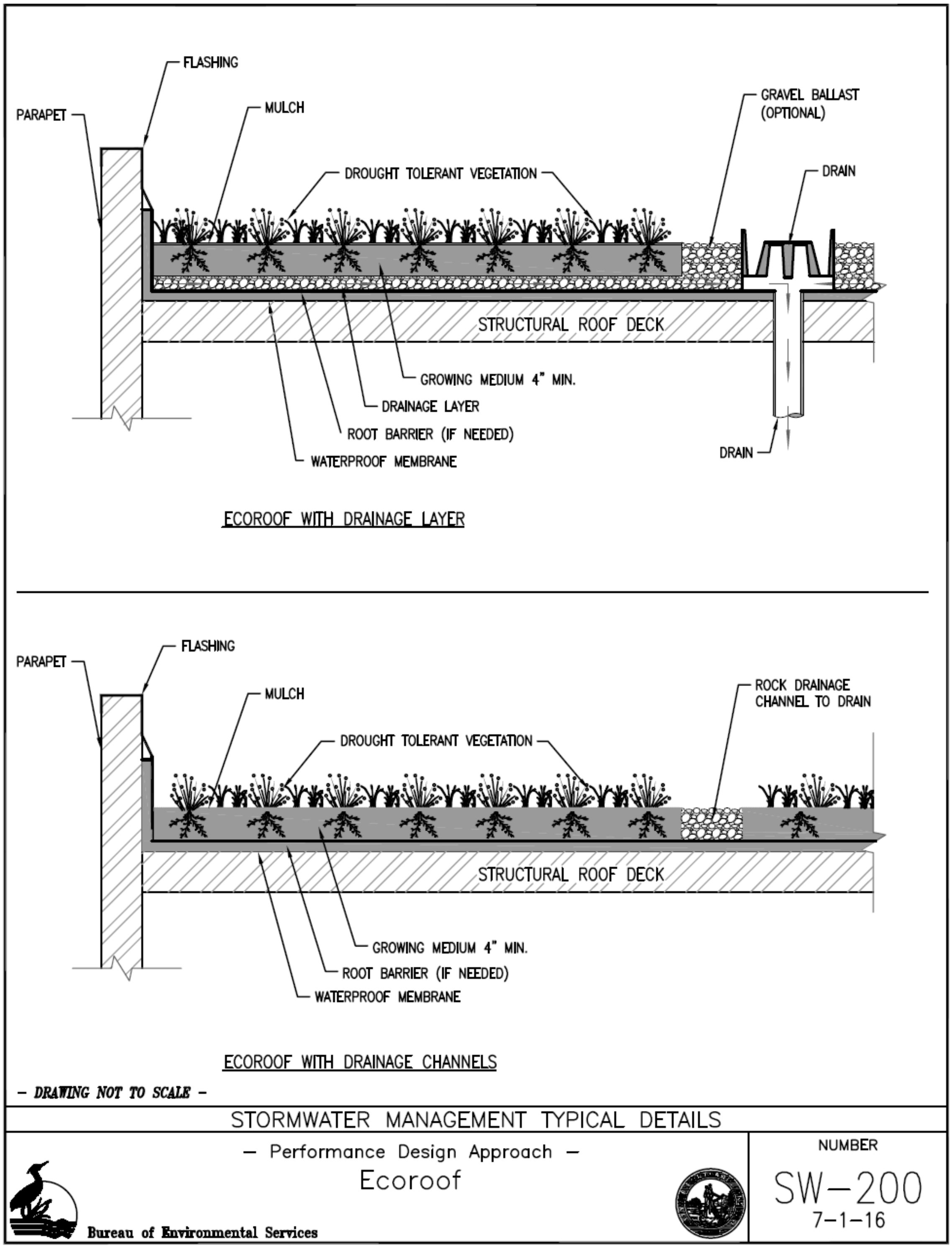
NUMBER

SW–291

7–1–16

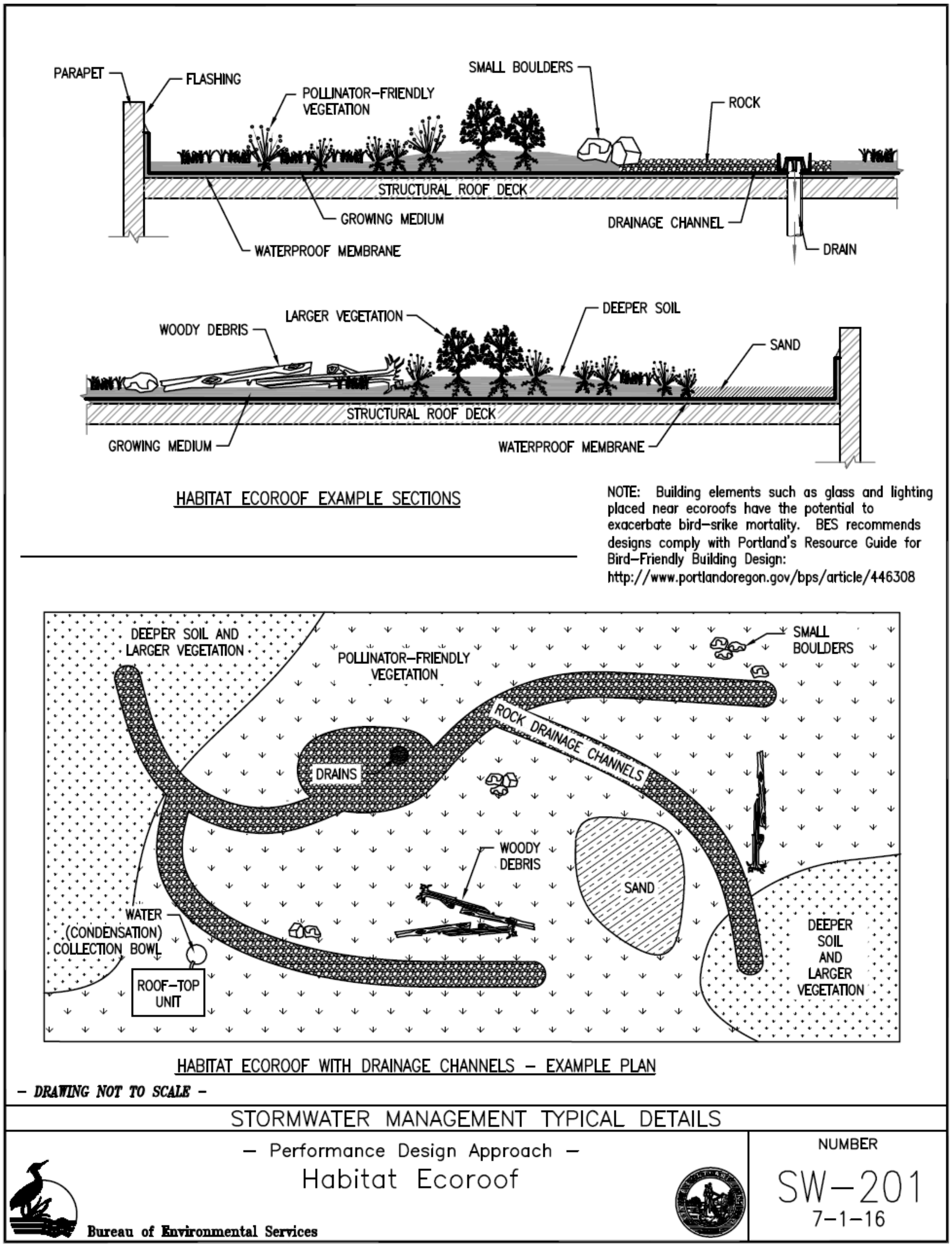
(City, 2016)

Ecoroof



(City, 2016)

Habitat Ecoroof



(City, 2016)