Rain Garden and Bioretention Literature Review:

An Assessment of Functional Parameters, BMPs and Landowner Perspectives

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Abstract
Stormwater runoff is actively managed in the Pacific Northwest by cities and counties who are increasingly turning to Low Impact Development (LID) techniques, particularly infiltration Best Management Practices (BMPs) called rain gardens and bioretention facilities. Rain gardens and bioretention facilities can mitigate the loss of natural hydrologic functions that occur through the process of land development. Infiltration BMPs are frequently promoted by government agencies, utility districts and conservation organizations to restore hydrologic conditions and improve water quality treatment of runoff in urban and suburban settings. They are located on both public and private lands. As more and more rain gardens and bioretention facilities are installed, a diversity of approaches have been developed to assess their effectiveness in a variety of settings and over time. Many different parameters are used as field-based proxies for effective function, such as soil texture, water chemistry tests, vegetation survival and condition of flow control devices. There are also themes that have emerged in the social science literature about private landowner views of rain gardens and landscaping preferences, as well as several survey methodologies that can be applied to further understanding of community attitudes and values. This literature review identifies the basic functions of rain gardens and bioretention facilities, summarizes common designs and maintenance practices of these facilities in the Pacific Northwest and identifies performance indicators correlated to each basic function along with related monitoring approaches. In addition, this review summarizes community attitudes and perceptions about rain gardens and bioretention facilities. In conclusion, a series of methodology recommendations are made for use in the Rain Garden and Bioretention Assessment Protocol.

Contents

Introduction

This document represents a review of rain garden and bioretention facility studies in published literature with a focus on three main goals: 1) identify rain garden and bioretention functions, their field indicators and potential field- based monitoring procedures; 2) review industry-standard designs, construction and installation practices, and maintenance activities that influence their function, and; 3) review survey methodologies to gather information on landowner attitudes and perspectives on rain garden and bioretention function and acceptance. This literature review is the first task of the Rain Garden and Bioretention Assessment Protocol project, funded by pooled resources from Western Washington jurisdictions (cities and counties) and administered by the Washington State Department of Ecology (Ecology) under the Regional Stormwater Monitoring Program (RSMP) http://www.ecy.wa.gov/programs/wq/stormwater/municipal/rsmp/rsmp.html

The intentions of the project are to: (1) develop volunteer / staff-friendly data collection methods that can be implemented across western Washington, that do not need access to extensive lab facilities; (2) better understand landowner values about rain gardens and rain garden maintenance incentives; (3) collect defensible data, regardless of who collects it; and (4) provide an initial assessment of rain gardens and bioretention function and acceptance.

There are a number of similarities between a rain garden and a bioretention area, many of which are visual. They both contain "shallow, vegetated depressions, designed to receive stormwater runoff from impervious surfaces such as parking lots, roofs and roads." (Stander et al., 2010, page 3018). Rain gardens are often smaller than bioretention sites and shaped to fit a residential yard. Both are built with augmented or new soil mixes that allow water to percolate rapidly, treat runoff and encourage vegetation growth (Hinman, June 2013).

There are also a few key differences that must be acknowledged because they are factors that likely influence functional performance, potentially acceptance by landowners, and therefore protocol development. Bioretention facilities (cells or areas) are held to more design criteria than rain gardens. Definitions from the two preeminent literature sources for the Pacific Northwest region are provided below.

Bioretention cells

The most important key difference for bioretention facilities vs raingardens is that bioretention facilities must be sized to treat 91% of the runoff draining to the area. Bioretention engineering specifications are given as BMPT7.30 in Ecology's 2014 Stormwater Management Manual for Western Washington (SMMWW, Ecology 2012). Other design criteria requirements are an overflow structure, adequate separation from ground water and that an imported bioretention soil mix be 18" in depth to provide enhanced treatment of runoff.

Hinman et al, 2012describes bioretention facilities as follows "Shallow depressions accepting stormwater from small contributing area with plants and a soil media designed to provide a specific saturated hydraulic conductivity and pollutant removal characteristics and support healthy plants. A variety of plants are used in bioretention areas, including trees, shrubs, grasses and/or other herbaceous plants. Bioretention cells may or may not have an under-drain and are not designed as a conveyance system."

Rain gardens

Hinman et al, 2012 describes raingardens as "A non-engineered, shallow landscape depression with native soil or a soil mix and plants that is designed to capture stormwater from small, adjacent contributing areas."

The SMMWW gives specification for Rain Gardens in BMPT5.14A to provide cities and counties an option for smaller development projects to address cumulative impacts on hydrology and water quality. Design criteria <u>are guidelines</u> and not requirements. The raingardens guidelines are they are non-engineered, on-site depressions to temporarily store and infiltrate stormwater runoff from adjacent areas such as roof runoff. Ecology recommends raingardens are sized to receive 5-7% of the impervious surface draining to it, native soil is amended with compost except in phosphorus sensitive receiving water, overflow structures are considered, and not to use underdrains.

The important differences therefore between raingardens and bioretention are primarily below the surface and not visually assessable. Raingarden construction *may* use some or all of the same design principles as a bioretention cell, but is not required to. For example, a rain garden may be built with native soil or choose to use some or all bioretention soil media. Bioretention facilities only use bioretention soil media that meets specifications in the SWWMM. A typical schematic of a rain garden is shown in Figure 1 and a typical bioretention cell in Figure 2.

Figure 1: Typical Raingarden

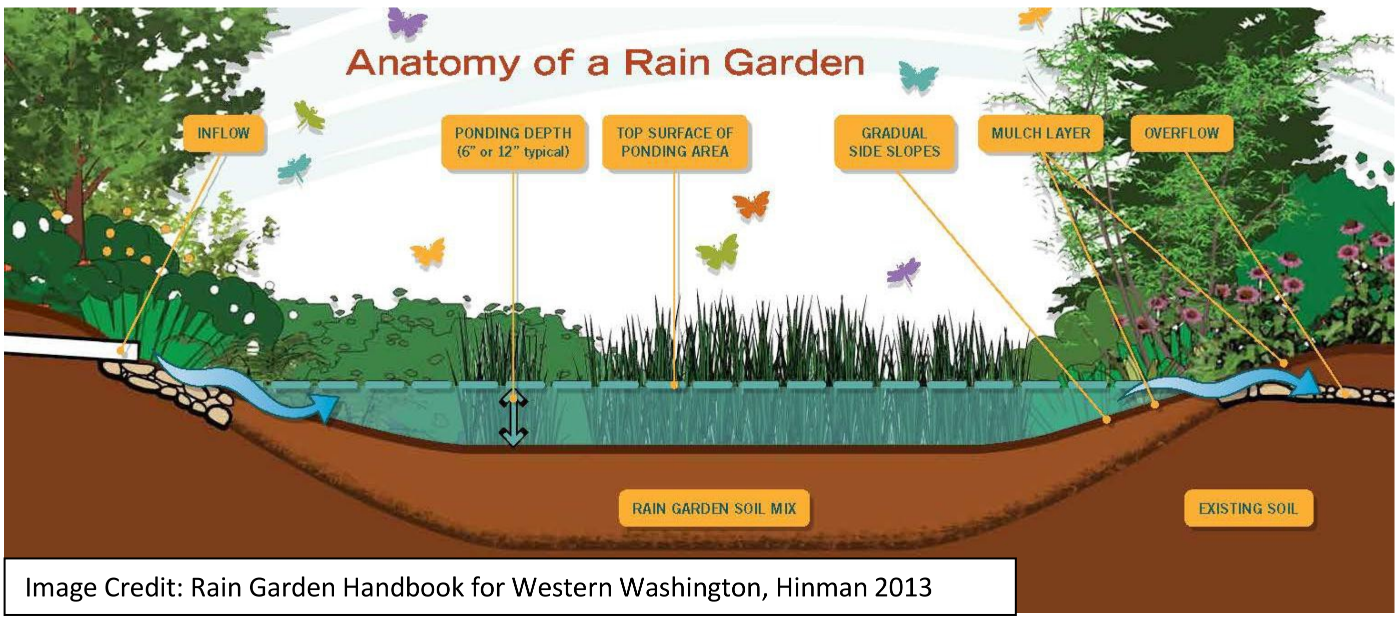
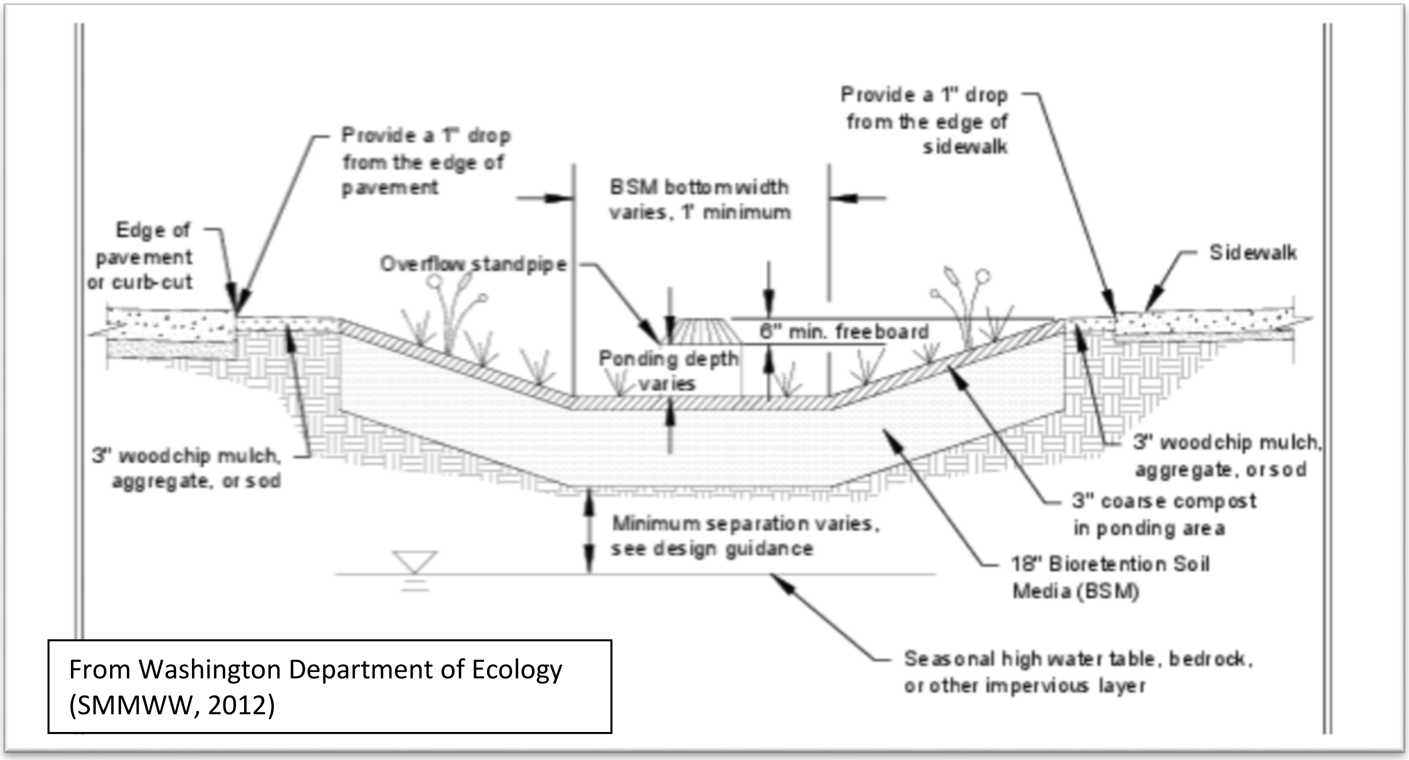


Image Credit: Rain Garden Handbook for Western Washington, Hinman 2013

Figure 2. Typical Bioretention Facility



From Washington Department of Ecology (SMMWW, 2012)

Review of Literature: Best Management Practices Overview

Rain Garden Literature Sources:

Several literature sources were consulted for rain garden design, construction and maintenance in the Puget Sound region. The *Rain Garden Handbook for Western Washington* (Hinman 2013) is the most frequently cited guidance for residential and increasingly at the commercial, industrial, and larger scales. Parallel and cross-referenced guidance is also provided by Washington State University and the Puget Sound Partnership for the Puget Sound region in the *Low Impact Development Technical Guidance Manual for Puget Sound* (Hinman 2012). SMMWW has limited additional information on rain gardens (BMP T5.14A) which describes applicability and infeasibility for their use, and how to make rain gardens more like bioretention (BMP T7.30). For design and maintenance guidance, Ecology directs the reader to Hinman, 2012 and 2013.

A detailed "Green Stormwater Operations and Maintenance Manual" developed by Seattle Public Utilities in 2016 is also included as an appendix to the *Low Impact Development Technical Guidance Manual for Puget Sound.*

The US Environmental Protection Agency website offers green infrastructure manuals and resources by state. Additional resources include design tools, addressing various design challenges, implementation guides, and homeowner resources. The EPA green infrastructure web page refers directly to the above-noted *Low Impact Development Technical Guidance Manual for Puget Sound* for use in this region.

Bioretention Literature Sources:

The primary source for bioretention facility BMPs (BMPT7.30 - cells, swales, and planter boxes) is Ecology's *SMMWW (Ecology, 2012).* The SMMWW references other guidance documents for information, clarify that the SMMWW criteria overrules other references for bioretention design and construction. The other guidance manuals referenced in BMP T7.30 are the *Low Impact Development Technical Guidance Manual for Puget Sound* (Hinman 2012) and *Guidance Document Western Washington Low Impact Development (LID) Operation and Maintenance (O&M)* (Hererra and WSC, 2013).

Key Shared Design, Construction, and Maintenance Criteria

Design Criteria:

1. Facility sizing should be relative to characteristics of the proposed site, with consideration to existing soil conditions, soil drainage rates, runoff from contributing area, and rainfall rates. Actual sizing criteria differ as previously noted.
2. Facility design needs to incorporate infiltration rate, flow entrance considerations, bottom area and side slopes, ponding area and surface overflow guidelines, potential underdrain needs, check dam and weir guidelines, and hydraulic restriction layers.
3. Facility placement should avoid proximity to steep slopes, poor draining areas, building foundations, utility locations, and cannot drain to phosphorus sensitive water bodies.
4. For rain gardens, two options for bioretention soil media are recommended – If native soil drains well, amend with 35% compost by volume, then mix thoroughly. If importing bioretention soil, use a mix of 60% screened sand and 40% certified compost. For bioretention facilities, a mix of 60% screened sand and 40% certified compost is required.
5. Select a mix of trees, shrubs, and groundcovers that are appropriate for the site conditions, as well as provide aesthetic interest during all seasons. Plant each species within the proper rain garden

zone.

Construction Criteria

1. Compost should ideally contain organic matter content of 35%-65%, and a carbon to nitrogen ratio below 25C:1N, with mycorrhizal fungi, bacteria, and pH between 6.0 and 8.0 (or equal to the undisturbed soil).
2. Soil excavation depth should be 24” to 42”, and refilled with 18” to 24” of bioretention soil mix (12” is okay for raingardens).
3. Filter fabric use is contra-indicated for lining bioretention facilities according to current guidance, however variation in this recommendation exists in some previous guidance.
4. Armoring type and size used in the project should be determined by expected water flow at the proposed site and project type.
5. Mulching of facility is recommended to provide temporary protection from erosion, moisture conservation, temperature moderation and weed suppression.
6. Excavation guidelines should include determining the depth necessary to accommodate containment area ponding, soil mix, inflow and over flow areas.
7. Soil should be placed in 6” layers at a time, with a light tamping between layers until desired soil level is achieved.
8. Site construction considerations should include limiting the amount of site disturbance and preservation of existing vegetation in order to reduce soil compaction, protect soil biota, and reduce erosion when possible.
9. During design and construction phases, efforts should be made to temporarily control erosion and sediment by redirecting water flow away from the site, as well as silt fencing where necessary.
10. Quality of compost can often be determined through smell and examination. Characteristics should include an earthy smell, brown/black color, mixed particle sizes with a crumbly texture, and a stable temperature. Compost suppliers should provide verification of compliance with state and federal quality standards. Biosolids are not allowed for bioretention facilities.

Maintenance Guidance

1. Facility maintenance should include inspection of inflow, outflow and overflow for any debris that may interfere with flow and ensuring plants are well established.
2. Additional woodchip mulch can be used to help prevent erosion, control weeds and maintain soil moisture.
3. Maintenance recommendations related to plant selection, with guidelines on site conditions and watering requirements that are appropriate for each plant species (aka right plant, right place).
4. Access to the bottom of the rain garden should be maintained for weeding and other tasks. Access can be facilitated with a few strategically placed flat rocks or pavers. Activities that compact soil should kept to a minimum, especially in the bottom area of the rain garden.
5. To prevent erosion, minimize exposed soil by maintaining a healthy cover of plants. If necessary, stabilize areas of erosion with rocks to spread water flow.
6. Irrigation may be necessary the first 1 to 3 years or during prolonged dry spells.

Review of Literature: Rain Garden and Bioretention Assessment

Performance Goals:

The purpose of rain gardens and bioretention facilities are to "…mitigate urban runoff…" (Carpenter et al., 2010, p. 404) by infiltrating, storing and treating a quantity of stormwater runoff from a specific drainage area. (Brown et al. 2011; Carpenter et al 2010; Turk, et al. 2014; Kazemi et al 2009; Mehring et al. 2015; Stander et al. 2010, and Tornes 2005). By controlling the stormwater volume and peak flows draining to local receiving waters, these facilities are providing incremental protection and aim to improve "the physical and biological integrity of receiving streams [and other receiving bodies] by reducing stream bank erosion and negative effects on aquatic communities" (Stander, 2010, p. 3018.). A properly functioning facility is able to achieve that goal by controlling stormwater volume, removing pollution from stormwater runoff, and contributing to ground water recharge. Secondarily, these facilities also serve to increase the amount of green space and provide biological diversity in urban / suburban areas (Kazemi et al., 2009; Mehring et al 2015; and Tornes 2005).

Performance Indicators:

There are numerous approaches to assessing rain garden and bioretention performance and function. Across the literature, the indicators used were: Age and sizing of the facility, plant health, pollutant removal, infiltration capacity, water budgets, soil fauna and soil texture. Methods to assess these parameters included visual inspection, observation, quantitative biological diversity surveys, continuous monitoring, and soil compaction and infiltration testing. The following is an overview of these performance indicators and the different assessment methods employed to measure those indicators to gauge rain garden effectiveness.

<u>Ponding, Drawdown and Bypass Performance Indicators</u>

Several studies incorporate measured overall infiltration capability in assessments of function (Davis, 2008; Hatt et al., 2008; Tang et al., 2015; Li et al., 2009; and Schlea et al., 2014). In each of these studies, the facilities did perform the intended functions, such as: flow reduction, peak attenuation, peak delay, infiltration, exfiltration (infiltration into native soils or an underdrain), evaporation and evapotranspiration. Some facilities have been shown to cease infiltrating or fail to infiltrate as expected (Asleson et al., 2009) citing lack of maintenance as a likely cause that may have led to sediment build up and clogging of soil porosity. In at least one study, the conclusion was reached that rain gardens performed better than they were designed to (i.e. overflowed less frequently and handled larger storm events than expected) (Jennings et al., 2015).

Methods described in the research and "operations and maintenance" literature for monitoring hydrologic effectiveness range from observational site visits (low level of monitoring effort in Welker et al., 2013 and Seattle Public Utilities, 2009) to continuous monitoring of real-world storm events (Hatt et al., 2008; Welker et al., 2013; Li et al., 2009) to simulated storm events and artificial drawdown tests (Asleson et al., 2009; Schlea et al., 2014) and smaller-scale infiltration testing (Asleson et al., 2009, Schlea et al., 2014, USGS, 1963). Some observable factors provide clear indications of rain garden failure because they are synonymous with rain garden failure such as: Presence of ponded water for a prolonged period after a rain event, hydric soils, wetland obligate vegetation, or failing vegetation (Asleson et al., 2009). Each method is described below.

Observational Site Visits: Direct hydrologic observations include: presence of ponded water 48 hours or more post- rainfall event and observation during rain events of overflow/bypass or failure of runoff to reach the site/inflow point. For each of these methods, it is worth noting that the element of timing in relation to storm events is critical and adds a significant element of unpredictability and therefore likely expense for timing sensitive observation methods. Assessment of hydrologic failure through observation of related impacts include: presence of wetland obligate vegetation (volunteer/unplanted), poor health of planted vegetation, presence of hydric soils, visible erosion or scouring within the facility or at its overflow, and presence of sediments in inflow or the facility's bottom area. These indirect measures of failing hydrologic performance do not rely on specific timing other than taking into account recent overall weather and seasonal factors that might affect the appearance of plant health.

Continuous monitoring of real-world storm events: The increasing prominence of autonomous electronic monitoring equipment (e.g. sensors and dataloggers) and the detailed data that it can produce make continuous monitoring of a feasible option. Most such data provide information on ponding depth and drawdown times, frequency and duration of overflow/bypass events (and thereby an estimate of how much stormwater is not detained or treated by the facility), and often also include rainfall monitoring (e.g. Dietz and Clausen 2005, Li et al. 2009). No information on causation for poor function or failure is readily extracted from these measures and some amount of data processing and analysis is needed to determine how much water the facility treated vs. how much bypassed the system. There are varying levels of expense, time/labor and expertise for the equipment itself, its proper installation and calibration, data processing and accuracy for these methods.

Artificial Drawdown Testing: Testing the hydrologic function of rain gardens is most thoroughly done using controlled experimental designs wherein realistic rainfall conditions are simulated using large volumes of water during dry-weather conditions (Anderson 2011; Aselson et al 2009). These methods, while effective at demonstrating hydrologic performance of individual facilities, require large volumes of water (either from portable cisterns with gas-powered high-volume pumps, or fire hydrants fitted with flow-control devices and authority from local fire departments).

Small scale infiltrometer testing: Infiltrometers are typically a very simple apparatus consisting of a length of pipe that is inserted a specific depth into the soil that will be tested (sometimes two concentric pipes are used to further limit lateral dispersion and capture data just for vertical infiltration). The infiltrometer is filled with a specific volume/height of water and the time for that water to infiltrate is recorded. While some variation can be observed between infiltrometer test sites within a single site, averaged infiltrometer results are generally predictive of hydrologic function or failure in rain gardens (Asleson et al., 2009). Several measurement devices exist, including five that were tested by Asleson (2007 presentation summarized in MPCA 2016; Asleson et al., 2009); these include mini-disk infiltrometer, tension infiltrometer, Guelph permeameter, modified Phillip-Dunne (MPD) permeameter/infiltrometer, and double-ring infiltrometer. The MPD infiltrometer was preferred by Asleson's 2009 study (for cost, ease of use and replicability). It consists of a thin-walled (2mm) aluminum pipe of 10 cm diameter that is 45 cm high, pounded 5 cm deep into the rain garden soils. When artificial drawdown flood testing was conducted, results from each of the tools tested underestimated whole rain garden infiltration rates by 2.7 times (infiltrometers measured 1 inch per hour infiltration or less, while drawdown testing demonstrated 2.71 inches per hour across the entire rain garden). It is worth noting that small-scale infiltrometer testing primarily tests the infiltration rates of the amended soils within the rain garden which should consistently have good infiltration (Hinman, 2012), while the subsoil or underlying native soils' ability to infiltrate are not necessarily assessed with these tools post construction.

Peak Stage Monitoring: The City of Seattle identified a simple overflow monitoring approach which is to embed a bottle in a pipe with the mouth positioned at the same level as a rain garden overflow. Presence of any water in the bottle indicates that runoff is leaving the rain garden through the overflow, thus indicating a bypass of infiltration and water treatment (Hutchinson, 2016). This method provides binary information (Y/N), but does not indicate the specific volume of water that overflowed.

The following table provides an overview of several hydrology monitoring approaches.

Table 1: Summary of Ponding, Drawdown and Bypass Performance Indicator Methods

Method Description	Reference of hydrologic function	Level of specialized training and/or specialized equipment	Does method simultaneously identify causes and/or treatments for failure?	Citations
Infiltrometer testing	Asleson et al., 2009). But results vary a lot within a single rain garden and only matched	Training: moderate. Equipment: not expensive.	Indicates rate of infiltration thru BMP soil (not subsoil). Does not identify	Asleson et al., 2009; USGS, 1963
Artificial drawdown/ simulated storm	Schlea et al. 2014. Whole facility	Training: varies depending on methods.	No	Asleson et al. 2009; Schlea et
Inflow/Overflow/ ponding. Continuous monitoring (often linked with artificial	Hatt et al., 2008 & 2009. Depth of water or flow rate	Training: high for installation, data collection and analysis. Equipment: expensive.	No	Hatt et al.. 2008 & 2009; Jarden et al., 2015; Li et al., 2009; Schlea et al.,
Peak Stage Monitoring	Hutchinson, 2016. Overflow occurrence	Training: moderate for installation and monitoring. Equipment: inexpensive	No	Hutchinson 2016
Size (for rain gardens only)	Brown et al. 2011.	Training: limited Equipment: inexpensive	Size can be a cause of failure and is a factor in ponding, drawdown and bypass function	Brown et al. 2011; Stander et al 2010; Luell et al. 2011

Size as a Performance Indicator:

Brown et al. (2011) found that the size of the constructed rain garden ponding area had the greatest impact on rain garden performance, given that undersized rain gardens caused more frequent overflows. Size recommendations for rain gardens are anywhere from 3 – 43% of the associated drainage area, as determined by soil type, site slope, drainage rates of the native soils, and regional climate and rainfall patterns. In general, the finer the soil texture, the larger the rain garden needs to be (Stander et al 2010). Greater media depth increases exfiltration (i.e. infiltration to native soils beyond/below the excavated area of the rain garden itself) and decreases stormwater overflow, however increased organic content seems to reduce porosity. Luell et al. (2011) found that even undersized rain gardens can provide valuable water-quality benefit and flow attenuation and perform better than predicted. Post-construction measuring of rain garden size did not seem to be a common monitoring activity, despite the importance of size for infiltration and water treatment functions. Since bioretention facilities are modeled using infiltration area, ponding depth, pool area, bioretention soil mix depth and native soil infiltration rate, size is not considered a good performance indicator.

Soil Biota Performance Indicator:

The potential role of abundance and diversity of soil fauna in assessing infiltration and water treatment functions for stormwater treatment seem to have been largely ignored (Mehring et al., 2015). Benefits provided by a rich and diverse soil fauna include:

- Improved infiltration: Earthworm burrows increase infiltration 2 to 15 times, while termite, ant, millipede, wasps and bees also have beneficial impacts.
- Plant growth and nutrient uptake: Bioturbation by soil fauna produce a soil matrix that helps plant roots expand and become denser. “Some species of earthworms have been shown to enhance plant uptake of nitrogen and phosphorus in vertical flow constructed wetlands by as much as 216% to 355%, respectively” (Mehring et al., 2015, p. 1449). Soil fauna can also encourage beneficial mycorrhizae.
- Particulate organic matter processing: Many soil organisms “are adapted to feed on large organic particles including leaf litter” (Mehring et al., 2015, p. 1450) which makes associated nutrients available for plant uptake. They can enrich soil mixture and plant growth.

There are some areas where the beneficial impact of soil fauna to rain garden performance is uncertain. The net benefit of soil organisms' role in retaining and removing nutrients through their lifecycle is one area. While soil organisms do store carbon, nitrogen and phosphorus in their bodies, the decomposition process releases nutrients back into the system. Nutrients can be more easily accessed by plants in this form. In addition, the increased infiltration caused by burrowing can often lead to macropores that create quicker pathways for nutrients to travel through the rain garden soil and subsoils. Removal and retention of pathogens and heavy metals are also uncertain. While soil fauna can accumulate and process several metals into basic elements or somewhat altered compounds, they can also physically leave the rain garden system and take those materials with them (Mehring et al., 2015). The rain garden characteristic that most aligned with invertebrate presence was leaf- and plant-litter depth (Kazemi et al., 2009). Leaf-litter layers provide refuge during disturbance and shelter against predators. A second predictor of invertebrate presence was facility size, although this variable was most likely an indicator of the increased plant types and habitat units associated with larger rain gardens. Age of facilities was the third factor that correlated well with increased invertebrate presence, with older rain gardens being associated with larger and more stable populations of soil fauna species. Maximum invertebrate biodiversity was attained “when a relatively higher number of plant taxa are combined with greater leaf/plant litter depth and lower mat cover percentage” (Kazemi et al., 2009, p. 310). (The ‘lower mat depth’ refers to geotextile or geotextile-like material used in some facilities). An additional observation about invertebrate biodiversity was that it increased towards the center of the rain gardens, and was least diverse at the edges. Kazemi et al. (2009) suggest that creating rain gardens with larger, rounder footprints that minimize edge and maximize internal rain garden space can positively impact soil fauna presence. The seasonal fluctuations of soil fauna densities also complicate the use of soil fauna as an indicator.

Mehring 2015 recommends more research on determining the factors (such as soil-media specifications and surrounding land use) affecting variability in organismal abundance. Pitfall traps were the only methods used to assess invertebrate diversity in rain gardens, based on the limited studies on this topic. The trap was set in summer and left for five days, with the rim located at ground level. Dead invertebrates had to be sorted from leaf litter and other organic debris and mud. All species were sorted at least to order level and family level on most. Pitfall traps only gather those creatures that move along the surface of the soil, rather than living entirely within the soil matrix.

An alternative soil fauna sampling method, the Brelese trap, was identified by University of Washington professor Dr. Evan A. Sugden (2016 personal conversation). These traps allow for collection of in-soil fauna by taking soil samples, which are then left in a lab setting exposed to adverse conditions (light), which force the in-soil fauna to evacuate the soil into a specimen jar. These traps can be quite inexpensive and small, provide mostly clean samples, and can be sorted based on a diagnostic guide that Dr. Sugden created.

The main question with soil fauna is whether or not there is a strong enough correlation between diversity and/or abundance and rain garden performance and function. At this point, the research is incomplete. This could be an opportunity to draw correlations between soil fauna and other indicators of rain garden performance; however, it is not currently as well understood an indicator of rain garden performance as other factors.

Soil Compaction and Texture Performance Indicator:

Infiltration rates of soils in rain gardens and bioretention facilities are the primary indication of performance. Infiltration rates can be impacted negatively by improper or insufficient pre-installation infiltration analysis, siltation, decreased porosity, and soil compaction over time. Despite recommended soil mix and depth design specifications, as built rain garden conditions do not always match those BMPs as materials used and depth of soil media may deviate from recommendations. Soil compaction during construction can reduce soil infiltration (Pitt, 2002). Soil mix composition and depth may not be appropriate for the facility’s drainage area. Over time, there may also be changes in the amended soils as is evidenced in urban soils. (Pitt, 2008)

Soil compaction is defined as increased density and a reduction in pore space size within the soil matrix. “Although depth to soil compaction is not a substitute for direct measure of infiltration, it can be a satisfactory survey tool to screen sites” (Yergeau & Obtropta, 2013, pg. 1236). Based on an assessment of 41 sites in multiple counties, aged from 1 – 6 years old, it was determined that age of rain gardens “may not be a strong factor in determining the levels of soil compaction…” (Yergeau & Obtropta, 2013, pg. 1236), although more research is required.

Effective infiltration requires permeable soils; however, soil compaction can reduce rates of infiltration. Compacted soils occur as there is “an increase in to soil bulk density and a reduction to smaller-sized pore spaces with the soil matrix" (Yergeau & Obtropta, 2013, p. 1233). "While much of the change of runoff volume has been associated with the decrease in surfaces available for infiltration, urban soils also undergo major modifications that result in increased runoff" (Pitts et. al, 2008, p. 653).

Construction practices that compact soils can increase bulk density and also reduce infiltration rates by 70 to 99 percent (Gregory et. al, 2006). Compacted clayey soils are more susceptible to reduced infiltration rates than compacted sandy soils, although both still experience significant reductions (Pitts et. al, 2002). A Rutgers study (Yergeau & Obtropta, 2013) did soil compaction assessments, however none of the rain gardens assessed had engineered or compost-added soils. No soil compaction studies were found in rain gardens with soil amendments, a unique Pacific Northwest design feature.

Given that soil compaction is well correlated with infiltration capacity of a rain garden (Yergeau et al., 2013), a study showed that a handheld static cone penetrator was a suitable instrument for field-based assessment of rain garden soil compaction. Researchers took 10 readings per rain garden, using a 300 psi threshold for measurement. At that 300 psi threshold, the depth of compaction was measured (Yergeau & Obtropta, 2013). In the same study, redox potential was also assessed as an indicator of pollutant removal since redox potential is well correlated with processes like nitrification, sulfate reduction and methanogenesis. Whether or not it is worthwhile to do soil compaction studies in the amended rain garden soils in different aged rain gardens is uncertain. The Rutgers study was not continued, although Rutgers University Ocean County Extension has trained local Master Gardeners to assess soil compaction in non-rain garden residential landscapes, using a penetrometer (Yergeau, 2016).

Soil texture is the most common variable assessed in rain garden performance. In studies conducted by Asleson (2007) and Yergeau & Obtropta (2013), soil texture was shown to correlate with infiltration rates, soil-compaction levels, organic content and overall aeration. Asleason, 2007, used the "Four-level Assessment Method" assessed soil texture using USDA soil textural classes that are correlated with hydraulic conductivity (Asleson, 2007, Table 3.1, p. 7). As percentage of fines increase in the soil matrix, soil compaction increases, thus reducing porosity and the infiltration functioning of a rain garden. Yergeau & Obtropta (2013) employed the Feel Method (Thien, 1979), collecting 25 grams of soil from 2 to 4 locations within a rain garden. Once the soil was wetted, it was run through fingers to estimate texture based on a flow chart provided to assessors. The "Feel Method" was deemed inconsistent and was not recommended. A more rigorous method to quantifying percent of silts, clay and sands was recommended but was not identified. Since that time, they have use labs to assess soil texture (Yergeau, Personal Communication, 2016). Washington State University soil scientists had a differing view, that with training and a soil texture chart, any field assessor can accurately determine soil texture (Coggers, 2016; Collins, 2016)

In one study, researchers also evaluated soil color (in comparison to Munsell Soil Color Charts) to determine if hydric (non-draining) conditions existed. The field assessors gathered a 47-inch soil core to characterize soil texture variability to that depth (Gonzalez-Merchan, et al., 2014). No meaningful conclusions were found.

Vegetation Performance Indicator

Background: The value of vegetation in rain garden performance relates to its ability to create macropores, which help to maintain soil porosity (Gonzalez-Merchan et al., 2014) and likely do so via cycles of root growth and senescence (Hatt et al., 2008). For one two-year old, multi-celled rain garden, evapotranspiration seemed to be a low percentage of total runoff reduction (3 percent in annual water balance). Exfiltration (intended effluent) was a much greater factor (Brown, 2011 and Li et al., 2009). Older rain garden water budgets were not found.

Bare ground had a relatively constant infiltration capacity through all seasons, while vegetated sites had great seasonal variation in infiltration and greater infiltration than bare ground at all times. "During summer, the stems and roots present a development and an extension through the sediments, probably allowing creation of the preferential flows that could explain the improvement of the infiltration capacity" (Gonzalez-Merchan et al., 2014, p. 5423). Vegetative dormancy periods had infiltration rates that were 2 to 4 times lower than during vegetative growth periods (Gonzalez-Merchan et al., 2014). Vegetative dormancy periods roughly match the greatest periods of stormwater runoff in the Pacific Northwest (November through February).

All plant species do not treat pollutants or encourage infiltration equally. It is believed the grasses' "growth mode by horizontal and underground stems could keep the soil more porous and permeable". There was no research found that compares soil-building qualities of Pacific Northwest weedy plant species to native or commonly deemed desirable species (Gonzalez-Merchan et al., 2014, p. 1522).

Australian research has found that some plant species are better able to absorb nutrients than others (Bratieres et al., 2008). In all cases, vegetated plots did a better job removing total nitrogen (TN) and NOx (composed of nitrate and nitrite compounds) compared to unvegetated plots. Of the species examined, *Carex appressa* provided the best removal capability for total phosphorus, filterable reactive phosphorus, TN and NOx, with performance improving over time. Water absorptive capabilities also improved over time. The root structure of this sedge is very fine and dense, providing a great deal of surface area for water and nutrient uptake.

Metaleuca ericifolia is a species that showed a 70 percent increase in removal of Total Nitrogen over time. A mycorrhizal fungus was found associated with this species and root growth expanded during the improved filtration periods, reinforcing the idea that root presence and extent are important for optimal filtration performance. Other species studied did not demonstrate such strong pollution-removal capacities (Bratieres et al., 2008).

Vegetation Monitoring Approaches: Current vegetation monitoring for rain garden performance is often focused on survival of planted vegetation, plant health and percent coverage. The three field-based assessment methods reviewed inferred a correlation between a decline in plant species diversity, the vegetation's condition, an increase in unplanted weedy species, and/or a reduction in percent coverage as indicative of a rain garden that is not functioning properly (Aselson 2007, City of Seattle 2009, and Duwamish Infrastructure Restoration Training, undated). A Washington developed checklist allows surveyors to record percent cover by species, native and non-native (Duwamish Infrastructure Restoration Training, undated). Seattle Public Utilities (2009) has developed a pictorial guide for assessment of the vegetation community.

Asleson's Four-level Visual Assessment that was developed in Minnesota includes the age of the site, time of growing season, species present and their growing habits, and conditions of the site (Asleson, 2007). It was qualitative, with vegetation health assessed by "poor to good" descriptors. In one instance, a site received a "poor" rating because of the state of the tree canopy; however, there were perennials and prairie grasses that were growing well.

Turk (2014) developed a ranking metric of plant health ascribing a rank of 1 for dead and non-living matter, and a rank of 5 for plants in excellent condition and exhibiting good color and growth. Plants were stratified by species that ranged from grasses to trees. All plants were grown in tightly controlled laboratory settings. Turk's (2014) methodology resulted in a quantifiable and arguably a more accurate description of health of individual species across the rain gardens.

These approaches may not factor into account that some plants are more beneficial to rain garden and bioretention facility function than others (Gonzalez-Merchan et al., 2014 and Asleson, 2007), including some invasive weeds. "The fact that certain plant species have a significantly different effect on nutrient removal … challenges the concept that biofiltration simply needs to be 'vegetated' to be effective (Bratieres et al., 2008, p.3935). This emerging body of research is not currently reflected in guidance for rain gardens in the Puget Sound region. These findings indicate that vegetative coverage, as compared to bare ground, is a good indication of infiltration and water quality treatment functions, however there is a greater need to understand the functional effectiveness of individual plant species intentionally placed into and / or colonizing Pacific Northwest rain gardens.

Gara and Stapapin (2015) presented a summary of the different vegetation indices that are available in different parts of the country, and evaluated those used in the Midwest. These indices were used as ways to assess the habitat functions in which the vegetation communities were found, such as natural or created wetlands. To utilize the methods presented by Gara and Stapapin in a rain garden or bioretention setting would presume that a process of natural succession is correlated to overall function and effectiveness of rain gardens, which does not match well with the fact that such designed and/or engineered sites often are intentionally managed for species composition (i.e. weeded), some are intentionally made into monocultures or manicured for aesthetic purposes. This is not likely to be an appropriate measure of the vegetation indicator given the artificial conditions and lack of natural succession allowed in rain gardens.

Water Chemistry Performance Indicator

In rain gardens with an underdrain as well as soil columns or rain garden "microcosms", runoff that has passed through rain garden soils and plants has been collected and measured for water quality and compared to the water quality before passing through the rain garden soils (e.g. Bratieres et al., 2008; Brown and Hunt 2011; Davis 2007; Dietz and Clausen 2005; Hatt et al. 2009). These methods require access to water below the amended rain garden soils as well as laboratory processing of before and after samples. Results are significantly affected by the initial quality of the water (i.e. % removal in more highly contaminated water is often higher than when cleaner water is used). Across several studies, rain garden soils are considered effective at reducing hydrocarbons, metals, and total suspended solids but results for nutrients are more variable and export of nutrients can occur at least during some initial period following installation (Davis 2007; Dietz and Clausen 2005; Hatt et al. 2009). These water chemistry-based monitoring approaches do not seem suitable for a volunteer based assessment protocol for all types of rain gardens and bioretention facilities found in the Pacific Northwest due to the required below-ground infrastructure, high cost of lab tests and / or the short window for water collection during storm events.

Multiple Performance Indicator Methods

Three assessment protocols reviewed used multiple performance indicator categories. The first was a four-level rain garden assessment protocol developed by the University of Minnesota (Asleson et al. 2007), including a field-based visual evaluation. The visual evaluation was designed to estimate infiltration effectiveness based on soil texture and inspecting a checklist of attributes to determine if any type of rain garden maintenance was required. Those attributes included vegetation, soil, condition of inlets and overflow structures, overall appearance of the site, and photo records. All assessments began with review of design and plant lists. A Capacity Test was conducted that used permeameters and infiltrometers to make infiltration measurements in the rain gardens (Asleson et al., 2007). It is unclear if all of these visual factors were indicators of rain garden function, however several, by definition, are accepted as visual signs of rain garden failure (ponded water, blocked inflow, hydric soils and wetland obligate plant species) (Gulliver et al. eds., 2010; Asleson et al., 2009; Seattle Public Utilities, 2009; Welker et al., 2013).

The second rain garden visual site assessment is intended to help assess maintenance needs and relies heavily on pictures to consistently differentiate conditions and quality despite differences in field observers (Seattle Public Utilities, 2009). A third assessment collects species lists and percent coverage (native and non-native), infrastructure condition, soil quality and a qualitative assessment of concerns (Duwamish Infrastructure Restoration Training, undated).

The final research design reviewed placed five 50 cm x 50 cm quadrats along a single belt transect, which bisected a rain garden, to evaluate ten habitat factors related to biodiversity as indicated by terrestrial invertebrate coverage. The habitat factors included site age, amount of gravel, percent coverage of any geotextile-like mat, plant biomass, leaf litter depth (at two random points), plant diversity (in three groups), pH, electrical conductivity, grammoid (sedges, rushes, lilies and grasses) percent coverage, number of plant taxa, and substrate texture. There were two edge quadrats (within 50 cm of the rain garden edge), one center quadrat and two quadrats between the edge and the center, on either side (Yergeau & Obtropta, 2013). The belt transect may provide a structure for standardizing and anchoring western Washington rain garden assessment methods.

Field Assessment Recommendations

Multiple field assessment methods for rain gardens have been tried and evaluated, including some that require laboratory analyses. Following is a description of the recommended methods and indicators for the western Washington Rain Garden and Bioretention Assessment Protocol. Specific recommendations are identified in the Master Checklist (Appendix 1).

Proposed Research Questions:

1. What attributes of rain garden/bioretention functionality measured by volunteers and staff through visual observations and simple field or lab tests correlate best with functional success of the system?
2. What construction activities and maintenance actions identifiable by volunteers and staff have the greatest correlation with functional success of a rain garden/bioretention facility?
3. What attributes of rain garden/bioretention facilities correlate best with landowner perceptions of functional success, as measured by volunteers and staff through surveys and interviews?

To further refine these questions in the protocol, based on what was learned in the literature review, several specific questions have been identified for the Rain Garden and Bioretention Assessment Project field assessment.

- Does the facility infiltrate stormwater during storm events?

- Is the facility supporting plant growth?
- Do existing vegetation community conditions create enhanced green spaces?
- How well do soils parameters measured reflect infiltration conditions?
- Are facility conditions conducive for soil fauna? (worm, insects, bees)
- Do site design, construction and maintenance activities correlate with other signs of rain garden success?
- Does the facility offer community value to neighbors and passersby?
- Does the facility age correlate with other signs of functional success and community acceptance?

Assessment Schedule and Locations: There will be a two phase pilot period with 15 rain gardens spread over four counties assessed in Fall 2016 and 40 sites over five counties assessed in Spring 2017. In Fall and Spring, each site will be visited by two independent teams of up to four volunteers, contractors or municipal staff. A variety of sites will be identified of various ages, engineering, size and type. The project will include bioretention sites that are being monitored through an RSMP City of Bellingham project, measuring continuous hydrology. A data repository as well as analysis methods will be defined once assessment protocols are completed.

Performance Indicator and Assessment Recommendations:

Methodology: The field assessments will include conducting a visual inspection with specific quantitative and qualitative reply options on visual clues of infiltration, size measurements, vegetation health and weed prevalence, conditions of inflow and overflow structures, vegetation community coverage, bare ground coverage and public amenity value. Extent of use of design, construction and maintenance guidance will be incorporated into the visual checklist. The methodology will also include establishing sampling locations for soil-texture analysis, penetrometer readings and species-specific vegetation percent coverage. To the extent possible, project sampling should include collecting site and design data prior to sampling to compare to as-built conditions.

Soil: Soil Texture Analysis should be completed, using a Soil Texture Chart to determine predominant grain size, with a percentage of samples being replicated by soil samples sent to a lab for processing, for quality control purposes. It is necessary to determine the number of analyses needed based on the size of a particular rain garden, and recommended depth at which samples are taken for texture analysis. To make soil compaction assessments worthwhile, it will be necessary to first determine if there are existing rain gardens in which soil amendments have not been added, or if it is worthwhile to assess soil compaction in rain gardens with amended soils as they age. Conducting soil compaction assessments would require an equipment purchase and a potential check-out process for volunteers. Additional research should be gathered to explore if there are less expensive yet high quality soil compaction- assessment techniques and possibly conduct both at field sites to determine relative efficacy.

Drawdown / Ponding: Of those assessment methods discussed, only observational methods and review of design elements appear to be of high value for inclusion in the assessment protocol. Observation should include inflow and overflow structures, and clear indications of failing hydrologic conditions, including dead vegetation, standing water more than 48 hours after a storm event, bare soils, channelization away from inflow and visible algae or algae crusts. Design elements to review include contributing-area size in relation to rain garden infiltration area, retention volume (volume of the rain garden), as-built conditions of those features, and infiltration rate of underlying native soil (referring to infiltration testing done at the time of design). Small scale infiltrometers should not be included in the protocol because findings appear not to predict whole rain garden performance accurately (MPCA, 2016). Peak Stage Monitoring could be conducted in the first pilot round to detect/confirm overflow events. The monitoring bottles would need to be fabricated and placed in the rain gardens ahead of sampling (Hutchinson, 2016).

Vegetative Coverage: Collect quantitative data on presence or absence of a select group of wetland species (to be identified), percent coverage of different classes or actual species of both intended and weedy plants, as well as bare ground. Visual assessments could include a *Likert '1 to 5'* "beauty scale," whether or not the plant community seems healthy as a whole.

Soil Fauna Presence: Deprioritize soil fauna presence monitoring as there is too little background research to correlate results with rain garden performance. To add to the understanding of rain gardens, leaf litter depth, geotextile mat coverage, and rain garden shape could be included in the visual inspection. Future research could include conducting invertebrate trapping with Brelese Funnel Traps, species keys, with Master Gardeners and other volunteers processing the samples.

Community Value of Rain Gardens: Visual assessments will include categories that reflect the believed value of rain gardens to communities, discussed below in Community Perspectives, such as quality of vegetation canopy (dead or alive, healthy or not), ease of access, wildlife, educational signage or materials, and attractiveness when compared to lawn.

Review of Literature: Community Perspectives

Research Purpose

An important element of the Rain Garden and Bioretention Assessment Project is to better understand landowner and community values about rain gardens and how that impacts rain garden installation and maintenance practices. While municipal staff may perceive rain garden functions solely in terms of infiltration and water treatment, private landowners may perceive rain garden functional success as something else entirely, thus impacting their willingness to follow design, construction and maintenance guidance.

The driver for the community perspectives research stems from the belief that long-term rain garden maintenance and installation in residential communities largely falls to private landowners. To better understand how to increase installation and improve maintenance guidance implementation, municipalities and community groups advocating rain gardens must better understand the values and attitudes of landowners. In short, "…people will act in accordance with their mental picture of a situation. That is, people are willing to take action, if that action is believed by them to be connected to a viable solution to a problem that they believe is real. The key is to look at these elements – problem, solution, action – from the point of view of community members. They are the ones who will be called to action" (Elway Research, 2009, pg. 1).

The primary research is to assess landowner and community perspectives on rain garden and bioretention value, and what landowners consider success. To inform this effort, Puget Sound-based social marketing research reports were reviewed to glean any information on the attributes of landscapes valued by landowners. Additional information was captured about their environmental views and knowledge levels. Research designs were also noted and are shared below.

Community Perspective Findings

Puget Sound Resident's Stormwater Knowledge and Willingness to Act:

Most residents think the quality of the water in and around Puget Sound is good. However, there has been a slight increase in the number of those residents who have a sense of extreme urgency to clean up and protect those same waters since 2012 (19 percent to 24 percent) (PRR Inc., 2015). Fifty-two percent of Puget Sound residents recognized that stormwater pollution is a regional and local problem, with many identifying the need to forego yard chemicals as a solution.

There is, however, still a lack of understanding on the scale of the problem at the regional level. Moreover, the same study found that residents were motivated to act upon learning that most stormwater systems do not remove pollutants. They would much rather change behavior than pay for clean-up. Keeping families healthy and safe, specifically protecting children and pets, continues to motivate behavior change. People want to be given something they can do that will fix or ease a problem, especially when the problem is discussed at a local level. At the same time, residents were still confused by terms like stormwater and runoff (Elway Research Inc., 2009).

Positive Views of Rain Gardens

Private landowners state rain gardens had positive impacts on their communities and properties. In one case, 86 percent of surveyed landowners with rain gardens in Seattle, WA stated that they had very positive feelings about their rain gardens (Vowels, 2013). In that same study, 100 percent of surveyed landowners stated that their rain gardens evoked neighbor responses that were either inquisitive or positive. In a Portland, OR neighborhood with rain gardens, a study found that 74 percent of residents surveyed thought these types of facilities were a good idea, while 9.5 percent had only negative views on them. The majority of surveyed neighborhood participants had noticed or heard about rain gardens (Church, 2015).

The variety of reasons for the positive views of rain gardens can be grouped into the following four categories, and can be viewed as landowner motivators. These views also mirror Puget Sound-based research on how residents value their own property and definition of quality of life.

Beautify Yards and Neighborhoods: The perception that rain gardens can green up communities and beautify yards seems to be a primary community definition of success for rain gardens and is also a highly valued aspect of a private landscape. Nine out of ten landowners in one watershed preferred "…the aesthetics and environmental benefits of diverse plants…," even though most of them still had lawn (Murphy et al., 2016, p. 2).

The sense of beauty needs to fit into how a landowner wants to engage with his/her yard such as entertaining, maintaining views, wildlife viewing, gardening for food or flowers, personal enjoyment and/or seeking privacy (Pierce ECO Net, 2013; Bertolotto, 2013; Roesch, 2012; Hardwick Research, 2013; PRR Inc., 2013). The ability of big plants to create shade had a mixed response. However, the lack of big trees in most rain gardens makes this less of an issue. In one study, one-third of study participants found rain gardens to be a break from the monotony of a built environment, while some other residents found them to be monotonous and unimaginative (Church 2015), which serves as a reminder of how highly personalized humans' sense of beauty can be. Two studies further noted that beautiful landscapes also have the positive result of increasing property values and encouraging neighbors to keep their yards better maintained (WSU Mason County Extension, 2013; Hardwick Research, 2013).

Preventing Flooding: In Seattle, WA, 100 percent of participating land owners who had experienced flooding in the past found some level of reduction when they installed a rain garden (Vowels, 2013). Another study indicated that neighborhood residents found that frequency and/or levels of basement flooding were also reduced (Church, 2015).

Creating More Welcoming and Friendly Neighborhoods: What defines a "welcoming and friendly neighborhood" can vary widely based on personal tastes. However, several attributes were identified that explain why communities felt rain gardens enhanced their neighborhoods, including:

- Bringing communities together (Resource Media, undated) by residents walking more and being more friendly (waving, saying hello) with their neighbors (Dill, 2010), as well as sparking conversations about the rain gardens themselves (Vowels, 2013);
- Increasing desirable wildlife habitat for viewing and enjoyment (Church, 2015; Resource Media, undated) which is mirrored by Puget Sound quality-of-life values (Roesch, 2012, Hardwick Research, 2013; WSU Mason County Extension, 2013);
- Providing traffic calming (Church, 2012);
- Providing connections with and access to nature in more urbanized settings, mostly attributed to the addition of plants to streetscapes (Church, 2015).

Help the Environment by Keeping More Pollution Out of the Water: There is an environmental motivation for many private landowners to take on recommended garden practices, such as planting trees or adopting natural yard-care techniques (Pierce ECO Net, 2013; WSU Mason County Extension, 2013) and installing and perhaps maintaining rain gardens (Murphy et al., 2016; Resource Media, undated; Church, 2015). The City of Portland, OR combined their installations of rain gardens and other Green Stormwater Infrastructure (GSI) with educational signage, resulting in an increased understanding of the value of the natural stormwater filtration system and the benefits of rain gardens to stormwater pollution reductions (Church, 2015).

How well this information is received by community members depends on how it is shared. Research shows that it is important to use local place names rather than generically mentioning lakes, streams, etc. Sharing specific facts about local pollution impacts and sources can increase resonance and reception. Use messages and imagery that relate the value of what rain gardens do for people (families, children, or pets) first and the environment second. Focus on the end result rather than how rain gardens work. Sample language includes "keeping Pacific Northwest iconic waters clean and our communities thriving" (Resource Media, undated, p. 3).

In short, Resource Media summarized what moves people to create rain gardens. "The public is far more inclined to support GSI if it is framed as a way of greening yards and communities while keeping pollution out of the Sound, rather than a way of restoring it to health" (Undated, p. 5).

Negative Views of Rain Gardens

Private landowners and neighbors do articulate some negative values about rain gardens and neighborhood bioretention facilities. High levels of maintenance are universally considered drawbacks to any landscape addition (Murphy et al., 2016; PRR Inc., 2013; Bertolotto, 2013). Of the rain garden owners in Seattle who responded to a survey, all indicated a need to conduct maintenance on their rain gardens, including the following activities: weeding - 100 percent; mulching - 63 percent; removing trash - 52 percent; watering - 26 percent; removing sediment - 26 percent; replacing plants - 22 percent; replacing ground covers - 18.5 percent; and fertilizing - 15 percent (Vowel, 2013). An additional potential drawback is pressure from neighbors to conform to certain landscape expectations (WSU Mason County Extension, 2013).

Rain gardens and bioretention facilities s can collect litter, decrease community safety and reduce street parking. Additionally, some survey participants expressed doubts that they actually work. Some also felt the rain gardens in a street-scape were boring and unattractive, and can even result in displacing emblematic neighborhood plants, such as the roses of Portland, OR (Church, 2015). These comments were shared, but not consistently or frequently.

Additional concerns were raised about particular types of plants, and trees in particular. Puget Sound community research includes these concerns:

- Vegetation can block desirable views and also block views of children at play;
- Plants can be messy;
- Some yards don't have room for trees or other bushy vegetation; and,
- Some plants can trigger allergic reactions (Bertolotto, 2012; Hardwick Research, 2013).

There are anecdotal stories shared by some rain garden proponents that additional negative perceptions of rain gardens exist, such as fear of drowning, fear of mosquito breeding and fear of basement flooding. While these observations were not found in the literature reviewed, it is possible that the list of negative views of rain gardens is incomplete.

Community Survey Methods:

Several social research methods were used in the studies described above. Some used written surveys with a variety of types of questions such as multiple choice, short answers and clustered question types. One survey was in Spanish as well as English. Participants received the surveys based on being known rain garden owners or living in a specific neighborhood (Vowels, 2013; Dill, 2010). Another method was to conduct a large number of random telephone interviews, with professional callers. This survey was conducted in one week and reached 800 people (Elway Research Inc., 2008).

Dill (2010) also conducted a walkability study that got direct feedback on personal experiences and views of rain gardens. There was a control area without rain gardens and a neighborhood with rain gardens. This involved a small number of participants—only 12.

Another approach was to develop qualitative, semi-structured interviews with individuals who lived or worked in a target neighborhood (Church, 2015). Recruitment was through posters, newspaper articles, social media, neighborhood meeting announcements, internet advertising, and word of mouth.

Responses were assessed based on a qualitative content analysis that identified emergent themes. Thirty-five households were interviewed (42 individuals) in one target community.

Several Puget Sound-based social research methods involved focus groups. These are normally a very small population size, so it is not possible to generalize responses to a larger community (Bertolotto, 2014; Hardwick Research, 2013; Pierce ECO Net, 2013; PRR Inc., 2014; Roesch, 2012; Snohomish County Surface Water Management, 2012; WSU Mason County Extension, 2013).

Community Perspectives Recommendations:

Research Questions:

At the outset of the Rain Garden and Bioretention Assessment Project, the intended community research was somewhat vaguely defined, allowing room for the literature review to inform the most important work to conduct. Several preliminary research inquiries have been identified community perspectives to further explore through a more detailed set of questions and approaches.

- Are the themes identified in this literature review as common ways the community values rain gardens/bioretention facilities the same here in the PNW?
- How can the community value of these facilities be measured through field observations?
- What are the best methods to incentivize or facilitate neighborhood or landowner implementation of maintenance of these facilities?
- What incentives would increase new landowner willingness to install rain gardens? (assumption that most homeowners are not installing bioretention facilities)
- Do residents know / agree that both facilities are successful in infiltrating water and removing pollutants?
- Does perceived function match actual function as measured by this projects protocol?

Survey Focus:

The reviewed literature seems to reinforce several primary themes of what landowners' value in their own and neighborhood landscapes. Most research is on what landscape attributes landowners' value rather than explicitly about rain gardens. The limited community-based research that does exist on rain gardens is more focused on what motivations/barriers exist for rain garden installation. There seems to be little information on motivations and barriers to care and maintenance.

There are three potential ways to focus the community-based research:

- Test identified themes about rain garden and bioretention value to communities and landowners since several research sources included how Puget Sound-area residents value their landscape in general, and not the facilities in particular;
- Explore how to best incentivize or support implementation of maintenance to these BMPs by private landowners, neighborhood, or local community groups;
- Include additional items in the proposed visual assessment checklist (under "Community Value s" heading above) to determine each facility's ability to meet the expectations of both landowners and the larger community's definitions of success, such as:
  - Are the facilities public or private? What is the access ease? Is there a walkability score? Is vegetation blocking pathways?
  - Are there any educational signs or elements in or nearby?
  - Are any desirable wildlife (or undesirable?) observed?
  - What is the perceived relative attractiveness as compared to residential lawn?

Community Research Methodology:

There are currently over 3,230 rain gardens registered with the 12,000 Rain Garden program, distributed across the Puget Sound region with greater concentrations in the more urban areas. Those private individuals could be sent a survey, both by email and regular mail, perhaps requiring more than one mailing. A small sub-sample of non-respondents will be invited, again, to complete the survey to check how the variation of their responses to those who required less prompting to respond. The survey could be designed to get information specifically from landowners with rain gardens and draw upon examples of other surveys conducted for comparison purposes.

A subset of those landowners could also be invited to participate in semi-structured telephone interviews to go a bit deeper than the paper survey allowed. Landowners who have their rain gardens as part of the field assessment will be explicitly invited to be part of the interviews. There would be a maximum cap of 30 interviews, with the goal of a geographic spread.

In addition, rain garden or bioretention facility "walk-abouts" could be scheduled in two or three target neighborhoods, with targeted invitations to landowners (both with and without rain gardens) to share their thoughts, concerns and needs regarding the rain gardens being viewed. These walk-abouts would serve as outdoor focus-group discussions, with a discussion guide developed that identifies prompting questions. When possible, the facilities visited would also be those that are monitored as part of the Rain Garden and Bioretention Monitoring Project, to determine how well the methodology assesses rain garden success from a community perspective.

Given budget limitations, it may not be possible to do all three elements of this community-based research. If that is the case, the surveys and interviews are recommended.

Literature Review Summary

This literature review has informed several aspects of the Rain Garden and Bioretention Assessment Project.

Created an annotated compilation of the design, installation and maintenance best management practices recommended in the Puget Sound region was collected;

1. Identified several performance indicators that seem most likely to correlate to rain garden and bioretention facility functional success. Soil permeability, soil texture, plant community type and coverage assessment and status of structures, use of mulch and rock, and water presence in the system are best suited for this study. Those performance indicators are captured in more detail in the Master Checklist (Appendix 1).
2. Identified multiple methods and approaches that researchers use to assess rain garden and bioretention functional performance indicators, and the strengths and weaknesses for each as related to creating a volunteer-based, field assessment of functional success. For this project, soil compaction and texture, vegetation surveys and visual observations will be embedded in the pilot study;
3. Revealed four strong themes on how private landowners value landscapes in general and rain gardens in particular, including neighborhood beautification, preventing flooding, creating more welcoming and friendly neighborhoods and helping the environment keep pollution out of waterbodies; and,
4. Identified a glaring gap in understanding how to best incentivize landowner or neighborhood willingness and ability to maintain BMPs on private land.

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Appendix 1: Master Checklist

Rain Garden / Bioretention Effectiveness Assessment Project Goals

1. What attributes of rain garden/bioretention functionality measured by volunteers and staff through visual observations and simple field or lab tests correlate best with functional success of the system?
2. What construction activities and maintenance actions identifiable by volunteers and staff have the greatest correlation with functional success of a rain garden/bioretention facility?
3. What attributes of rain garden/bioretention facilities correlate best with landowner perceptions of functional success, as measured by volunteers and staff through surveys and interviews?

Master List

Project Goal	Project Goal	Project Goal	Overarching Research Question	Function Assessed	Metric Categor	Assessment Methods	Recommendation for Use	Reason for Not Including
X				infiltration / Flow Control	Hydrology	Artificial Drawdown / Simulated Storm Testing	No	Requires access to water surges and very intrusive.
X				Infiltration	Hydrology	Infiltrometer Testing of Soils	No	Results are too variable, literature does not support
X				Infiltration	Hydrology	Continuous monitoring of inflow / outflow / overflow	No	Requires access to modeling equipment
X				infiltration	Hydrology	Bypass/overflow frequency	No	Storm sampling not viable for volunteer assessment
X			Does the rain garden / bioretention site infiltrate stormwater during storm events ?	Flow Control/Infiltration	Hydrology	(From Doug): Measure amount in plastic bottle placed at the same height as the overflow outlet after storm events. (From Curtis): Place data loggers in shallow wells in which volunteers can download data. (From Aaron) Place cork dust in the rain garden and then look for 'bathtub ring' and potential outflow locations, for verification purposes. (From Philomena): Put a rain gauge at each site.	Yes / Limited	Conduct overflow measurements and cork reading in Phase 1 Pilot. Confirm that use of WDOE / Bellingham rain garden sites are collecting water retention data as a data logger would, and eliminate that from our monitoring.

X			Does the rain garden / bioretention site infiltrate stormwater?	Flow Control/infiltration	Hydrology	Visual Assessment (standing water, blocked inflow / outflow, erosion, bare soil, sedimentation), biotic indications of unintended hydrology (obligate plants, bioretention-suited plant mortality, soil crusts, algae)	Yes	Yes, and have common sites with the flow study being led by City of Bellingham
X				Water Quality Improvement	Hydrology	Laboratory-based testing of pH, nitrogen, phosphorus, heavy metals, hydrocarbons, sediment.	No	Requires lab processing.
X				Water Quality Improvement	Hydrology	On-site testing of above parameters in inflow and outflow of a facility	No	Storm sampling not conducive for volunteer program.
		X	Is the facility supporting plant growth?	Infiltration / Neighborhood Attractiveness	Vegetation / Community Perceptions	Plot-based or full site assessment of Percent Coverage of Species, Plant Community	Yes on percent coverage of entire community, full site coverage	
X	X		Is the facility supporting plant growth?	Neighborhood Beautification	Vegetation	Use of Plant Health Indicators (Dead / Alive / Stressed or numeric ranking)	Yes	
		X	Do existing vegetation community conditions create enhanced green spaces?	Infiltration	Vegetation / Community Perceptions	Weediness Percent Coverage	Yes	
X			Are conditions allowing water loving plants to thrive?	Infiltration	Vegetation	Presence / Absence of unintended wetland obligate species	Yes	
X		X	Is the facility supporting plant growth?	Infiltration	Vegetation	Determine Percent Bare Ground Coverage	Yes on percent coverage of each species, full site coverage	
X			??	Water Quality Improvement	Soil	Lab-based soil chemistry tests (pH, cat-ion exchange rate, nutrients, metals)	No	Requires lab processing, expensive.

X	X		How well do soils reflect infiltration conditions?	Infiltration	Soil	Determine Soil Texture in rain garden matrix, using cores at various depths	Yes	
X	X		How well do soils reflect infiltration conditions?	Infiltration	Soil	Determine soil Texture in rain garden sub and surrounding soils, using cores at various depths	Yes	
	X		Do site design, construction, maintenance activities correlate with other signs of rain garden success?	Infiltration/Water Quality	As Built Conditions	Measure Dimension for facility size (gather dimensions at ponding depth for bioretention and top of “bowl” for raingardens)	Yes	
	X		Do site design, construction, maintenance activities correlate with other signs of rain garden success?	Infiltration/Water Quality	As Built Conditions	Presence of Signs of construction compaction (signs of parked vehicles, other compacting uses)	Yes	
X	X	X	Do site design, construction, maintenance activities correlate with other signs of rain garden success?	Infiltration/Water Quality	As Built Conditions	Record Plant Survival of Placed Vegetation	Yes: When plan available	
X	X		Do site design, construction, maintenance activities correlate with other signs of rain garden success?	Infiltration/Water Quality	As Built Conditions	Percent Coverage with Filter Fabric	Yes	
X	X		Do site design, construction, maintenance activities correlate with other signs of rain garden success?	Infiltration/Water Quality	As Built Conditions	Presence / Absence of Gravel Layers	Yes: When plan available	

		X	Does rain garden offer community value to neighbors and passerbys?	Neighborhood Beautification	Community Perception (new)	Presence / Absence Access	Yes	
		X	Does rain garden offer community value to neighbors and passerbys?	Neighborhood Beautification	Community Perception (new)	Use Numeric or Visual Scale for team assessment of attractiveness	Yes	
		X	Does rain garden offer community value to neighbors and passerbys?	Neighborhood Beautification	Community Perception (new)	Presence / Absence Educational Components	Yes	
		X	Does rain garden offer community value to neighbors and passerbys?	Neighborhood Beautification/Habitat	Community Perception (new)	Record signs of/or actual wildlife sightings	Yes	