Bureau of Environmental Services • City of Portland

2013 Stormwater Management Facility Monitoring Report

Sustainable Stormwater Management Program

▪

December 2013

ENVIRONMENTAL SERVICES
CITY OF PORTLAND
working for clean rivers

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Appendix 1

Pollution Reduction Facility Monitoring Criteria 2

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1. Introduction

Stormwater management facilities handle runoff from impervious areas and alleviate potentially negative impacts to the combined and storm sewer systems, and to watershed health. In particular, they can be used to reduce peak flows, reduce runoff volume, and improve water quality. Vegetated facilities are ideal because they not only manage stormwater but reduce impervious area, improve aesthetics, provide a natural biological system that maintains infiltration pathways, and filter stormwater runoff.

Information on how well facilities perform is critical to quantify their benefits, lower maintenance costs, ensure public safety, and improve overall design and function. In particular, information was desired on how well the facilities could reduce peak flows and total flow volume, which have implications for watershed health and regulatory compliance in the combined sewer system. Water quality monitoring is limited but will be increased in the future as budget allows. Sampling of facility soils is also being done to determine if there are any long-term issues with pollutant accumulation.

Monitoring data collected through December 2012 is included in this report. Evaluated facilities are located throughout the city and represent an effort to include a variety of facility types, facility configurations, facility ages, and land uses.

2. Monitoring Objectives

Gathering performance data for stormwater facilities is important to quantify their benefits to sewer and open channel systems, lower maintenance costs, ensure public safety, and improve overall design and function. Monitoring data can also be used in a more direct way, such as in the assumptions used in hydrologic and hydraulic modeling, or in determining the suitability of a facility type at a particular location.

Performance measures include:

1. **Peak flow attenuation** (peak out / peak in) – in particular, provide the expected protection for homes in risk of basement sewer backups in the combined sewer area, and help control erosion in open channel systems.

2. **Flow volume retention** (volume out / volume in) – in particular, quantify the benefit to CSO control in the combined sewer area, or provide flood and erosion control in open channels or storm sewer systems.

3. **Water quality** – determine the impact of the facility on water quality in receiving waters and on overall watershed health.

4. **Soil infiltration rates** – determine the ability of the facility to recover its storage capacity after a large storm event. This is also an important issue for vector control.

5. **Design modifications / improvements** – identify issues that would suggest altering the design of the facility, or the design of future facilities.

6. **Facility sizing** – evaluate the performance of the facility as it relates to the ratio of facility area to drainage area. This includes a comparison to the sizing requirements in the BES Stormwater Management Manual (SWMM) used for new development and re-development projects.

7. **Maintenance** – identify any major issues during the current monitoring period associated with the facility and the vegetation. Recommend modifications that may decrease the amount or frequency of maintenance.

8. **Sediment / soil sampling** – assess pollutant accumulation in stormwater facility soils and compare to screening levels to protect human health and watershed health.

9. **Performance baseline** – test results will build a performance history that can be used to track changes caused by antecedent moisture, seasonal variation, and facility age.

Not all items will be evaluated for each site. For example, water quality sampling is done very selectively because of cost limitations.

The compiled information becomes an important educational tool that advances the City’s interests in sustainable site design, and provides important lessons about the challenges of integrating new technologies given existing City codes, standards, and policies.

3. Types of Monitoring

The type of monitoring performed at each site is based upon resources available and the importance of the information in guiding bureau work.

Each type of monitoring has strengths and weaknesses and no monitoring data are free from uncertainty. Despite uncertainty, meaningful results can be obtained. The act of monitoring will often point out issues with the design of the facility – how stormwater enters, moves through, and exits; overflow elevations; overall sizing; and others. Relative performance changes over time or for different storm events are meaningful as long as the monitoring conditions at the site stay consistent.

3.1. Infiltration Testing

For infiltration facilities, the rate at which water moves into the ground is the primary variable that determines how well it will manage large storm events, recover capacity between storm events, and prevent vector control problems.

Testing involves filling the facility one or more times and measuring changes in depth over time. Depths are recorded at several locations in the facility and average and minimum rates are calculated. Antecedent moisture, soil type, soil compaction, underlying rock galleries, and vegetative health are important variables.

***Figure 3-1*: Recording drawdown rates at the WPCL Test Planters**

Infiltration performance is evaluated using the “minimum infiltration rate” – the minimum rate approached as the test time increases (Figure 3-2). This value will be greater than or equal to the saturated infiltration rate. The minimum rate was chosen over the average infiltration rate because infiltration rates at the beginning of a test are highly dependent on antecedent soil moisture and the ponding depth (head). Minimum rates tend to reflect long-term performance and are driven by the holding capacity and permeability of subsurface soils. This makes the minimum rate a good representative value for long-term events like the CSO Design Storms, but will be quite conservative for short, intense storms like the 25-Year Design Storm (see Section 4).

In the example in Figure 3-2, water drawdown was measured with staff gages at regular time intervals. The initial infiltration rate was 5.0 inches per hour, the average rate was 1.8 inches per hour, and the minimum rate was 1.5 inches per hour.

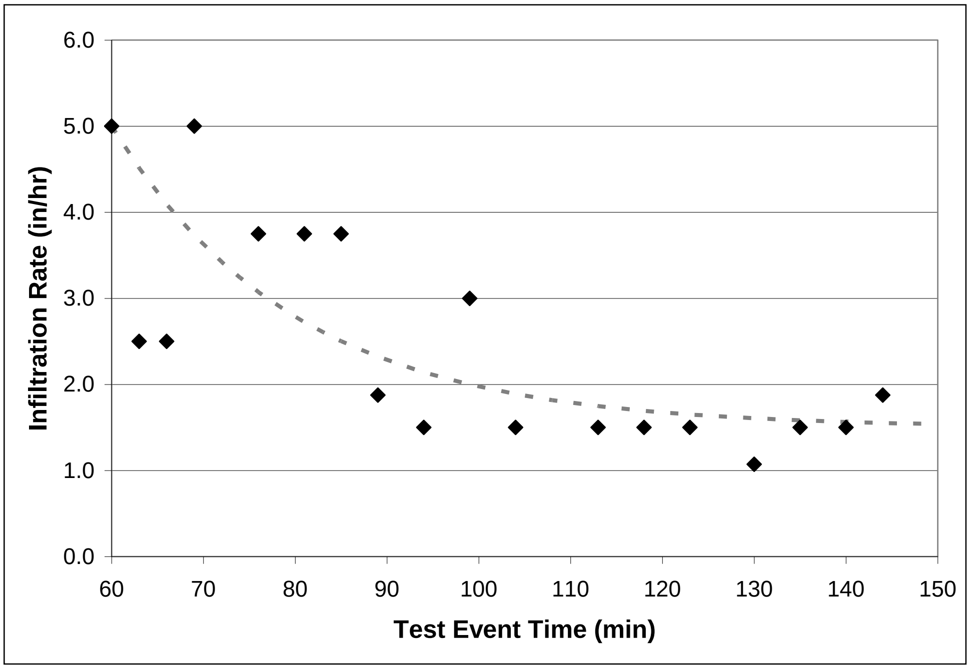


***Figure 3-2*: Infiltration approaching a minimum rate of 1½ inches per hour**
(Siskiyou Green Street, Station #3, April 2005 flow test)

Results must be used carefully. It may not be appropriate to use the performance data of a single facility to assess the suitability of similar facilities elsewhere. Performance results can be highly dependent upon construction methods and physical characteristics like drainage area sediment loads and soil conditions both at the surface and underneath the facility. Physical characteristics can vary widely over short distances in an urban area.

Testing is simple and straightforward, so costs are limited to a hydrant permit and water usage (typically $330) and staff time (8-12 hours).

3.2. Flow Metering

As used in this report, flow metering means full-time monitoring of the inflow and/or outflow from the facility. A typical setup involves battery powered sensors that register depth and velocity that are then translated into flow. Readings are typically taken every 5 minutes to provide a good balance between battery life and data quality. All storm events are monitored, and minimal labor is required after the initial setup.

***Figure 3-3*: Flow sensors installed in sewer**

There are potential problems with this approach. Most stormwater facilities have small drainage areas with times of concentration of less than 5-minutes. This means it is possible that significant peak flow activity could occur while the meter is not recording data. If performance data for extreme events (a 3-year, 10-year, or 25-year event) is desired, there is no guarantee that rainfall events of the desired intensity will occur while the monitor is in place. The meter is unattended for a month between uploads, so data quality and meter problems can occur. Even under the best of circumstances, the accuracy of flow measurements is +/- 10% and it is not unusual for a dead battery or clogged sensors to result in the loss of valuable data.

Cost is approximately $8,500 per year for each meter. This includes a monthly equipment fee as well as the labor to maintain the meter and download the data.

3.3. Flow Testing

Design storm flows (peak, volume, and/or pattern) are replicated using a flow meter, fire hose, and a hydrant. Permits and traffic control are often necessary depending upon facility location.

Flow testing is an efficient way of collecting performance data in response to design storm events used by BES as performance standards (see Section 4 ‘Design Storms’). It allows for more detailed data collection (1-minute time intervals), enhanced quality control through manual verification, and does not depend upon the natural occurrence of large, infrequent rain events (e.g. 25-year event) during the monitoring period.

***Figure 3-4*: Flow test at SW 12th & Montgomery Green Street**

Testing long duration, volume-driven storms, like the CSO Design Storms, can be problematic due to time compression. In order to simulate a 24- or more hour design storm in a single workday, the test must be compressed into a reasonable amount of time (typically no more than 6 hours of test time to allow for setup and take down). To get the appropriate volume in the shorter time period, the flow rates must be increased. This creates much higher inflows to the facility than would be encountered during the actual storm (***Figure 3-5***). Results from such tests are therefore conservative, and performance during an actual storm event is likely to be better.

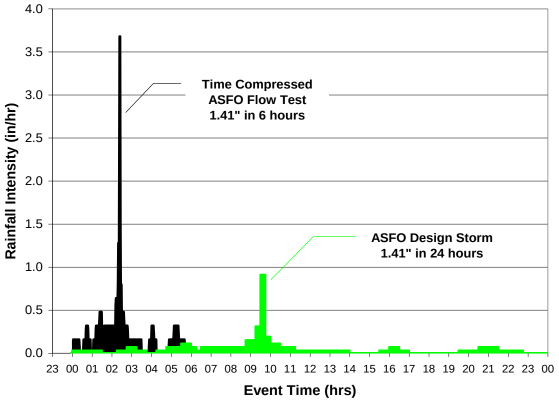


***Figure 3-5:* Result of compressing the 24-hour ASFO Design Storm down to 6-hours**

Some facilities are not conveniently located near a fire hydrant – either because of distance or the need to cross busy streets. In those cases, it is possible to use a water truck to provide the water source. Depending upon the drainage area, the truck may need to be refilled one or more times during the simulation.

The cost is typically around $3,000 per test including water usage, street closure permits as necessary, intern hours (12 hours per test), and Field Operations staff to assist with the test and oversee the flow meters (20 hours per test).

3.4. Water Quality Sampling

Water Quality sampling involves storm event-based analysis of facility influent and effluent. Sampling is typically done manually, though some installations may be appropriate for automated samplers. Samples are typically screened for TSS, metals, nutrients, and oils.

Staff resources and storm requirements determine how often events can be sampled. There are only so many storm events each year with the right amount of antecedent dry period combined with forecast rainfall totals above a minimum threshold. Because there are usually many projects desiring water quality sampling, the number of events that can be sampled in a single year is dependent upon project priority.

Using the sampling criteria established by BES (see Appendix A), cost for each sample is approximately $2,700. At least 15 storm events are desired for results to be statistically significant, and assuming that both inflow and outflow samples will be taken, it would be a minimum cost of approximately $40,000 per facility.

3.5. Sediment / Soil Sampling

Soil sampling to assess whether surface stormwater facilities are receiving significant pollutant concentrations from adjoining drainage areas. Samples are typically taken near the inlets or in forebays, as these are the entry points for sediments. Additional samples may be taken to characterize distribution throughout the facility. Typical sampling depths are 0 to 6 inches, 6 to 12 inches, and 12 to 18 inches. Most locations are discrete grab samples, but, in some cases, may be composited together. Background samples are taken adjacent to some facilities to provide a comparison to ambient soils that are not exposed to stormwater runoff. Samples are typically collected from planting strips between the street and sidewalk, or landscape areas.

The primary sampling depth is 0 to 6 inches, as this is the layer that will most easily come into contact with humans and other organisms. Samples are tested for heavy oils, metals, polycyclic aromatic hydrocarbons (PAHs), and phthalates. As samples are taken over time, pollutant concentrations will be analyzed for trends.

Pesticides and polychlorinated biphenyls (PCBs) were added in 2011 and 2012.

4. Design Storms

BES uses a number of design storms – a rainfall event of specified pattern, depth, and duration – as design standards for facilities [BES 1991]. They are typically derived from the statistical analysis of area rainfall data, but may also be actual storm events.

Storms are often referred to in terms of their return period – or chance of occurrence – and their duration. For instance, a 3-year / 24-hour event is the amount of rainfall expected to occur in a 24-hour period once every 3 years. It should be noted that these are statistical averages and it is possible for multiple 3-year events to occur in a single year.

Potentially relevant design storms are described in the following sections and compared in ***Figure 4-1***.

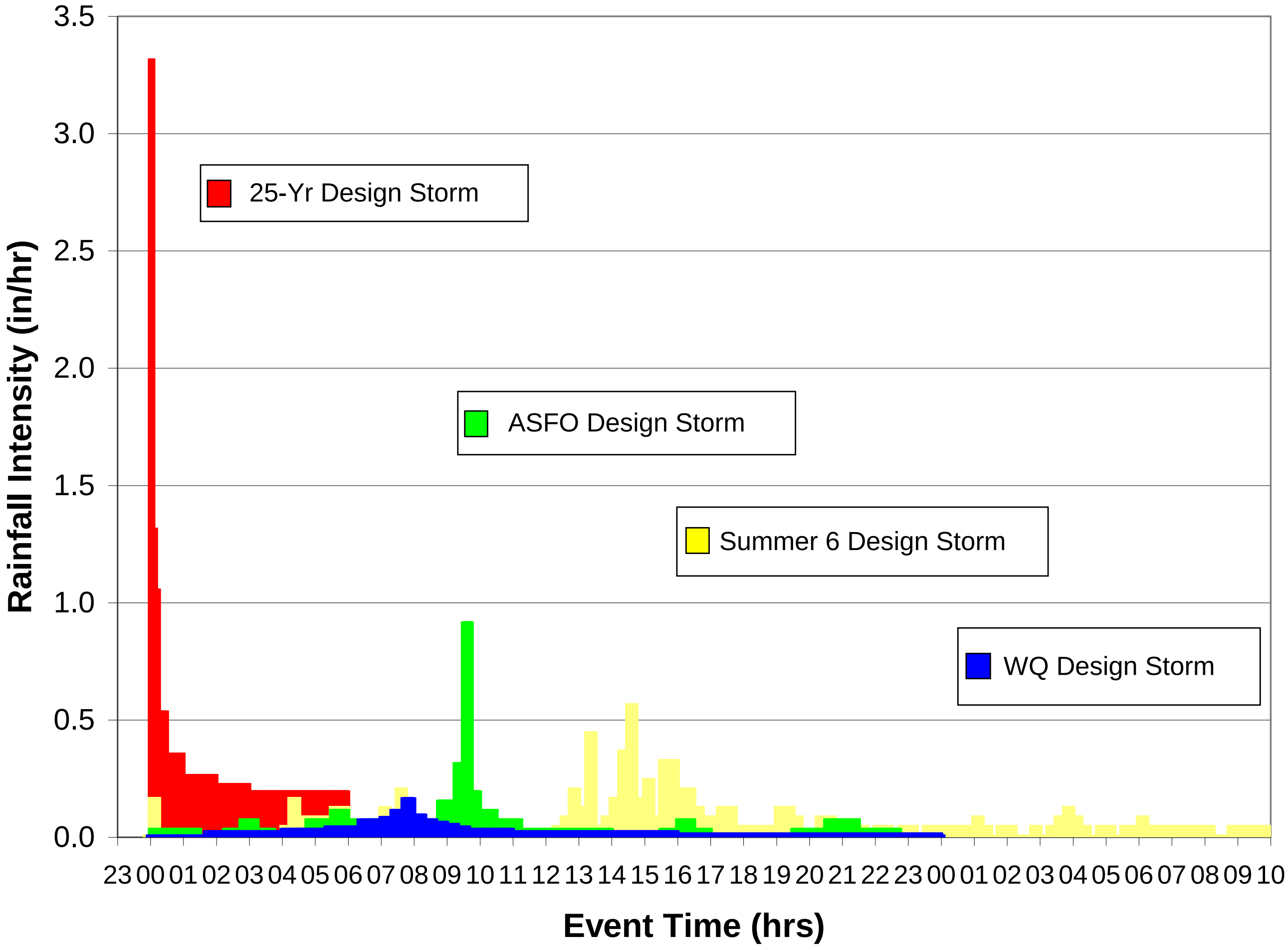


***Figure 4-1*: Comparison of design storms**

***Table 4-1*: Design storm characteristics**

Design Storm	Rain Depth (in)	Duration (hrs)	Peak Intensity (in/hr)
25-Year	1.89	6	3.32
ASFO	1.41	24	0.92
Summer 6	2.17	35	0.60
WQ	0.83	24	0.17

4.1. Basement Sewer Backup Protection (25-Year) Design Storm [1.89” in 6 hours]

Represents the 25-year / 6-hour storm, which is essentially a very intense thunderstorm. The extremely heavy rainfall in the first 15-minutes generates large peak flows that can overwhelm combined sewers. This can result in combined sewage being pushed into basements through floor drains, toilets, or other plumbing fixtures.

This storm is the BES basement sewer backup protection standard and is used to size any additions or replacements in the combined sewer system.

4.2. CSO Control (ASFO) Design Storm [1.41” in 24 hours]

Represents the 3-year / 24-hour summer storm, and is the primary regulatory control storm for CSO discharges to the Willamette River as established in the Amended Stipulated Final Order (ASFO). CSO regulations allow one overflow every 3 summers, so this design storm is intended to represent that statistical event. It can only be used when it is appropriate to assume that rainfall is uniform throughout the drainage area.

This storm is used to size individual sewer basin projects (system-wide projects use the Summer 6 Storm Series).

4.3. CSO Control (Summer 6) Storm Series [key storm is 2.17” in 35 hours]

A series of six actual storm events that were the largest summer storms occurring each year during a historically average six year period (two wet years, two dry years, and two average years). CSO regulations will permit only two overflows during a six year period, so four of the six storms must generate no overflows. Rainfall data is available from rainfall gages throughout the city for each storm. This provides proper spatial timing of rainfall over the entire City, which makes it the best choice for facilities that collect runoff from a very large drainage area.

This storm is used to size system wide projects like the CSO tunnels (individual sewer basin projects use the ASFO design storm).

4.4. Water Quality (WQ) Design Storm [0.83” in 24 hours]

The Water Quality Design Storm represents the water quality treatment standard for capture and treatment of 90% of annual runoff. This storm event occurs relatively frequently – more than twice a year on average – so rainfall depth and peak intensity are much lower when compared to the other design storms.

This storm is used as a minimum sizing criteria for most facilities located outside the combined sewer area.

5. Facility Types

Facility types monitored during the report period fall into the general categories described below.

5.1. Ecoroofs

Ecoroofs consist of soil media and vegetation atop a waterproof membrane. They reduce peak flows and total runoff volume. Soil depths typically vary from 4 to 6 inches, and a variety of soils and plantings are possible. The primary consideration is the structural rating of the roof which must be able to support the weight of the plants and soil when fully saturated. Ecoroofs are also referred to as Green Roofs, Living Roofs, or Roof Gardens.

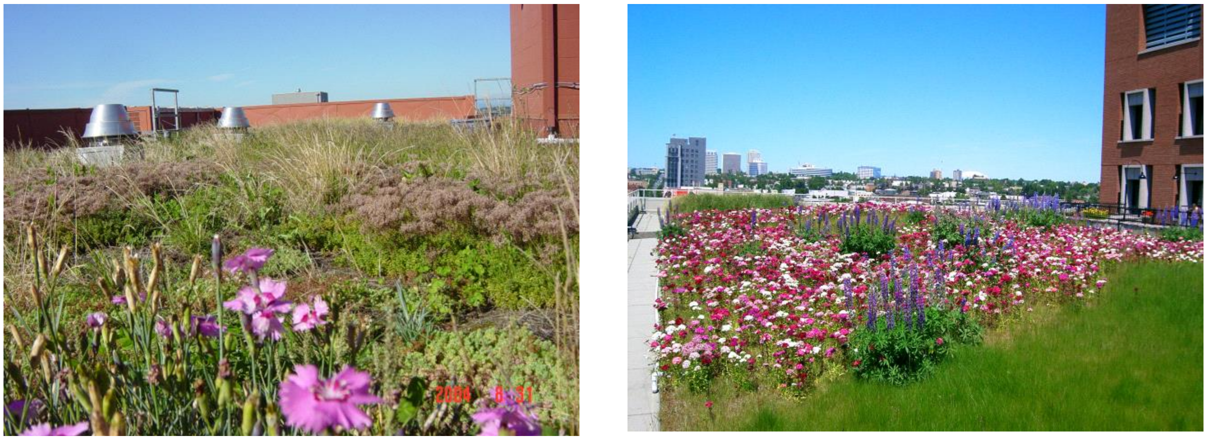


***Figure 5-1*: Hamilton Apartment Ecoroof (left) and the Multnomah County Green Roof (right)**

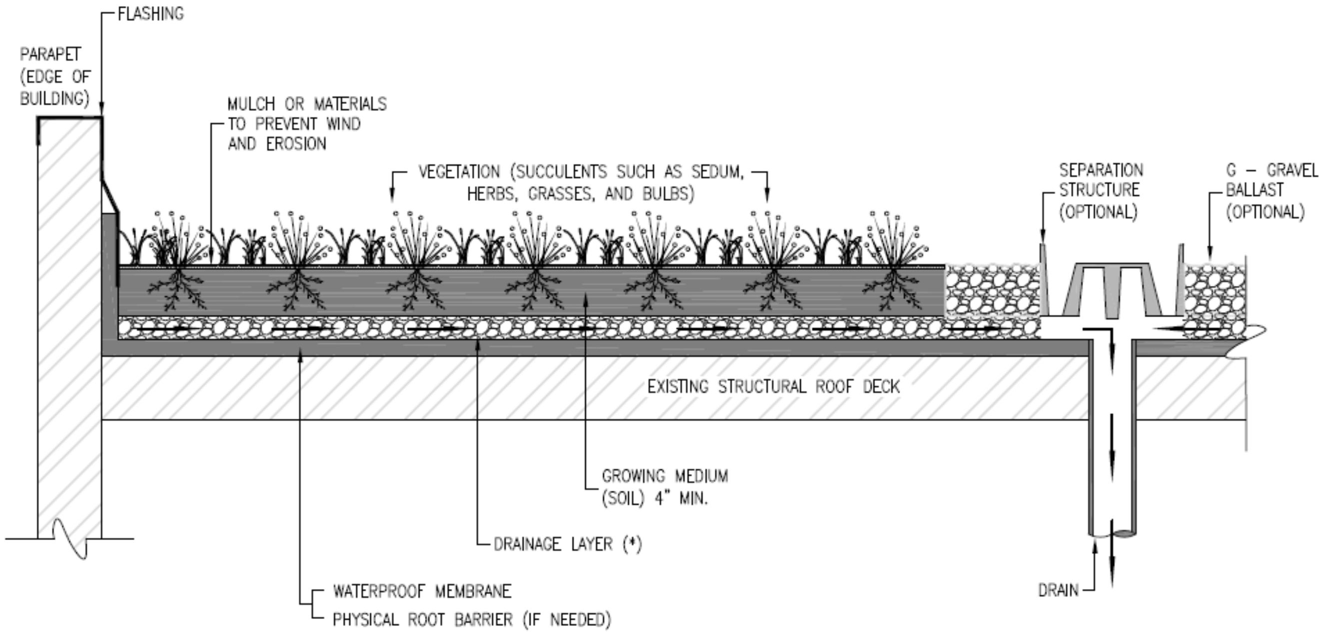


***Figure 5-2*: Typical ecoroof cross section**
[Source: 2008 Stormwater Management Manual, Appendix G.1]

5.2. Green Streets (public right-of-way stormwater facilities)

Green streets come in three basic formats: planters, swales, and basins. All are vegetated facilities in the public right-of-way that manage street runoff. Planters have vertical walls while swales and basins have sloped sides. Their design is highly flexible making them a versatile tool in managing peak flows, flow volume, and water quality.

All facilities typically range from 3 – 8 feet wide and have a ponding depth of 4 – 9 inches. Sizing depends upon the goals for the facility (peak flow reduction, flow volume reduction, and/or water quality improvement). Any overflows during large rain events are directed to a conventional drainage system.

The planter and swale configurations can either be behind or beyond the existing curb alignment. When beyond the existing curb alignment, they extend into the street surface (usually the parking lane) and are called curb extensions.

Because the curb extensions (Figure 5-3) bump out into the existing street, placement must take into account many variables – such as street width, utility locations, setbacks from driveways, overall traffic safety, and emergency / utility vehicle passage. They are typically 4 or 6 feet wide, with a typical ponding depth of 6 inches.

Figure 5-3: Green Street Curb Extensions at NE 35th & Siskiyou (left)
and SE Belmont & 42nd (right)

Planters (Figure 5-4) are typically 3 to 4 feet wide, with additional space needed for a step-out if curbside parking exists. The presence of utility vaults and street trees are common design challenges.

Swales (Figure 5-5) are typically 8 to 10 feet wide, and can have a step-out along the street curb to facilitate curb parking. Only some portions of the city have furnishing / planting strips with enough width for them to be located behind the existing curb alignment. The main challenges are existing street trees, utility poles, and water services.

Basins (Figure 5-6) are very similar to swales, but are typically larger and can be of any shape. Basins are often referred to as Rain Gardens or bioretention facilities.

***Figure 5-4*: Green Street Planters at SE Reedway & 89th (left) and SW 12th & Montgomery (right)**

***Figure 5-5*: Green Street Swale at N Willamette & Denver, before (May 2007) and after construction (September 2007)**

***Figure 5-6*: Green Street Basins at N Albina & Prescott (left) and SW 30th & Dolph (right)**

Facilities are constructed by the city and by private contractors to meet the requirements of the Stormwater Management Manual. Maintenance for all right-of-way facilities eventually falls to the city. Privately built facilities will typically have a warranty period of 2 years before becoming the city's responsibility.

Plans for extensions and planters are also reviewed by the Portland Bureau of Transportation and the Bureau of Water Works to ensure there are no adverse impacts to cars, emergency vehicles, pedestrians, or underground utilities.

5.3. Private Stormwater Facilities

This category includes infiltration facilities on private property that manage roof and parking lot runoff. The facility types are the same as those under Green Streets – planters, swales, and basins. As with all infiltration facilities, the infiltration rate of the native soil is a primary design factor. The facility also must be a safe distance from any structure that may be damaged by subsurface water.

Facilities are typically built by private contractors and maintenance is the responsibility of the property owner.

***Figure 5-7*: Glencoe School parking lot swale (left) and Mt Tabor School roof planter (right)**

5.4. Lined (flow-through) Facilities

Lined facilities look just like standard infiltration facilities but are sealed off from the surrounding soils and do not infiltrate. Any runoff not held by the soil and plants makes its way to an underdrain system which is connected to a conventional drainage system (Figure 5-8). Lining is accomplished through the use of a plastic (HDPE or PVC) liner, concrete, or impermeable soil.

Lining may be desirable or required because of the potential impact to adjacent structures (basements), utilities, slope stability, or groundwater.

Lined facilities can provide peak flow reduction and water quality treatment similar to infiltration facilities, but volume retention is significantly less because the underdrain allows some volume to reach the drainage system.

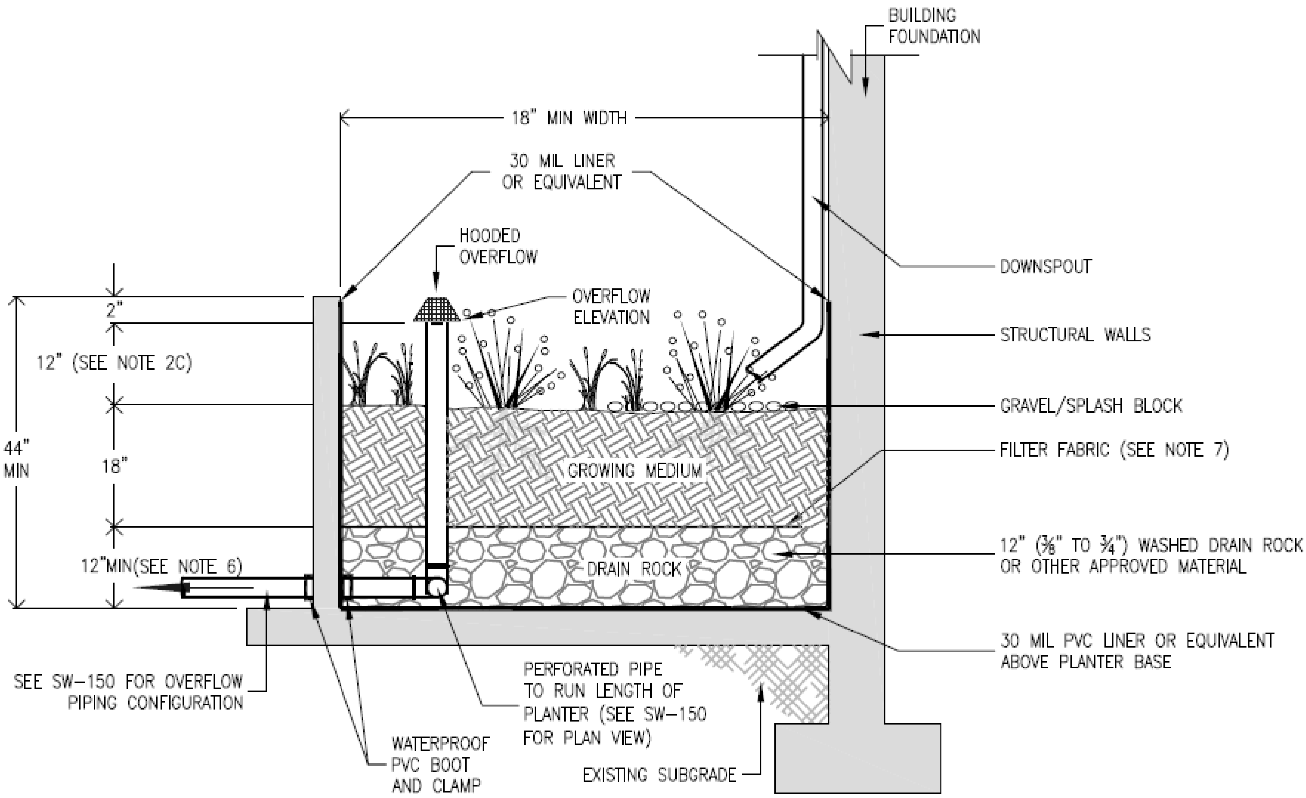


***Figure 5-8*: Lined planter cross-section**

[Source: 2008 Stormwater Management Manual]

***Figure 5-9*: Lined swale at the Oregon Zoo (left) and a lined planter at The ReBuilding Center (right)**

6. Facility Evaluations

Monitoring results for individual facilities are presented in the following sections. Comparison of one facility’s performance to another should be done cautiously. Differences in design, site conditions, and data quality must be considered before any difference is considered significant.

The evaluations reflect data collected through December 2012. An attempt was made to provide a good cross section of facility ages, types, and geographic locations. Facilities monitored during this reporting cycle are summarized in ***Table 6-1*** with locations indicated on ***Figure 6-1***.

***Table 6-1*: Monitored facilities during report period**

Facility	Facility Type	Year Installed	Monitoring Type		
			Infiltration Testing	Flow Testing	Continuous
Hamilton Apartments	Ecoroofs	1999			**11 yrs**
Multnomah County Green Roof		2004			**3 yrs**
Portland Building Ecoroof		2007			**5 yrs**
Albina Triangle (N Albina & Mississippi)	Infiltration Facilities (public, “green streets:)	2007	✓	✓	
Glencoe Rain Garden		2003	✓	✓	**9 yrs**
Glendoveer Commons (NE Davis & 158th)		2006	✓		
N Central & St Johns		2009	✓	✓	
N Gantenbein & Humboldt		2009	✓	✓	
N Haven & Cecelia		2007	✓	✓	
N Killingsworth, Maryland & Michigan		2008	✓		
N Willamette & Denver		2007	✓	✓	
NE 117th & Holladay		2007	✓	✓	
NE Alameda & Fremont		2009	✓	✓	
NE Fremont & 131st		2005	✓	✓	
NE Sandy & 21st		2006	✓	✓	
NE Sandy & Davis		2006	✓	✓	
NE Siskiyou Green Street		2003	✓	✓	
NE Winchell & Mallory		2008	✓	✓	
NW 35th & Yeon		2008	✓	✓	
NW Pettygrove & 26th		2010	✓	✓	
People’s Co-Op (SE 21st & Tibbetts)		2006	✓	✓	
SE Ankeny Green Street		2004	✓	✓	
SE 42nd & Belmont		2007	✓	✓	
SE 92nd & Francis		2007	✓	✓	
SE Lambert & 17th		2011	✓	✓	
SE Ramona & 133rd		2008	✓		
SE Reedway & 89th		2007	✓	✓	
SE Water & Clay		2008	✓	✓	
SW 12th & Montgomery Green Street		2005	✓	✓	
SW 29th & Sylvania		2008	✓		
SW 30th & Multnomah		2008	✓	✓	
SW Capitol & 33rd		2010	✓	✓	
SW Virginia & Florida		2009	✓	✓	

Tryon Headwater Rain Garden		2006	✓	✓	
Mt Tabor Middle School Rain Garden	Infiltration Facilities (private)	2006	✓	✓	
OMSI		1992	✓		
Oregon Wild (ONRC)		2002	✓		
Page 19 Parking Lot		2002	✓		
Parks Eastside Field Office		2003	✓		
St Andrews Parking Lot		2003	✓		
NE Glisan & 28th	Lined Facilities (public)	2011		✓	
SW 32nd & Capitol Hwy		2009		✓	
SW Barbur & Sheridan		2011		✓	
SW Moody & Abernethy		2007		✓	
Oregon Zoo Parking Lot	Lined Facilities (private)	2006		✓	**1 yr**
ReBuilding Center		2005		✓	**5 yrs**
Water Pollution Control Lab		2004		✓	

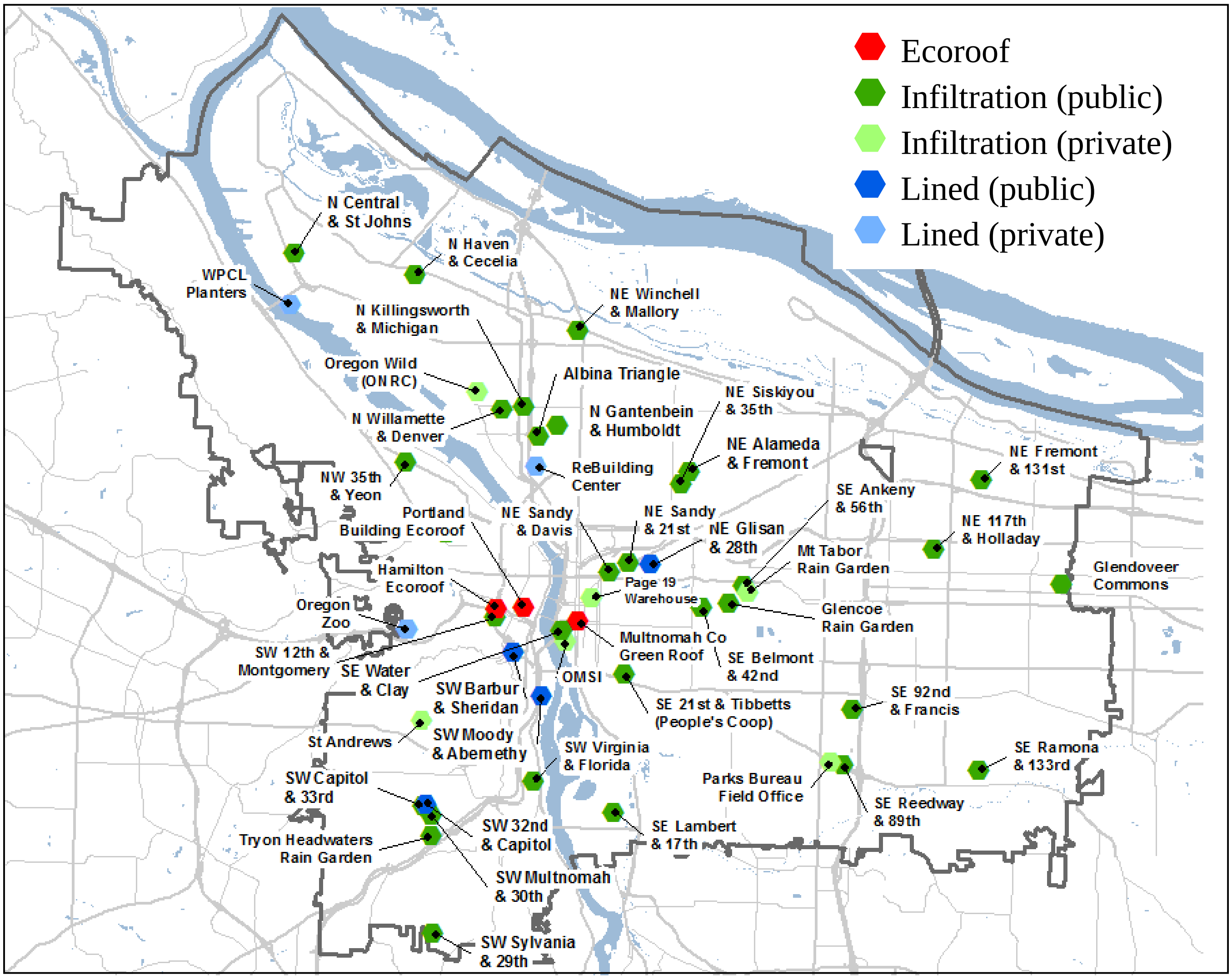
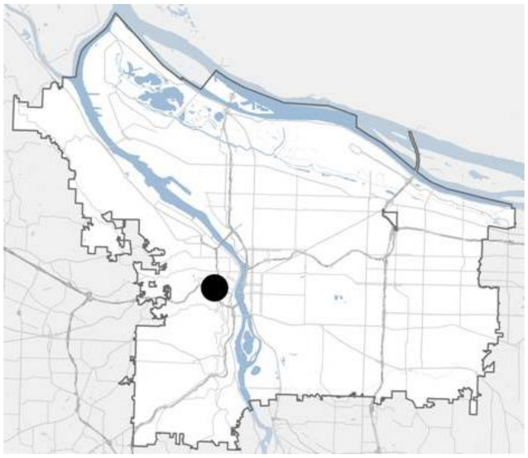


Figure 6-1: **Location of monitored facilities**

The following subsections discuss the performance of ecoroof, infiltration, and lined facilities, with some specific examples for each type. The last subsection compares soil sampling results for stormwater facilities and landscape areas.

Hamilton Ecoroof

Summary Information		
Evaluation Period:	**10-½ years** (January 2002 – June 2012)	**Ecoroof atop a 10 story building in downtown Portland. Two configurations were installed: a 3" thick, light-weight media on the east side and a 5" thick, heavy media on the west side.**
Constructed:	**September 1999**	
Facility Type:	**Ecoroof**	
Drainage Area:	**West: 3,655 ft^2 / East: 3,811 ft^2**	
Facility Area:	**West: 2,520 ft^2 / East: 2,620 ft^2**	
Sizing Factor:	**69%**	



Monitoring Result Summary

Peak Flow Reduction

96%

Flow Volume Reduction

Annual	**50%**
Summer (MAY – OCT)	80%
Winter (NOV-APR)	42%
CSO Events	62%

Water Quality

- Metals: copper and zinc levels appear to be trending upward; copper levels sometimes exceed standard for aquatic life protection
- Nutrients: nitrogen and phosphorus levels appear to be steady or declining, but phosphorus levels still exceed benchmarks

Soil / Infiltration

- West Side: contains 28% sandy loam in addition to typical ecoroof components
- East Side: contains 25% encapsulated polystyrene in addition to typical ecoroof components

Design

Attempts to prevent weed intrusion have been futile, but the roof appears to be adapting well. The same plant species are doing well on both sides of the roof, but the west side has denser coverage.

Maintenance

Irrigation is applied manually by hose as needed or using a timer. Irrigation period is typically from mid-July through September, with a frequency of up to 3 times per week.

Overview

The ecoroof was installed in the fall of 1999 and has been monitored since late 2001. The ecoroof is divided into distinct west and east drainage areas, each with a separate roof drain. A different soil media was used for each drainage area to compare the relative performance of thicker, heavier soils to thinner, lighter soils. Drainage areas and soil media are summarized in ***Table HA-1*** and ***Figure HA-1***.

***Table HA-1*: Hamilton Ecoroof Drainage Areas**

Drainage	Ecoroof (sq ft)	Impervious (sq ft)	Total Roof (sq ft)	Soil Depth (in)	Soil Media
West	2,620	1,035	3,655	5	28% sandy loam / 22% perlite / 20% digested fiber / 20% coir fiber / 10% compost
East	2,520	1,291	3,811	3	25% encapsulated polystyrene / 15% digested fiber / 15% coir fiber / 15% perlite / 15% peat moss / 15% compost

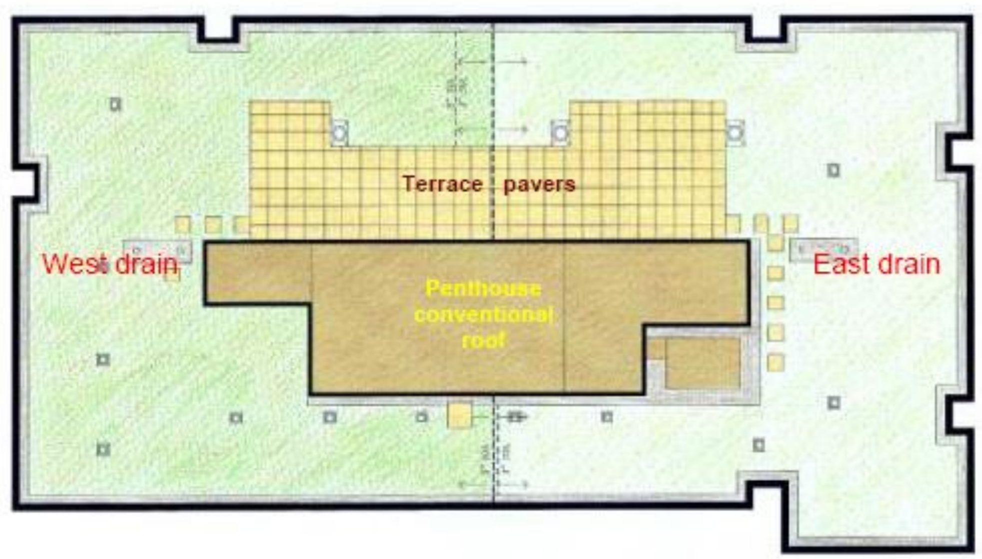


***Figure HA-1*: Hamilton Ecoroof layout**

Roof runoff is forced to pass through fiberglass flumes attached to each drain, where water depths are measured and converted to corresponding flow rates. Run-on is estimated from rainfall data collected from a raingage installed on the penthouse roof. The primary plantings on the ecoroof are sedum, thyme, and fescue species.

A substantial portion of the roof is not ecoroof. The conventional penthouse roof is designed to drain to a gutter system that is piped directly to the drains and is only monitored as a reference for conventional roof water quality. The large terrace, that provides access to residents of the building, and the perimeter pavers both drain to the flow meters through the ecoroof drainage system.

***Figure HA-2*: Monitoring setup – flume and datalogger**

It is notable that the depth of the soil media has decreased over time, likely due to compaction and wind erosion. As much as one inch has been lost on both sides. There are also problems with the penthouse roof drainage that allows spillover onto the east roof during moderate and heavy rain events. As a result, flows often exceed the flume capacity. This situation was not easily resolved, and the meter was removed from the east side of the roof in April 2006. East side flow data is only used in this report for comparative purposes or when it is believed that the additional run-on does not significantly compromise the results.

Peak Flow

The Hamilton Ecoroof does an excellent job of eliminating peak flows. Results for the most intense rainfall events are shown in ***Table HA-2***. While results are certainly impacted by antecedent moisture, the minimum reduction for an intense event was approximately 78%, and all but 4 were >90%.

***Table HA-2*: Peak flow reductions for 32 events with peak rainfall intensities >= 1 inch per hour**

		West Roof		**East Roof**	
Event Date	Peak 5-min Rainfall (in/hr)	Peak Flow (gpm)	Estimated Peak Flow Reduction[1]	Peak Flow (gpm)	Estimated Peak Flow Reduction[1]
01/07/02	1.19	5.6	87%	meter down	
02/23/02	2.51	5.4	94%	9.6	90%
09/29/02	2.38	0.8	99%	4.3	95%
09/16/03	1.06	0.0	100%	0.1	99%
10/09/03	1.32	0	100%	1.9	96%
05/27/04	1.45	0.6	99%	3.7	94%
06/06/04	1.06	0	100%	1.0	98%
04/17/05	1.45	2.5	95%	6.2	89%
05/16/05	1.19	0	100%	0	100%
06/01/05	1.32	0	100%	0	100%
06/22/05	1.72	0	100%	0	100%
09/30/05	1.32	6.1^{+}	88%	>11.6	<78%
04/05/06	1.06	0	99%	0^{+}	100%
05/21/06	3.56	2.7	98%	11.4^{+}	92%
03/31/07	1.19	0	97%		
04/12/09	1.19	0.6	99%		
05/04/09	1.58	4.2	93%		
06/19/09	1.32	0	100%		
10/26/09	1.06	2.5	94%		
11/07/09	1.19	4.0	91%		
05/19/10	1.06	2.9	93%		
06/06/10	1.19	4.2	91%		
09/07/10	2.16	1.2	98%		
09/18/10	2.40	4.4	95%		
10/24/10	1.20	4.4	90%		
12/14/10	1.56	5.4	91%		
01/12/11	2.04	3.8	95%		
10/07/11	1.08	0.1	99%		
10/11/11	1.44	3.4	94%		
03/15/12	2.04	4.9	94%		
04/11/12	1.08	0.3	99%		
05/26/12	3.12	3.4	97%		

East Average = 95%

West Average = 96%

[1] Runoff expected from a standard roof (CN=98) using the maximum 5-min rainfall intensity

$^{+}$ value from the less accurate HYDRA system

The runoff response for the most intense storm during the monitoring period, May 21 2006, is shown in ***Figure HA-3***. The event had a peak intensity of 3.56 inches per hour – almost 0.30 inches in a 5-minute period, roughly equivalent to a 35-year peak rain event. The peak flow reduction for both sides of the roof is quite high, averaging 96% (west = 96%, east = 95%).

This event intensity is beyond the 3.32 inches per hour intensity of the 25-Year Design Storm, indicating this ecoroof significantly reduces peak flows for intense rain events.

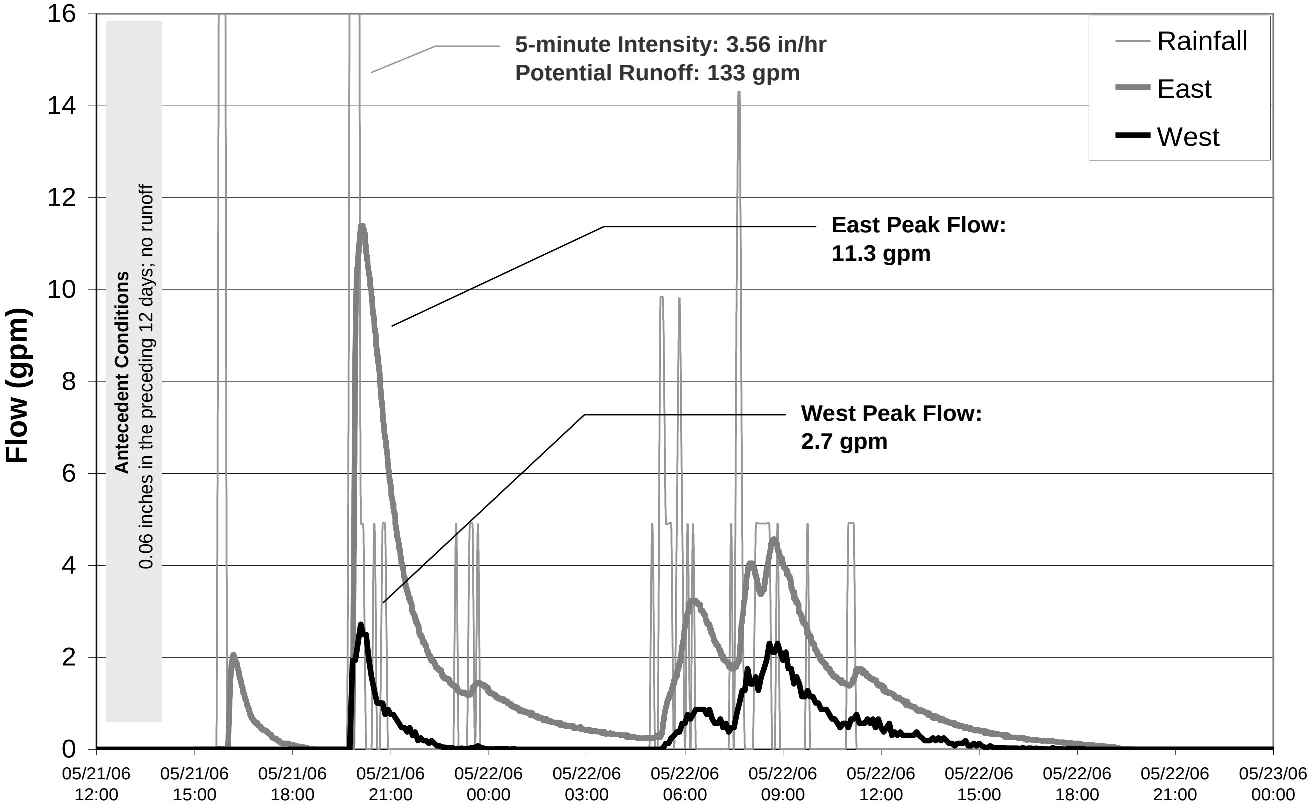


***Figure HA-3*: Roof runoff for 5/21/2006 event**

Flow Volume

West Side

Over more than ten years, the west side of the Hamilton Ecoroof has reduced annual runoff by approximately 50%. Data is summarized in ***Table HA-3*** and ***Figure HA-4***.

***Table HA-3*: Overall runoff retention, Hamilton Ecoroof - West Side**

Period	(in) Total Rainfall	(ft^3) Potential Runoff	(ft^3) Metered Runoff	Retention
January 2002 – June 2012	434.0	132,200	65,700	**50%**
Winter months (NOV-APR)	336.4	102,500	59,700	**42%**
Summer months (MAY-OCT)	97.6	29,700	6,000	**80%**

Note: The monitoring equipment was down during December 2002; that month is not included in retention calculations

Retention is the highest during the summer months when rainfall is low and evapo-transpiration rates are highest. However, even in the wet winter months, the ecoroof retains 40% of the rainfall volume.

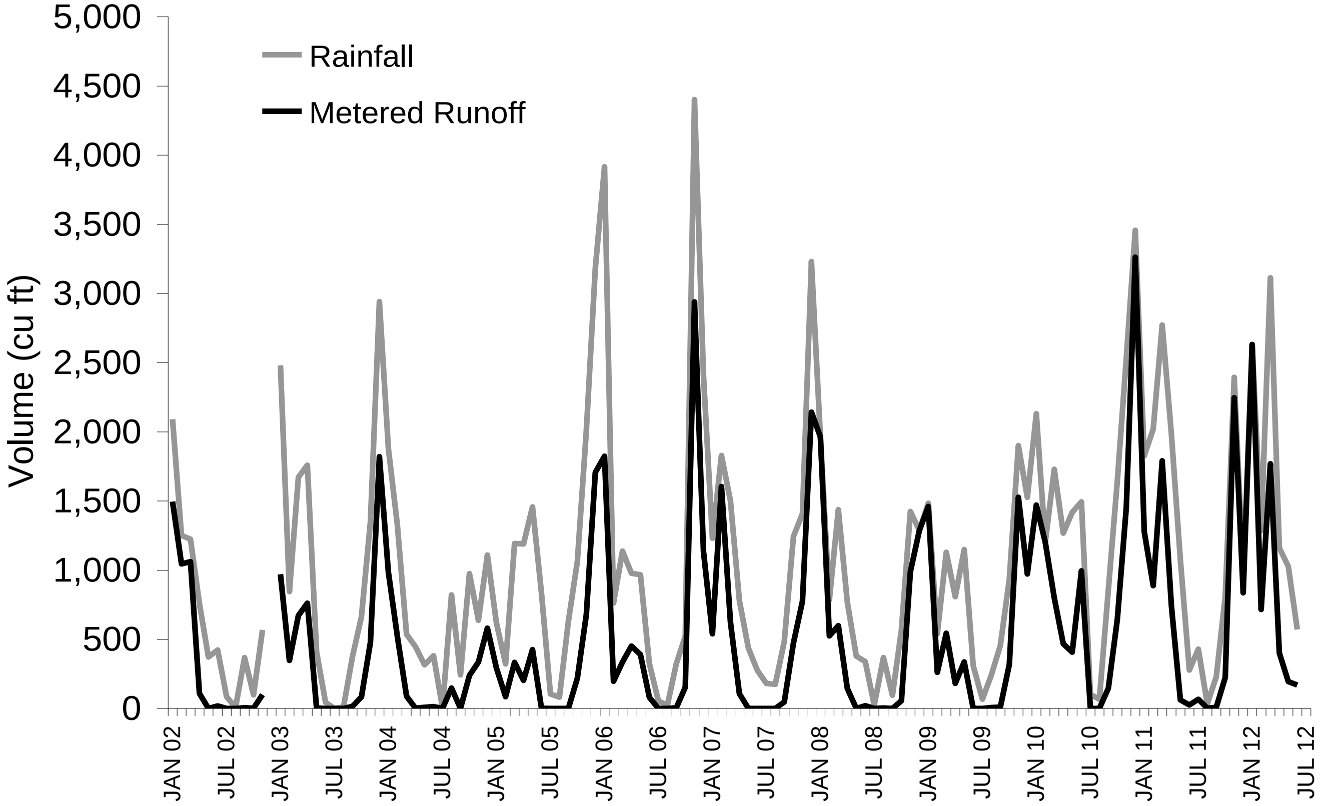


***Figure HA-4*: Monthly rainfall and associated runoff retention, Hamilton Ecoroof – West Side**

It was noted in a prior report (Hutchinson et al, 2003) that performance of the roof may be improving over time. However, substantial differences in yearly rainfall totals and patterns make comparisons difficult (***Table HA-4***). Annual retention has ranged from 39% to 69%. 2004 and 2005 had very high annual retentions (66% and 69%), but 2004 was a very low rainfall year and both years had relatively low amounts of winter rainfall when ecoroof performance is lowest. 2010 is the lowest retention year, but also had the most precipitation. However, 2008 is also a low retention year even though annual precipitation was low, as was winter precipitation.

***Table HA-4*: Runoff retention by year, Hamilton Ecoroof – West Side**

	2002[3]		**2003**		**2004**		**2005**	
	Rainfall (in)	Retention	Rainfall (in)	Retention	Rainfall (in)	Retention	Rainfall (in)	Retention
Annual	23.8	**47%**	41.2	**59%**	28.5	**66%**	41.6	**69%**
Winter[1]	19.3	**35%**	36.3	**54%**	19.5	**58%**	27.9	**61%**
Summer[2]	4.5	**98%**	4.9	**93%**	9.0	**85%**	13.7	**84%**
	2006		**2007**		**2008**		**2009**	
	Rainfall (in)	Retention	Rainfall (in)	Retention	Rainfall (in)	Retention	Rainfall (in)	Retention
Annual	51.9	**53%**	41.9	**51%**	31.0	**41%**	34.6	**47%**
Winter	44.6	**49%**	32.7	**42%**	25.2	**28%**	24.2	**33%**
Summer	7.3	**72%**	9.2	**81%**	5.8	**96%**	10.4	**79%**
	2010		**2011**		**2012[4]**			
	Rainfall (in)	Retention	Rainfall (in)	Retention	Rainfall (in)	Retention		
Annual	58.7	**39%**	48.6	**45%**	32.1	**40%**		
Winter	40.4	**30%**	39.2	**35%**	26.9	**33%**		
Summer	18.3	**61%**	9.4	**86%**	5.2	**77%**		

[1] Winter = JAN – APR, NOV – DEC

[2] Summer = MAY – OCT

[3] Runoff meter was down for much of December 2002; rainfall for this month was not included in the totals

[4] Only JAN - JUN

Annual precipitation and winter precipitation do not always correspond with annual retention. This would seem to suggest that antecedent conditions and rainfall pattern are equally important drivers. For example, 2 inches of rainfall falling in 24-hours will likely result in more runoff from the ecoroof than 2 inches of rain falling over 4 days. Likewise, a storm falling on an already wet roof will likely generate more runoff than the same storm falling on a dry roof.

Looking at individual storm events, it does appear that runoff is strongly related to the rainfall depth of an event (***Figure HA-5***). There is significant scatter, as would be expected from such a dataset with such a variety of storm patterns and antecedent conditions. There are nine events where metered runoff exceeded estimated rainfall. However, given the accuracy of the raingage and the flow meter, this number of outliers seems reasonable. There appear to be separate and well-defined linear trends for the summer and winter seasons.

There have been few events similar to the CSO Design Storms during the monitoring period. Those that occurred during the summer CSO regulatory period (May to October) are presented in ***Table HA-5***. It is a small sample of events, but most show substantial retention for the west side, averaging 62% - just about equal to the 63% retention estimated by using the summer trend line in ***Figure HA-5***.

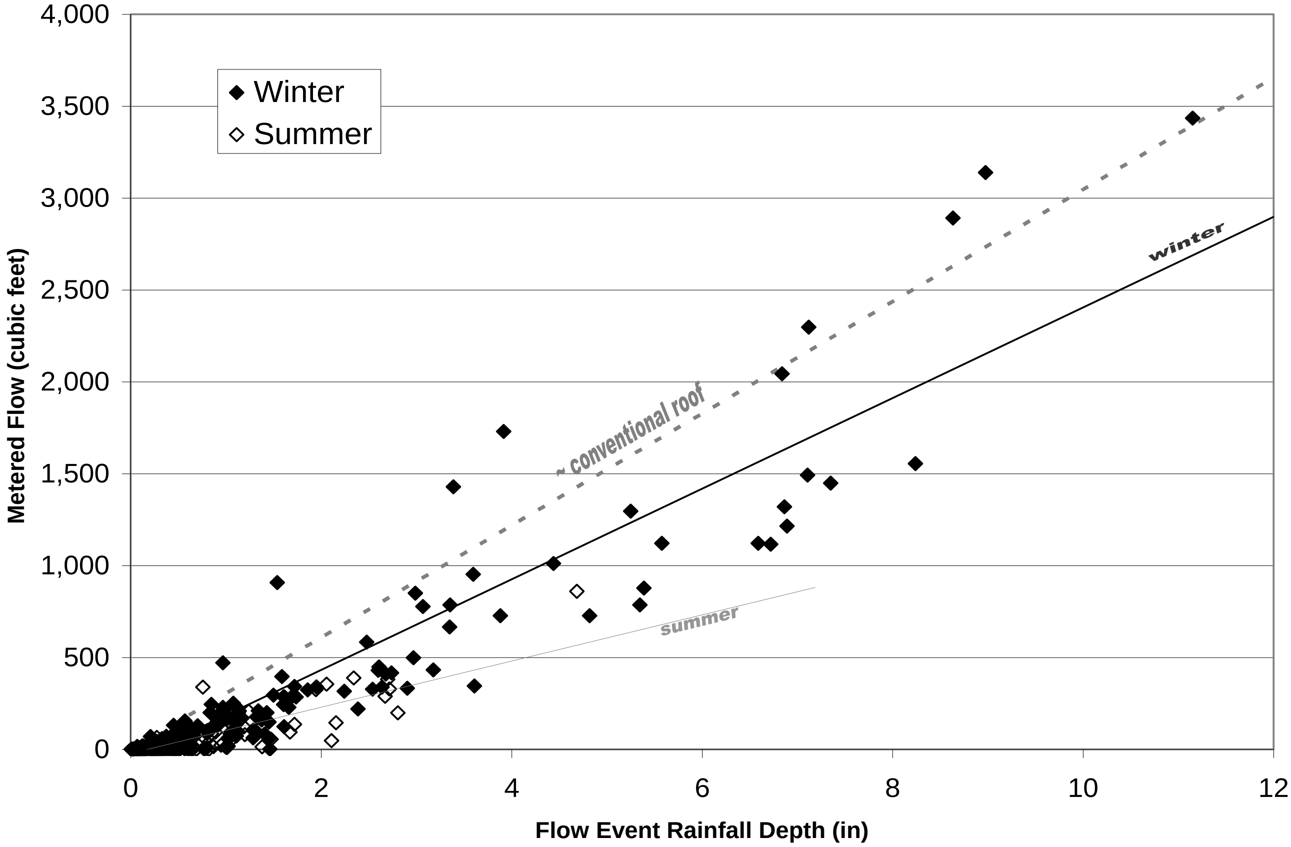


Figure HA-5: **Seasonal runoff as a function of total event rainfall, Hamilton – West Side**

(Winter linear $R^2 = 0.87$; Summer linear $R^2 = 0.73$)

"Flow Event": if runoff from a rain event extends beyond the 24-hour interevent window into a following rain event, they are combined into a single flow event

***Table HA-5*: Volume retention for storm events**

most similar to CSO Design Storms, Hamilton west side

				West Side		
Rain Event	(in) Total Rain	(hrs) Duration	(in/hr) Peak Intensity	(ft^3) Potential Runoff	(ft^3) Metered Runoff	Retention
Aug 21 2004[1]	1.20	22	0.53	359	35	**90%**
Oct 30 2005	2.46	40	0.53	735	285	**61%**
May 04 2009[2]	1.30	21	1.58	389	184	**47%**
Jun 06 2010	1.61	27	1.19	479	287	**40%**
Oct 09 2010	1.72	35	0.36	514	136	**73%**

[1] Storm defined by a 16-hour interevent period

[2] Storm defined by a 19-hour interevent period

East Side

Problems metering runoff on the east side led to monitoring equipment removal in 2006. It was not uncommon for the east side runoff to be much greater than run-on. This was due to additional runoff from the conventional penthouse roof that spills onto the ecoroof when the gutter system is overwhelmed.

Annual runoff retention averaged 33%, notably less than the 50% of the west side. Data is summarized in ***Table HA-6***.

***Table HA-6*: Overall runoff retention, Hamilton Ecoroof - East Side**

Period	(in) Total Rainfall	(ft^3) Potential Runoff	(ft^3) Metered Runoff	Retention
Jan 2002 – Mar 2006	154.1	49,000	32,700	**33%**
Winter (NOV-APR)	122.1	38,800	29,600	**24%**
Summer (MAY-OCT)	32.0	10,200	3,100	**70%**

***Table HA-7*: Runoff retention by year, Hamilton Ecoroof – East Side**

	2002[3]		**2003**		**2004**	
	Rainfall (in)	Retention	Rainfall (in)	Retention	Rainfall (in)	Retention
Annual	23.8	**15%**	41.2	**20%**	28.5	**39%**
Winter[1]	19.3	**3%**	36.3	**13%**	19.5	**21%**
Summer[2]	4.5	**65%**	4.9	**73%**	9.0	**78%**
	2005		**2006[4]**			
	Rainfall (in)	Retention	Rainfall (in)	Retention		
Annual	41.6	**61%**	19.1	**15%**		
Winter	27.9	**59%**	19.1	**15%**		
Summer	13.7	**66%**				

[1] Winter = JAN – APR, NOV – DEC

[2] Summer = MAY – OCT

[3] Runoff meter was down for much of December 2002; rainfall for this month was not included in the totals

[4] Only JAN - MAR

Winter season retention was nearly half the retention of the west side (24% versus 42%). Summer performance was much better, but still lagged behind the west side. However, it's good to keep in mind that the east side roof is thinner and has a bit more impervious surface in its drainage area.

Retentions for the storm events closest to the CSO Design Storms are presented in ***Table HA-8***. Unfortunately, it is a very small sample of three events, two of which provide no helpful information (for one the meter was down, while the other has a largely negative retention likely due to additional runoff from the conventional penthouse roof). A rough and uncertain estimate of the retention of CSO events can be obtained using the summer trend line from ***Figure HA-7***. Using the trend line, the roof would retain an average of 57% between the two CSO Design Storms – similar to the estimated west side retention of 62%.

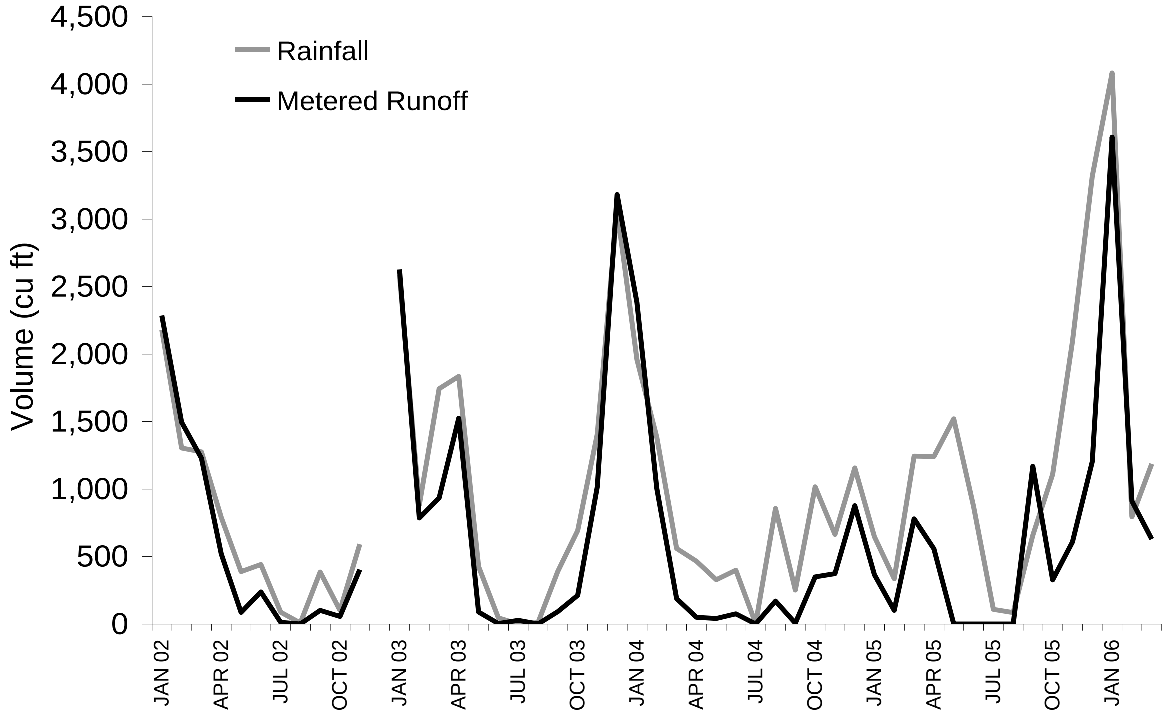


Figure HA-6: **Monthly rainfall and associated runoff retention,**

Hamilton Ecoroof – East Side

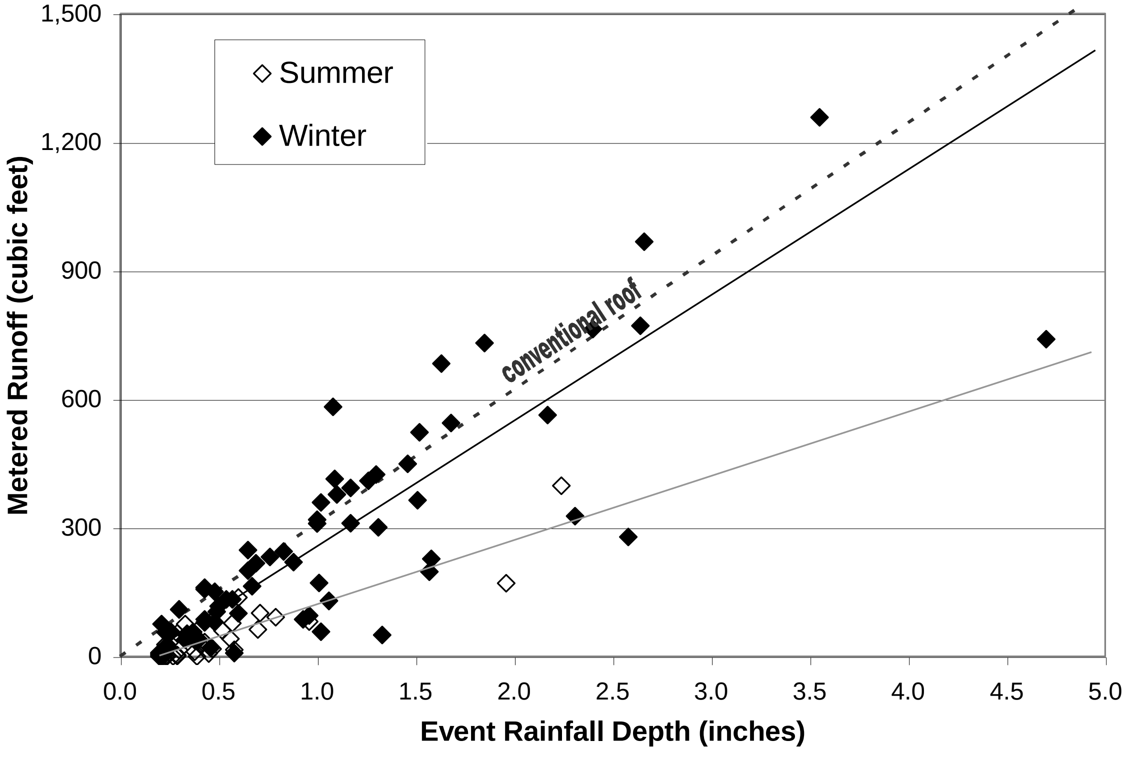


***Figure HA-7*: Seasonal runoff as a function of total storm rainfall, Hamilton – East Side**
(Winter linear $R^2 = 0.75$; Summer linear $R^2 = 0.79$; “Conventional roof” assumes a 0.98 runoff coefficient)

***Table HA-8*: Volume retention for storm events**

most similar to CSO Design Storms, Hamilton east side

				East Side		
Rain Event	(in) Total Rain	(hrs) Duration	(in/hr) Peak Intensity	(ft^3) Potential Runoff	(ft^3) Metered Runoff	Retention
Aug 21 2004	1.09	22	0.48	Meter Down		
Sep 30 2005	1.80	17	0.48	560	930	**-66%**
Oct 30 2005	2.24	40	0.48	700	400	**43%**

Comparison

The west side soil media is effective and outperforms the east side soil media. Retention can be estimated based upon total event rainfall using the linear trend lines from Figures HA-5 & HA-7. The resulting curves are presented in ***Figure HA-8***.

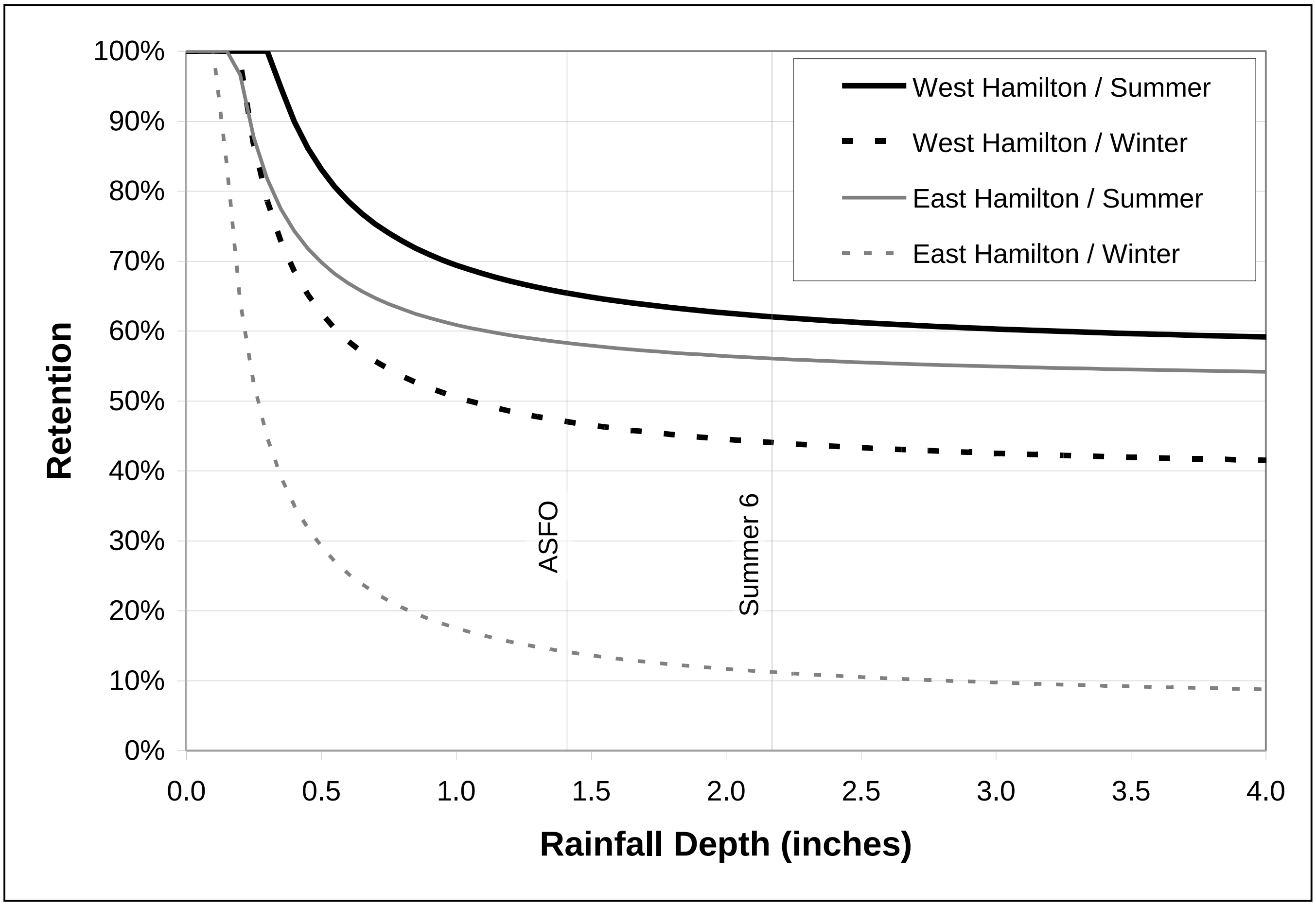


Figure HA-8**: Volume retention curves for both sides of Hamilton Ecoroof**

The organic content (digested fiber, coconut coir, and compost) by volume for both soils are roughly the same – averaging 55%. However, the west side soil is thicker so there is substantially more organic material available to soak up rainfall on the west roof. Also, the west side soil contains sandy loam which should have a higher field capacity (the ability to hold water against gravity drainage) than the encapsulated polystyrene (EPS) used on the east side. The sandy loam drains more slowly, allowing the organics to soak up more rainfall by providing a longer contact time.

However, taking into account the drainage problems on the east side and the differences in soil thickness and impervious area, the east side is actually performing well. The east side drainage area has a slightly higher percentage of impervious area than the west side (34% versus 28%), and is thinner (3 inches versus 5 inches).

Table HA-9**: Relative Performance of West and East sides of the Hamilton Ecoroof**

Hamilton Roof Area	Winter		Summer	
	Retention	Retention (cu ft per 1" of media)	Retention	Retention (cu ft per 1" of media)
West[1]	54%	4,040	88%	1,720
East	24%	3,050	70%	2,380

[1] Includes only data from the period from Jan 2002 – Mar 2006, the monitoring period for the East side

Adjusting for retention per inch, the East side summer performance actually exceeds the West side. This may be related to the lighter East side soil blend drying more quickly and completely. The lighter East side soil still underperforms during the winter, but the gap is much less when considering its shallower depth.

Figure HA-9 compares the west side and east side response to an October 2005 storm similar in depth to a CSO Design Storm, though not the same pattern.

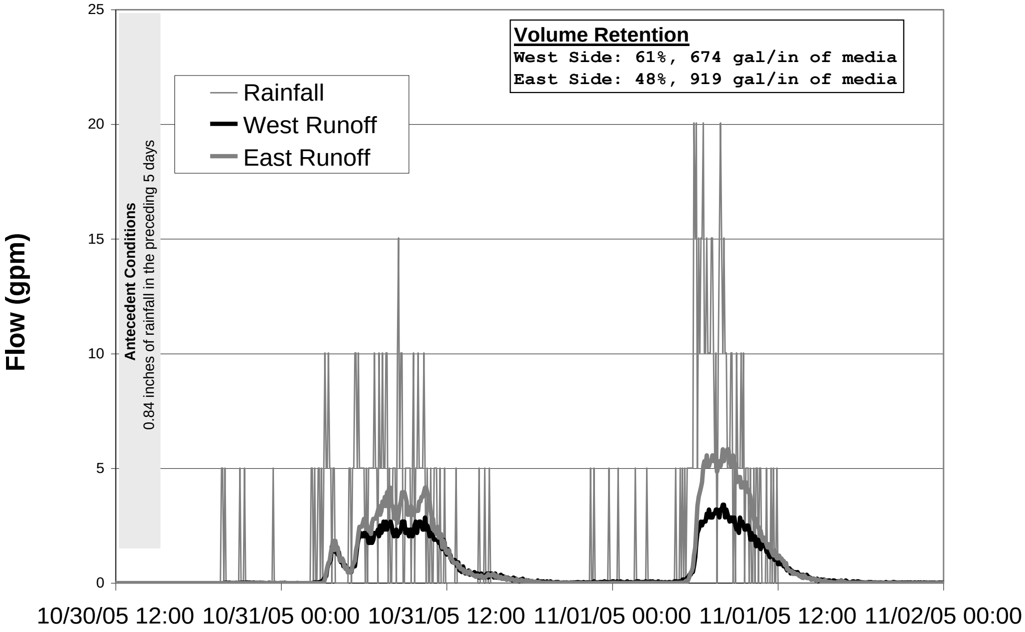


***Figure HA-9*: Runoff response to an October 2005 event**

Runoff from the East side is 40% higher than from the West side, but when adjusted for the thinner soil depth, the East side actually is retaining more per volume of soil media.

Given the potential benefits of a thinner, lighter soil (fewer structural requirements and fewer weeds) continued research on soil media similar to the one on the east side of Hamilton are warranted.

Water Quality

Runoff samples were taken from each side of the roof so that concentrations could be compared for the two different soil types. Of particular interest were heavy metals (copper, lead, and zinc) and nutrients (phosphorus and nitrogen), which have regulatory requirements because of potentially adverse watershed health impacts. Metals may be toxic to aquatic organisms while high concentrations of nutrients may lead to algal blooms. While these pollutants can come from rainfall or the breakdown of standard roofing materials, some stormwater facilities have been shown to export some metals and nutrients when runoff washes them from the soil or decaying vegetation.

Twenty-four runoff samples were taken from both sides of the roof between February 2001 and October 2012 – eight in the winter, eight in the spring, none in the summer, and eight in the fall. The number of samples appears adequate to identify preliminary trends, but the lack of summer samples and differences in storm pattern and antecedent conditions introduce many variables.

It should be noted that drainage issues on the east side could potentially have an impact on the east side water quality samples. Overflow from the penthouse roof during large events may carry pollutants not directly associated with the ecoroof to the east drain.

Metals

Effluent dissolved copper and dissolved zinc concentrations are shown in ***Figure HA-10***. The average dissolved copper concentrations are similar though slightly higher on the west side (12.2 µg/L west versus 7.8 µg/L east), but average dissolved zinc concentrations are much higher on the east side (15.9 µg/L west versus 49.8 µg/L east). Four of the final five east samples had zinc concentrations above 50 µg/L, with the last sampled event (June 2008) at a concentration of 274 µg/L. It is likely this dramatic increase is the result of galvanized roofing materials beginning a phase of rapid breakdown.

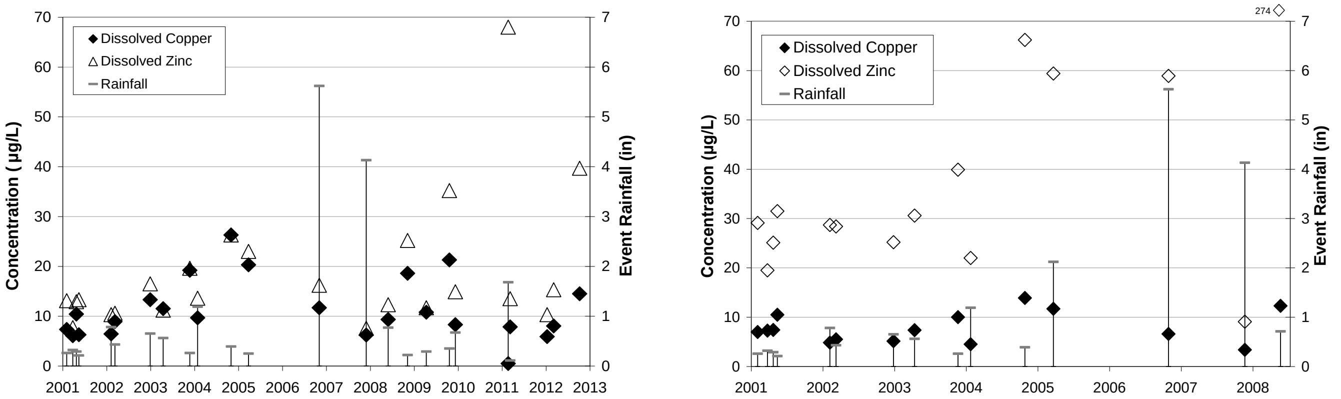


***Figure HA-10*: Dissolved copper and zinc levels – West roof (left) and East roof (right)**

There are no concerns over lead levels on the west side (***Figure HA-11***). All but 4 sample concentrations are non-detects, and the four that were detected are well below the 1.55 µg/L average concentration found in five rainfall samples collected on the ecoroof (Sullivan, 2005). Levels on the east side of the roof (average of 2.87 µg/L total; 1.29 µg/L dissolved) are much higher than those on the west side (average of 0.74 µg/L total / 0.11 µg/L dissolved).

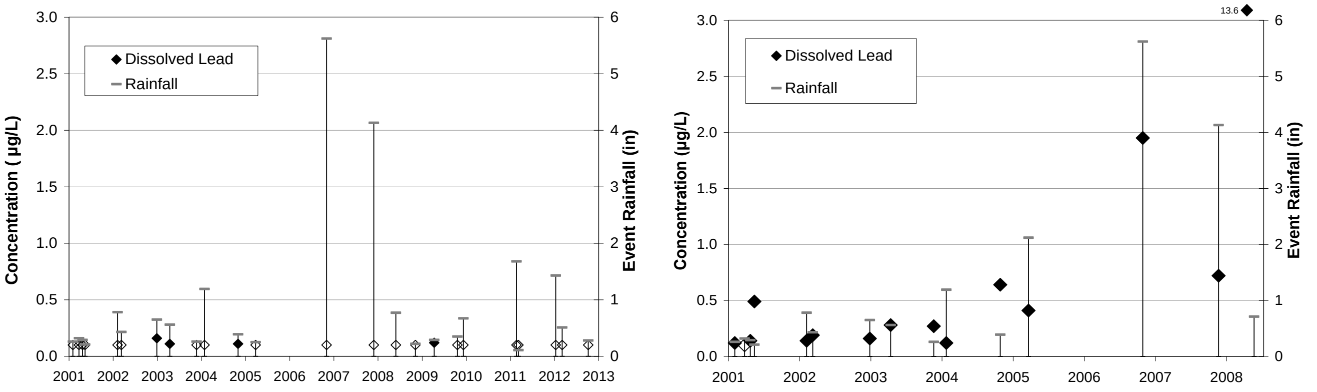


***Figure HA-11*: Lead levels – West roof (left) and East roof (right)**
(open diamonds are the minimum reporting limit for non-detects)

The source of the lead on the east side isn't certain, but the east side soil media does contains roughly 4 times the amount of lead found on the west side (***Table HA-10***).

***Table HA-10*: Comparison of metals in Hamilton Ecoroof soil media (2008)**

Metal	West (mg/kg)	East (mg/kg)
Copper, Total	30.9	33.4
Lead, Total	6.46	26.7
Zinc, Total	81.2	121.

Metal content in the east side soil media is generally higher than the west side soil media – especially for lead. Higher lead effluent levels on the east side seem to correspond to the higher levels in the soil media.

Copper effluent levels are roughly the same and so are the soil copper amounts. Zinc levels in the soil are somewhat higher on the east side, but not enough to explain the much higher zinc effluent on the east side. The east side does have more galvanized metal railing than the west side, and one railing section is close to the east drain.

***Figure HA-12*: east drain and metal railing**

Runoff samples for the last eleven storm events (December 2007 through October 2012) were also taken from the conventional penthouse roof on the Hamilton Apartment Building for comparison to the West roof. Results for metals are summarized in ***Table HA-11***.

***Table HA-11*: Comparison of metal concentrations in conventional roof and ecoroof runoff**

	Conventional Roof		**Hamilton West Ecoroof**	
	Average	Median	Average	Median
Copper (total)	3.41	2.22	11.3	10.3
Copper (dissolved)	2.47	1.20	10.1	8.30
Lead (total)	0.46	0.21	0.63	0.16
Lead (dissolved)	ND	ND	ND	ND
Zinc (total)	326	239	25.8	17.5
Zinc (dissolved)	301	229	23.1	14.9

ND = None Detected

n = 11 storm events where both ecoroof and conventional roof samples were taken

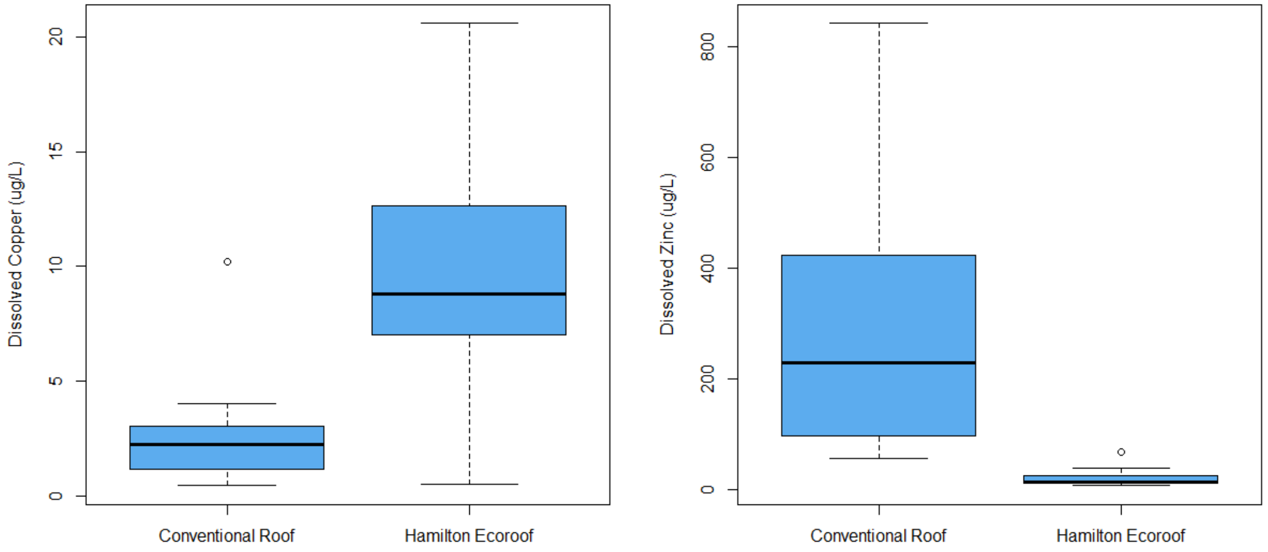


***Figure HA-11*: Box Plot of Conventional and Ecoroof Runoff Copper (left) and Zinc (right) Concentrations**

(box plots: the vertical line represents the range of values, the box is the middle two quartiles, and the black bar in the box is the median value; ° = statistical outliers. n = 11 storm event samples)

Conventional roof runoff has significantly higher levels of zinc, roughly the same level of lead, and lower levels of copper. Copper levels in ecoroof runoff are averaging just over 10 µg/L, roughly 4 times higher than the levels in the conventional roof runoff. During 24 total storm events sampled over the past 11 years, the highest zinc level in the ecoroof effluent has been 69 µg/L, while the 11 conventional runoff samples have an average concentration of over 300 µg/L.

Analysis of rainfall on the Hamilton Ecoroof found average concentration of 2.85 µg/L for copper, 1.34 µg/L for lead, and 20.4 µg/L for zinc (Sullivan, 2005). Results are based on a sample of only five rain events from December 2004 – May 2005, but they do suggest that copper and lead runoff levels may be influenced by rainfall.

The higher levels of copper in the ecoroof runoff may be the result of copper export from the soil media. Zinc levels are likely associated by conventional roofing materials like galvanized metals. The much lower ecoroof zinc levels suggest the soil media does an excellent job of buffering.

The copper levels on the west side and zinc levels on the east side, sometimes exceed acute water quality criteria for the State of Oregon (***Table HA-12***).

***Table HA-12*: Metal (dissolved) concentrations and how they relate to the State of Oregon water quality criteria**

Metal	**Average West Roof (µg/L)**	**Average East Roof (µg/L)**	**Oregon Water Quality Criteria[1]**	
			West Roof	East Roof
			Acute Criteria Exceeded?[2]	Acute Criteria Exceeded?[2]
Copper	11.2	7.83	**5 of 24**	None
Lead	ND	0.43	None	None
Zinc	18.7	49.8	**1 of 24**	**5 of 24**

[1] Based on values, lead and zinc corrected for hardness, as specified in OAR 340-041 Table 20 (OAR = Oregon Administrative Rules).
[2] Number of samples that exceeded water quality criteria.

Given the limited seasonal data, scatter of the data points, and the potential contributions from the penthouse roof to the east side, it is difficult to draw conclusions. However, it does appear that zinc concentrations are trending upward over the last four years. There's no definitive trend for copper, but it is known to impact aquatic life at relatively low levels and minimizing export should be a focus in the future.

Nutrients

The primary nutrients of concern are nitrogen and phosphorus. Nitrates and phosphorus promote algal blooms, while ammonia can be harmful to aquatic species.

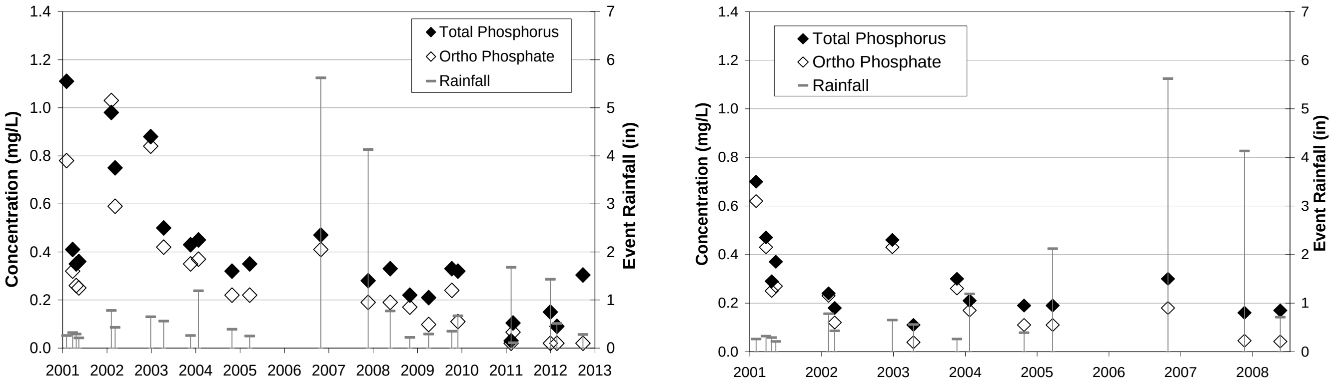


***Figure HA-13*: Phosphorus levels – West roof (left) and East roof (right)**

Phosphorus concentrations have trended downward on both sides of the roof over time, and appear to be leveling out. This could be explained by greater stabilization (compaction and maturity) of the soil media over time, or from reduced availability as phosphorus leaves the roof (net export). However, this leveling out is also occurring over a substantial period of time. The ecoroof was built in 1999, and it wasn't until 2004 until levels consistently dropped below 0.2 mg/L on the east side. The west side has taken even longer to drop – it wasn't until 2005 that levels dropped below 0.4 mg/L, and then

2011 before they dropped below 0.2 mg/L. Comparing soil samples taken in 2002 and 2010, total phosphorus in the soil media has remained similar, but ortho-phosphate and nitrate have dropped substantially (***Table HA-13***).

***Table HA-13*: Comparison of nutrients in West Hamilton Ecoroof soil media**

	2002 (mg/kg)	**2010** (mg/kg)
Phosphorus, Total [a]	958.	872.
Phosphorus, Ortho [b] (extractable)	100.	29.0
Nitrate [b] (extractable)	254.	0.25

[a] Method EPA 200.7; [b] Method EPA SM 4500

Though there are no general water quality criteria for phosphorus, levels from all events on the west side and all but one event on the east side exceed benchmarks for industrial point source discharges (0.16 mg/L) and the TMDL established for the Fanno Creek and Columbia Slough watersheds.

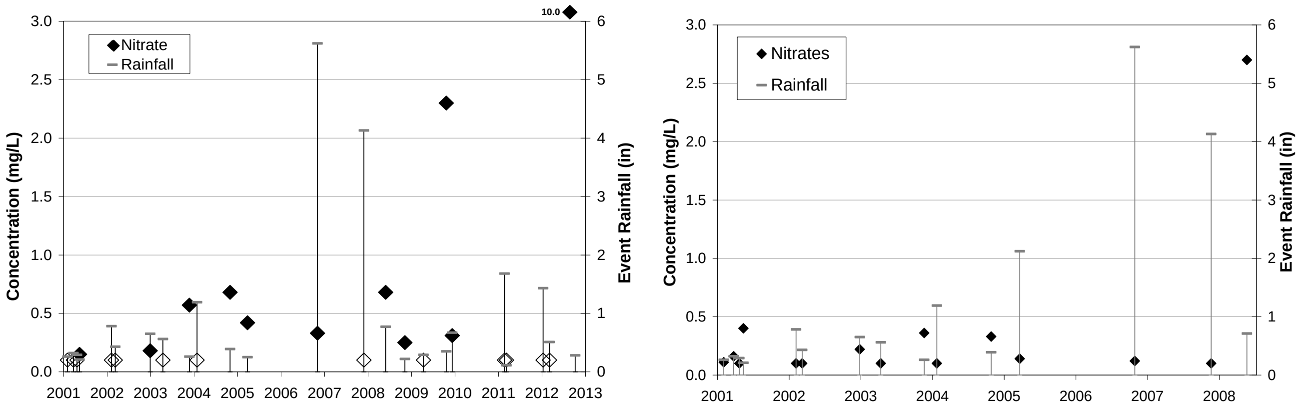


***Figure HA-14*: Nitrate levels – West roof (left) and East roof (right)**
(open diamonds are the minimum reporting limit for non-detects)

Nitrate levels for the west roof increased in late 2003 and have been highly variable since that time. However, the average nitrate value for east and west is similar and both sides are well below criteria levels. Some of the nitrate variability on the west side could be the result of clover and vetch that have become established on roof. Both are nitrogen fixers that bring nitrogen from the air into the soil. Clover was present shortly after the roof was completed, but vetch became more common around 2003. However, both clover and vetch are also present on the east side of the roof and there is no similar elevation in nitrates. Ammonia levels are similar on each side, and are both well below water quality benchmarks.

***Table HA-14*: Average nutrient concentrations and how they relate to the State of Oregon water quality criteria**

Parameter	**West Roof Avg Runoff Concentration (mg/L)**	**East Roof Avg Runoff Concentration (mg/L)**	**Oregon Water Quality Criteria**		
			mg/L	West Exceeded?	East Exceeded?
Nitrates	0.36	0.34	10^{+}	None	None
Ammonia	0.036	0.035	$3.5^{\dagger}$	None	None

Total Phosphorus	**0.48**	**0.29**	0.13-0.16[‡]	**20 of 24**	**14 of 15**
Ortho Phosphate	0.37	0.22	N/A		

[+] Based on drinking water standards (MCL) and human consumption (OAR 340-041 Table 33A)

[†] Average value, corrected for pH, as specified in OAR 340-041 Table 20.

[‡] No values exist in the OAR; the Fanno Creek TMDL is 0.13 mg/L, and the industrial NPDES permit benchmark (1200-COLS) is 0.16 mg/L.

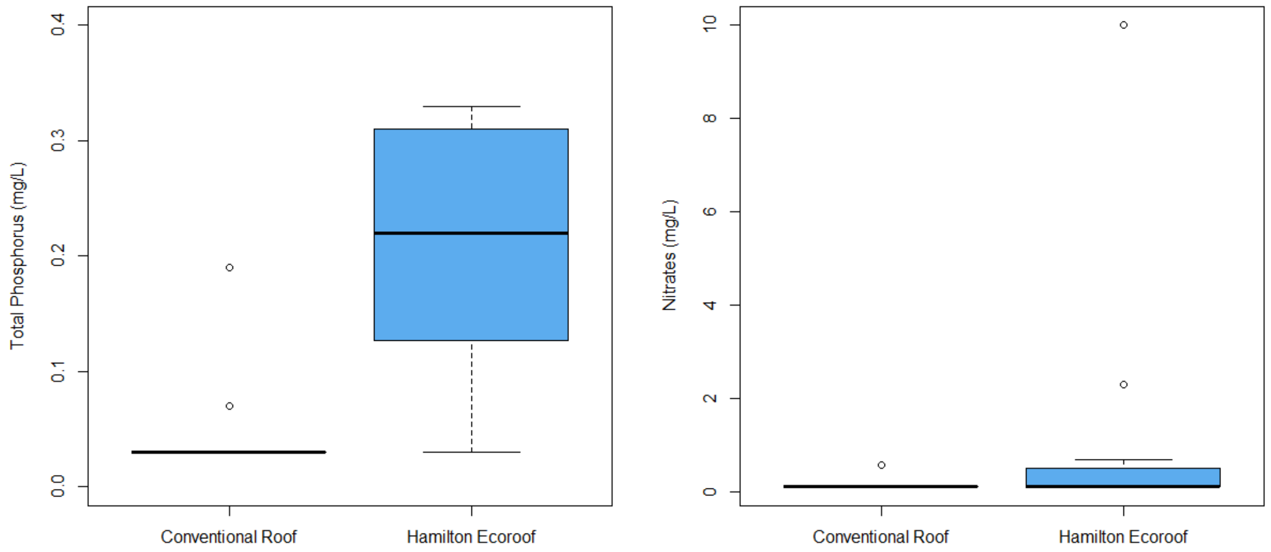


***Figure HA-15*: Box Plot of Conventional and Ecoroof Runoff Concentrations Total Phosphorus (left) and Nitrate (right)**

(box plots: the vertical line represents the range of values, the box is the middle two quartiles, and the black bar in the box is the median value; ° = statistical outliers. n = 11 storm event samples

***Table HA-15*: Comparison of nutrient concentrations in conventional roof and ecoroof runoff**

	Average Conventional Runoff Conc. (mg/L)	**Average West Ecoroof Runoff Conc. (mg/L)**
Nitrates	ND	0.62
Ammonia	0.088	0.033
Total Phosphorus	ND	0.28
Ortho Phosphate	0.06	0.17

ND = Non-detect

Conventional runoff showed little or no presence of nutrients (***Table HA-15*** and ***Figure HA-15***). All nutrients but ammonia are found in greater concentrations in ecoroof runoff. Rainfall at this location has not been shown to contain significant nutrients (Sullivan, 2005). This suggests nutrient runoff is driven mostly by the soil media, vegetation life cycles, and aerial (dry) deposition.

Other Analytes

Total suspended solids (TSS) levels were higher for the west side soil (an average of 8.9 mg/L versus 2.4 mg/L for the east side), but both are very low. Dissolved solids were also somewhat higher on the west side (an average of 124 mg/L versus 86 mg/L on the east side), but all levels are well below EPA guidelines for drinking water (500 mg/L).

There was little difference in the runoff pH between the two soil media, with both averaging about 6.2. Rainfall samples averaged 5.7, and the conventional roof runoff averaged 6.4.

The west side had higher hardness concentrations – averaging 38 mg $CaCO_3$/L versus 27 mg $CaCO_3$/L for the east side. Both fall into the moderately soft water category. Lower hardness results in more metal availability, and correspondingly lower water quality criteria.

Overall

There remain uncertainties regarding the impact of soil media on runoff quality. Runoff concentrations do not correlate well with event rainfall depth, event rainfall intensity, or deposition time (preceding time without significant rain). It is also likely that the corrosion of conventional roofing materials and even rainfall can be sources of various pollutants.

However, it is clear that for this ecoroof, levels of copper and phosphorus could be problematic depending upon where stormwater is discharged. This reinforces the idea that water quality characteristics of the ecoroof runoff must be considered when choosing soil media, vegetation types, and roofing materials.

Maintenance

Figure HA-14: **Sprinklers on Hamilton Ecoroof**

Irrigation is used periodically on the roof, but the soil retains moisture fairly well meaning that daily irrigation is not needed. This reduces irrigation costs and provides a better chance that the roof will have capacity to impact summer storm events.

Periodic irrigation line breaks have been an issue. Inadvertent damage caused by maintenance workers and the activities of residents of the apartment building have been a factor. Because the roof is accessible to residents, debris is routinely present on the roof including food, garbage, beer bottles, and paper.

Design

The primary design seems to be a good one. The roof has had only one significant leak, and a few small irrigation leaks caused by maintenance or resident activity on the roof.

Irrigation needs are minimal and plants seem to be doing well. Weed species have established on the roof but do not appear to should have a negative impact on the function of the roof. As the roof continues to age, the interaction between intended and unintended species will be evaluated.

When designing a new roof, the use of galvanized metals (zinc) and copper materials should be limited. There is evidence that high levels of copper and zinc may be exported off the roof. Elevated levels of both metals are harmful to the aquatic species and could potentially pose a health risk for humans.

Vegetation

Approximately one-third of the original 100+ species have ceased to survive for a variety of reasons, while other species thrive. Several species of grass and populations of vetch, geranium, clover, groundsel are healthy; noticeably spreading throughout the roof and appearing to out-compete some of the originally planted species.

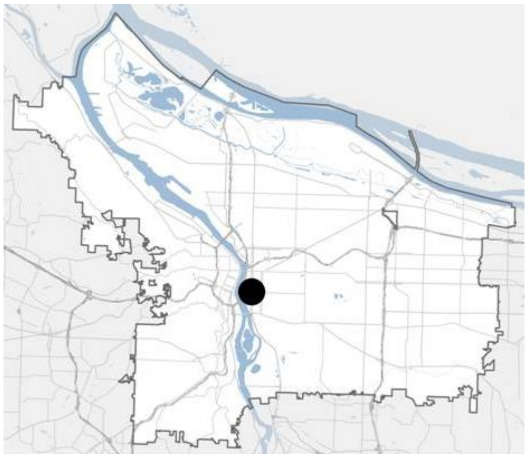
In general, the same species are doing well on both sides of the roof, but the density of vegetation is higher on the west side. Weeds (especially clover) are more of an issue on the west side of the roof - likely due to the thicker, denser soil. While both characteristics improve the ability to retain stormwater and limit runoff, it also provides a fertile and moist soil for weeds to establish.

Monitoring Summary

- Both soil media do an excellent job of reducing peak runoff and would be essentially remove any peak flow contribution from the roof. CSO design storm retention varies from 57% to 65% and would greatly benefit overflow control strategies.
- The balance between volume retention, runoff water quality, and plant health is a difficult one. At this point, it would appear that a heavier, thicker soil will be the best choice for volume retention and water quality benefits. The heavier soil also retains moisture better so could reduce maintenance costs by requiring less irrigation during the summer months.
- There is the potential for significant export of metals and nutrients off the roof via runoff. The selection of soil and the roofing materials should take this into account.
- Weeds will be an issue. If the soil retains moisture and is conducive to plant growth, at least some weed species will find the roof hospitable.

Multnomah County Building Green Roof

Summary Information		
Evaluation Period:	**3 years** (July 2004 – June 2007)	**The ecoroof soil media averages 6 inches in depth and is mostly perlite and pumice. The planted area is 11,900 sq ft, but 3,440 sq ft of flagstone terrace and pavers also drain through the soil to the roof drains. Only the west half of the roof is monitored to avoid issues associated with the paver drainage.**
Constructed:	**July 2003**	
Facility Type:	**Ecoroof**	
Drainage Area:	**15,420 ft^2 (7,000 ft^2 monitored)**	
Facility Area:	**11,900 ft^2**	
Sizing Factor:	**N/A**	



Monitoring Result Summary

Peak Flow Reduction

88%

Flow Volume Reduction

Annual	-5%
Summer (MAY – OCT)	-69%
Winter (NOV-APR)	16%
CSO-like Events	11%

Water Quality

N/A

Soil / Infiltration

Proprietary mixture of pumice, perlite, digested paper fiber, and paper pulp

Design

Mixture of sedum, perennials, bulbs, and ornamental grasses. The use of several tall grass and wildflower varieties requires annual trimming. Keeping vegetation green throughout the summer months requires substantial amounts of irrigation.

Maintenance

- Irrigation: rates were adjusted several times but significant runoff was generated; over irrigation reduces peak flow and flow volume benefits
- Vegetation: grasses and wildflowers require trimming once per year in the fall

Overview

The ecoroof on the 6th floor terrace of the Multnomah County Building was completed in July 2003. The roof consists of 11,900 square feet of ecoroof and 3,440 square feet of flagstone terrace and perimeter pavers. The soil averages 6 inches in depth and is a mix of pumice, perlite, digested fiber, and reclaimed paper pulp. Plantings include grasses, sedum, perennials, and wildflowers. A drip irrigation system was installed for daily irrigation during the summer months.

To ensure that monitoring results reflect the performance of the ecoroof as closely as possible, only the west roof drains were monitored. This is because the east roof drains receive not only ecoroof runoff, but also runoff from the impervious flagstone terrace. Runoff is measured by electro-magnetic flow meters and relayed to a data logger that is downloaded once per week.

***Figure MU-1*: Monitored Roof area (black outline, north is to the left)**

The monitored ecoroof area was estimated to be approximately 6,100 square feet. However, many rainfall events during the winter months generate more flow than could be generated by that drainage area. Based on the runoff flow record, the drainage area is more likely close to 7,000 square feet and that figure is used as the basis for performance in this report.

Rainfall data is obtained from a raingage that was installed on the roof in October 2004. Rainfall data for summer 2004 is based on data from the Ankeny raingage, 0.8 miles to the northwest, and the Sunnyside raingage, 1.5 miles to the east.

***Figure MU-2:* Monitoring equipment**

Peak Flow

The storm events with the highest rainfall intensities are shown in ***Table MU-1***. All events show a highly consistent average peak flow reduction of 86% and an average peak flow delay of 66 minutes.

***Table MU-1*: Peak flow reductions for events from October 2004 – June 2005 with rainfall intensities greater than 0.60 inches per hour**

Event Date	Peak Rainfall Intensity (in/hr)	Uncontrolled Roof Peak Flow (gpm)[1]	Metered Peak Flow (gpm)	Peak Flow Reduction	Average Peak Flow Reduction
10/23/04	0.72	52.4	4.3	92%	**88%**
04/16/05	0.96	69.8	12.5	82%	
04/17/05	0.96	69.8	6.6	91%	
05/16/05	0.72	52.4	8.9	83%	
05/19/05	1.08	78.5	9.7	88%	
06/10/05	0.84	61.1	8.0	87%	
06/17/05	0.72	52.4	5.4	90%	
06/22/05	1.44	104.7	14.5	86%	
08/29/05	0.72	52.4	9.9	81%	
10/01/05	0.84	61.1	6.0	90%	
12/30/05	0.84	61.1	10.2	83%	
04/05/06	0.72	52.4	12.7	76%	
05/07/06	0.84	61.1	8.3	86%	
05/21/06	3.00	218.1	22.0	90%	
09/14/06	0.72	52.4	7.6	85%	
11/01/06	0.96	69.8	0.1	100%	
11/21/06	0.84	61.1	8.1	87%	
03/19/07	0.72	52.4	5.6	89%	
03/30/07	0.72	52.4	2.3	96%	
04/16/07	1.32	96.0	7.3	92%	

[1] Runoff expected from a standard roof using the maximum 5-min rainfall intensity and assuming a 0.98 runoff coefficient.

The average peak flow reduction of 88% indicates that this ecoroof would be effective at reducing the risk of basement sewer backups. The most intense rainfall during the monitoring period was 3.00 inches per hour – just short of the 3.32 inches per hour intensity of the 25-Yr Design Storm used for basement sewer backup protection.

Flow Volume

Seasonal and overall runoff volumes are compared with rainfall and irrigation totals in ***Table MU-2*** and ***Figure MU-3***.

Table MU-2: Flow volume reductions for the Multnomah County Building Green Roof

Period	(in) Total Rainfall	(in) Irrigation	(ft^3) Potential Runoff¹ (including irrigation)	(ft^3) Metered Runoff	Retention (including irrigation)
Monitoring Period	115.7	89.5	66,100 (118,300)	69,400	**-5%** **(41%)**
Winter (NOV-APR)	87.3	11.0	49,900 (56,300)	41,900	**16%** **(26%)**
Summer (MAY-OCT)	28.4	78.5	16,200 (62,000)	27,500	**-69%** **(56%)**

¹ Rainfall + Irrigation

Comparing rainfall with total annual runoff, the ecoroof actually generates 6,200 gallons beyond what would be expected from a comparable conventional roof – this results in a ***negative*** retention (-10%). The reason for the negative retention is irrigation. Irrigation applied during the three year monitoring period almost doubles the total water the ecoroof must manage – 111 inches of rainfall alone, but 200 inches of rainfall plus irrigation.

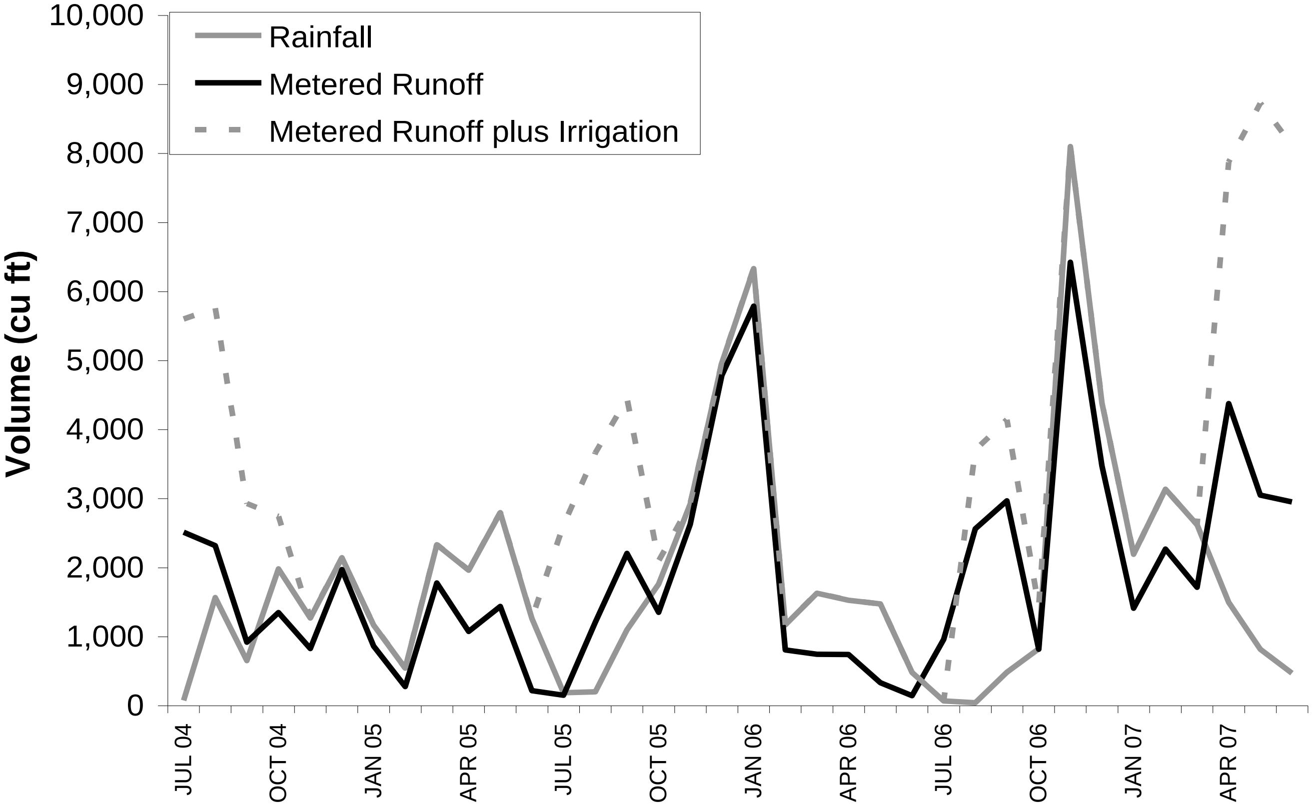


***Figure MU-3*: Monthly rainfall and runoff retention**

Rainfall data from July 2004 – October 2004 are from raingages in close proximity.

Flow data from July 2004 – April 2005 has been corrected due to a problem with the south flow meter.

The roof is irrigated with a drip system during the summer months to prevent the vegetation from going brown and dormant. Irrigation rates have been high enough that daily runoff occurs even when there is no rainfall. This also reduces the retention capacity of the soil when rain events do occur.

The greatest retention would be expected during the summer months when rainfall is low and evapotranspiration is high. However, when compared to rainfall alone, summer retention was -71%, with 11,500 more gallons metered than would be expected from a corresponding conventional roof. Winter retention was low, averaging 11% but was frequently 0% during the wettest periods.

When the applied irrigation volume is added to rainfall, the roof actually retains 40% of all the water entering the soil and the summer retention rose to 56%. This indicates rainfall retention could be greatly improved if irrigation could be minimized or eliminated.

Looking at individual storm events, the relationship between event runoff and event rainfall is generally linear (***Figure MU-4***). Higher retentions are seen for storm events below 0.5 inches, and are minimal for larger events.

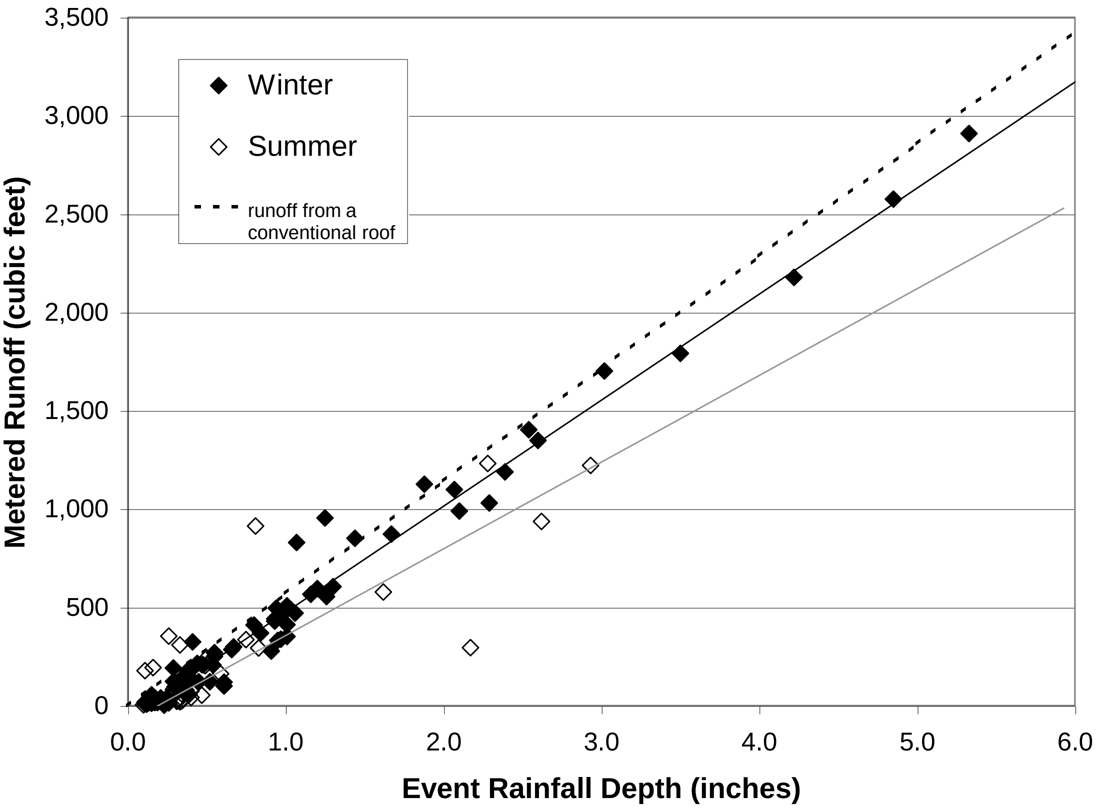


***Figure MU-4*: Seasonal rainfall / runoff relationship**
(122 events, Oct 2004 – Jun 2007)

Winter performance is similar to that of a conventional roof, with summer performance being somewhat better though with significant scatter of the data points. It could be assumed that the summer trend line would show a bigger difference if summer irrigation were not an issue.

There were no events during this monitoring period that closely match the CSO Design Storms, but those that were closest are presented in ***Table MU-3*** and have retentions between 5 and 18%.

***Table MU-3*: Multnomah County Green Roof - volume retention for storm events most similar to CSO Design Storms**

Rain Event	(in) Total Rain	(hrs) Duration	(in/hr) Peak Intensity	(ft^3) Potential Runoff[1]	(ft^3) Metered Runoff	% Retention
Aug 21 2004	1.03	21	0.60	515	480	7
May 17 2005	1.22	56	1.08	610	500	18
Sep 30 2005	1.76	16	0.60	1,010	929	8
Oct 30 2005	2.28	41	0.48	1,300	1,230	5

[1] Potential runoff from a conventional roof assuming a runoff coefficient of 0.98.

Two events occurred outside the May to October period when the summer design storms apply. However, both storms are close to the summer season and retentions do not differ substantially from the other events. The September 30, 2005 event is perhaps the most representative of the CSO Design Storms, and the roof runoff response for this event is shown in ***Figure MU-5***.

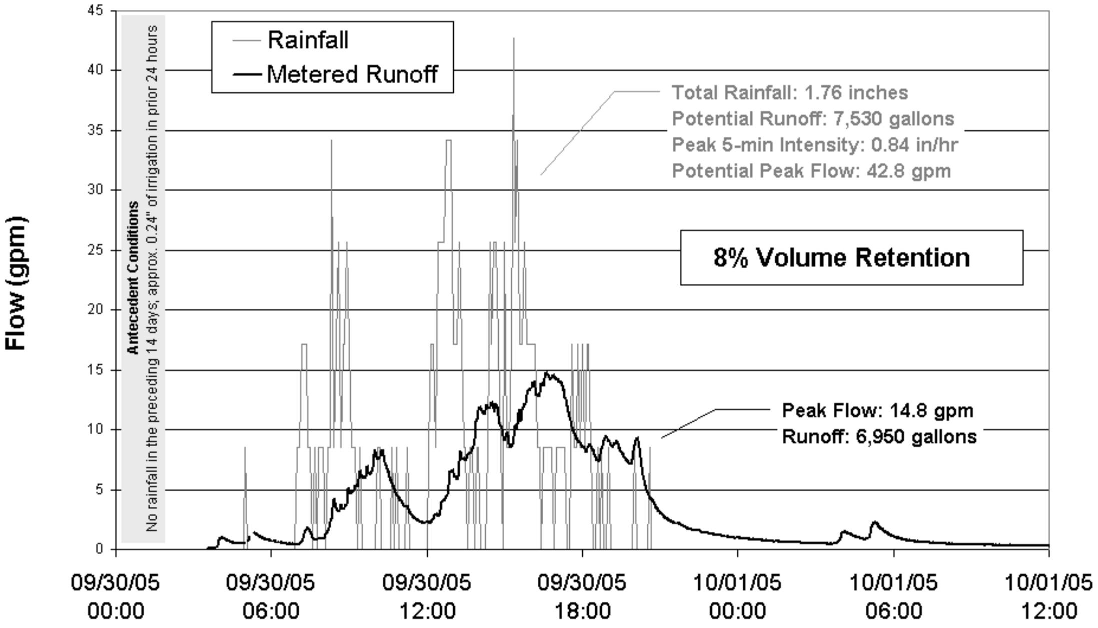


***Figure MU-5*: Response to September 2005 storm event, similar to summer CSO Design Storms**

The average retention of the events in ***Table MU-3*** is 11%, so it would appear that CSO design storm retention at this point is not substantial.

The maturing vegetation and soil media could increase volume retention in the future. However, performance is unlikely to increase substantially if irrigation rates are not reduced.

Vegetation & Maintenance

Vegetation consists of a mix of various wildflowers and fescue grass. Also planted were ornamental grass, sedum, and perennials. Unintended weed and grass growth was observed in the sedum sections in late 2005, along with some noticeable linear patches of browning among the fescue.

The grass appears to grow more densely around each irrigation drip emitter. Because the soils are limited in organic content, a time released nitrogen fertilizer is applied twice per year to keep the vegetation green and vigorous. Volunteers from the building pull weeds as needed throughout the year, and over-seeding of grass and wildflowers occurs every spring

Several grass and wildflower varieties on the roof grow to significant height, and Multnomah County trims the vegetation once a year in the fall and removes the debris from the roof. While this is not a substantial cost, heavier reliance on plant varieties with lower maintenance requirements, like sedum, may lower vegetative maintenance costs.

Multnomah County desired the roof to remain green throughout the dry summer months. Given the plant species (wildflowers and grasses) and the porous soil media with limited moisture retention capacity, this required daily irigation. Summer irrigation is summarized in ***Table MU-4***.

***Table MU-4*: Irrigation use by year**

Year	Irrigation Period	(in) Rainfall	(in) Irrigation	(in/day) Average Daily Irrigation	(ft^3) Est. Rainfall Runoff	(ft^3) Metered Runoff
2004	Jul 1st – Oct 18th	5.50	21.7	0.20	3,140	7,100
2005	Jul 5th – Oct 3rd	2.88	18.8	0.21	1,650	3,400
2006	Aug 2nd – Oct 5th	0.95	15.3	0.24	540	5,825
2007	Apr 5th – Jun 30th	4.86	45.0	0.50	2,770	10,370

Initial irrigation rates during summer 2004 coupled with a higher than normal summer rainfall resulted in daily runoff due to over-saturation. Irrigation rates were reduced throughout the summer in an effort to find a balance between minimizing irrigation runoff and keeping plants green. Irrigation rates stayed consistent during summer 2005, but a malfunction at the beginning of 2006 resulted in a browning roof and some plant death. Irrigation rate and frequency were increased in mid-August 2006 and remained fixed through the rest of the monitoring period. Irrigation was begun in April 2007 in response to an early heat wave. The combination of spring rains and irrigation resulted in large quantities of runoff through the end of June.

Monitoring Summary

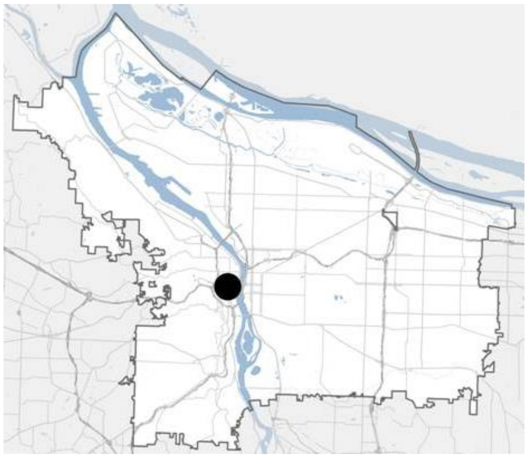
- This ecoroof appears to do an excellent job of reducing peak flows. While additional data from storm events with intensities closer to the 25-year Design Storm is desirable, the average 88% peak flow reduction to date would be very helpful in reducing basement sewer backup risk.

- At this point, the combination of soil media and irrigation on the Multnomah County Green Roof does not appear to be very effective at controlling runoff volume. Despite an average soil depth of 6 inches, winter retention is low (averaging 11%) and summer retention is compromised by daily irrigation runoff.

- In general, it would be desirable to limit the need for irrigation on ecoroofs. Irrigation reduces the ability to reduce flow volumes in the summer – the time during which control of CSO events is most crucial in the combined sewer and water quality issues are most important in the separated system. Irrigation also has associated costs for electricity and water that may be significant.

Portland Building Ecoroof

Summary Information		
Evaluation Period:	**5+ years** (March 2007 – June 2012)	**Retrofit atop a 15 story building downtown Portland. Soil media is 3" thick. Approximately 5,250 ft^2 is being monitored – the SW corner and half the penthouse which drains to that quadrant.**
Constructed:	**November 2006**	
Facility Type:	**Ecoroof**	
Drainage Area:	**18,000 ft^2**	
Facility Area:	**16,000 ft^2**	
Sizing Factor:	**89%**	



Monitoring Result Summary

Peak Flow Reduction

93%

Flow Volume Reduction

Annual	**70%**
Summer (MAY – OCT)	81%
Winter (NOV-APR)	66%
CSO Events	62%

Water Quality

- Metals: copper and zinc levels
- Nutrients: nitrogen and phosphorus levels

Soil / Infiltration

Proprietary mix of sandy loam, pumice, compost, and Stockosorb® polymer

Design

Mixture of two dozen sedum species and rows of blue oat grass.

Maintenance

Irrigation is metered and can be controlled manually as needed. Irrigation period is typically from mid-June through September.

Overview

The Portland Building roof was retrofitted in the summer and fall of 2006 and has been monitored since March 2007. Monitoring is occurring in the southwest quadrant of the roof which drains approximately 3,750 ft^2 of the main roof and 1,500 ft^2 of the penthouse roof that drains down onto the main roof.

Roof runoff is forced to pass through a fiberglass flume attached to the southwest drain (***Figure PB-1***), where water depths are measured and converted to corresponding flow rates. Run-on is estimated from rainfall data collected from a raingage installed on the penthouse roof.

Figure PB-1**: Portland Building Ecoroof (SW corner) – monitoring setup (flume, data logger, & raingage)**

Most of the roof is ecoroof, though there are pavers around the penthouse and roof parapet perimeter, and a large HVAC installation in the southeast quadrant.

Peak Flow

Limited data is available, but it appears the Portland Building Ecoroof does an excellent job of eliminating peak flows. Peak flow reduction for the most intense storm events is averaging 93%. Results for the most intense rainfall events are shown in ***Table PB-2***.

The maximum flow rate during the monitoring period was 11.7 gallons per minute, equivalent to the flow rate expected from a conventional roof of the same size for only 0.02 inches of rain in a 5 minute period.

The storm event generating the highest runoff rate during the monitoring period, May 4, 2009, is shown in ***Figure PB-2***.

***Table PB-2*: Peak flow reductions for events with 5-minute peak rainfall intensities >= 1.0 inch per hour**

Event Date	Peak 5-min Rainfall (in/hr)	Ecoroof Runoff		
		Peak Flow (gpm)	Peak Flow Reduction[1]	Average Peak Flow Reduction
08/18/08	1.08	0	100%	**93%**
12/24/08	2.40	2.3	98%	
05/04/09	1.20	9.9	85%	
06/19/09	1.32	N/A		
10/25/09	1.44	4.7	94%	
11/05/09	1.44	9.7	88%	
06/06/10	1.08	3.8	94%	
09/07/10	2.16	3.6	97%	
09/18/10	2.40	8.7	93%	
10/24/10	1.80	8.5	91%	
12/14/10	1.20	8.8	86%	
02/28/11	1.32	7.6	95%	
05/27/11	1.44	0.2	99%	
10/09/11	1.32	5.3	93%	
03/15/12	1.56	9.1	89%	
05/26/12	2.88	8.6	95%	

[1] Based on runoff expected from a standard roof using the maximum 5-min rainfall intensity and a 0.98 runoff coefficient.

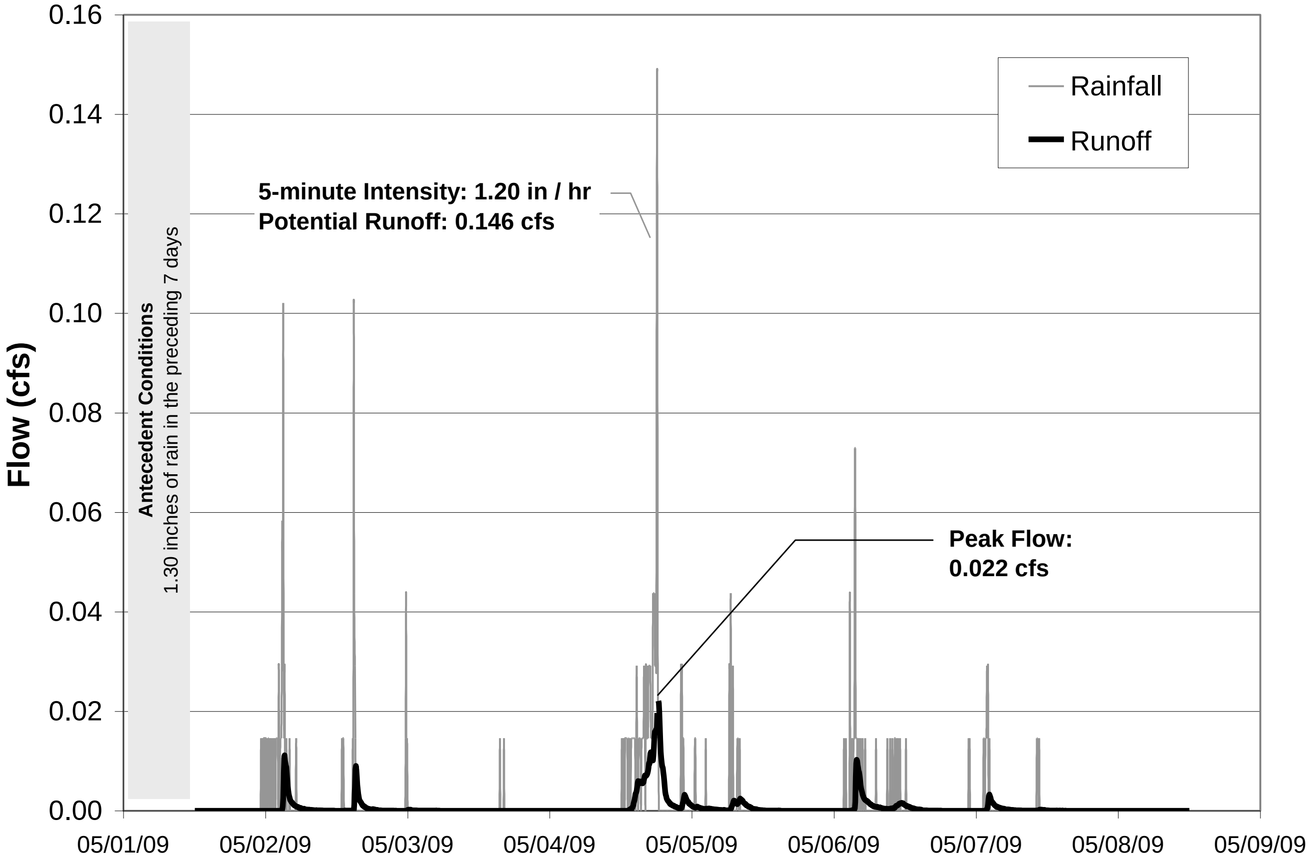


***Figure PB-2*: Roof runoff for the 5/4/2009 event**

While the roof has done well in reducing peak flows, there have been no rainfall events approaching the intensity of the 25-Year Design Storm during the short monitoring period.

Flow Volume

For just over 5 years of monitoring, the Portland Building reduced annual runoff by an average of 70%. Data is summarized in ***Table PB-3*** and ***Figure PB-3***.

***Table PB-3*: Overall runoff retention, Portland Building**

Period	(in) Total Rainfall	(ft^3) Potential Runoff	(ft^3) Metered Runoff	Retention
March 2007 – July 2012	209.2	89,700	27,000	**70%**
Winter months (NOV-APR)	156.3	67,000	22,800	**66%**
Summer months (MAY-OCT)	52.9	22,700	4,200	**81%**

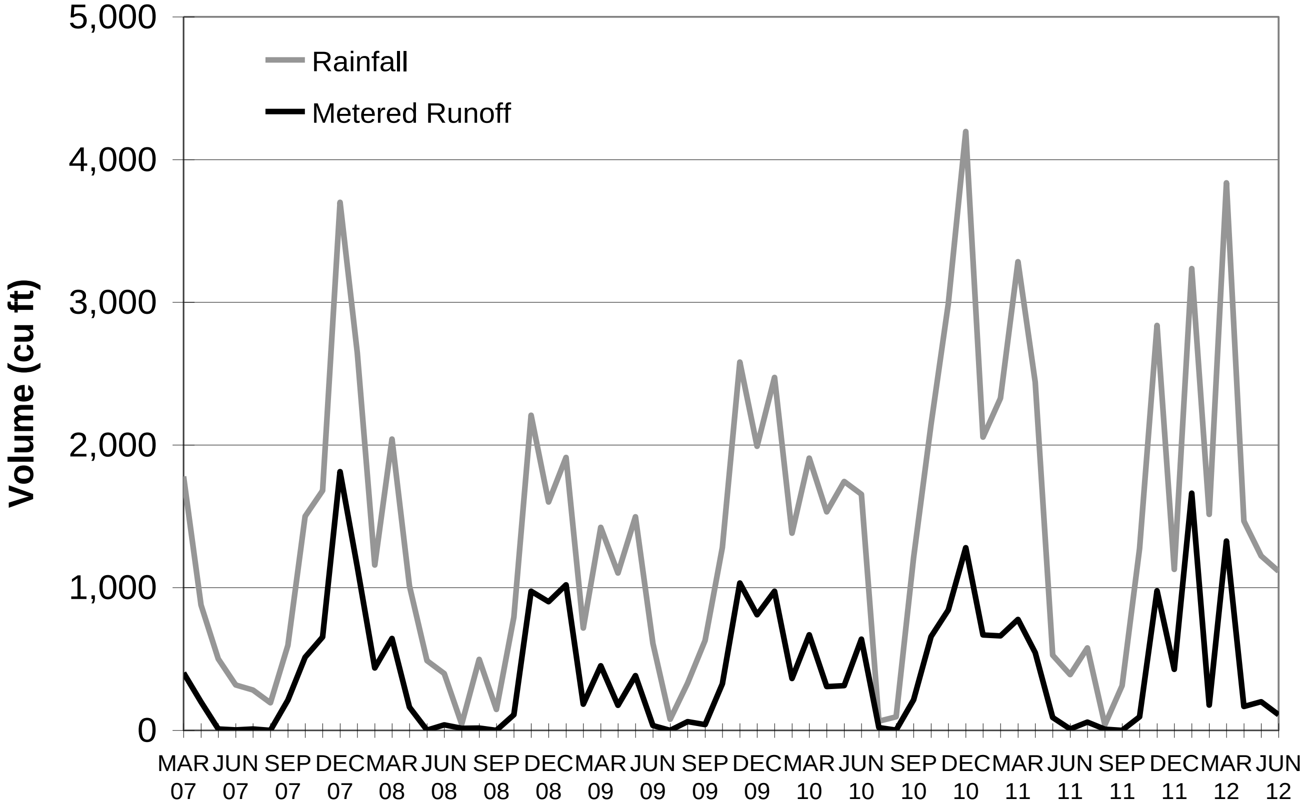


***Figure PB-3*: Monthly rainfall and associated runoff retention, Portland Building**

As expected, the roof has high retention rates during the summer months. However, it also has a relatively high retention rate during the winter as well. It performs similarly to Hamilton's west side which retained 58% of rainfall volume over the same winter months.

For individual storm events, it appears that runoff is strongly related to the rainfall depth of an event. While there is some scatter, there are separate and well-defined linear trends for the summer and winter seasons. These trends are compared to runoff expected from a conventional roof in ***Figure PB-4.***

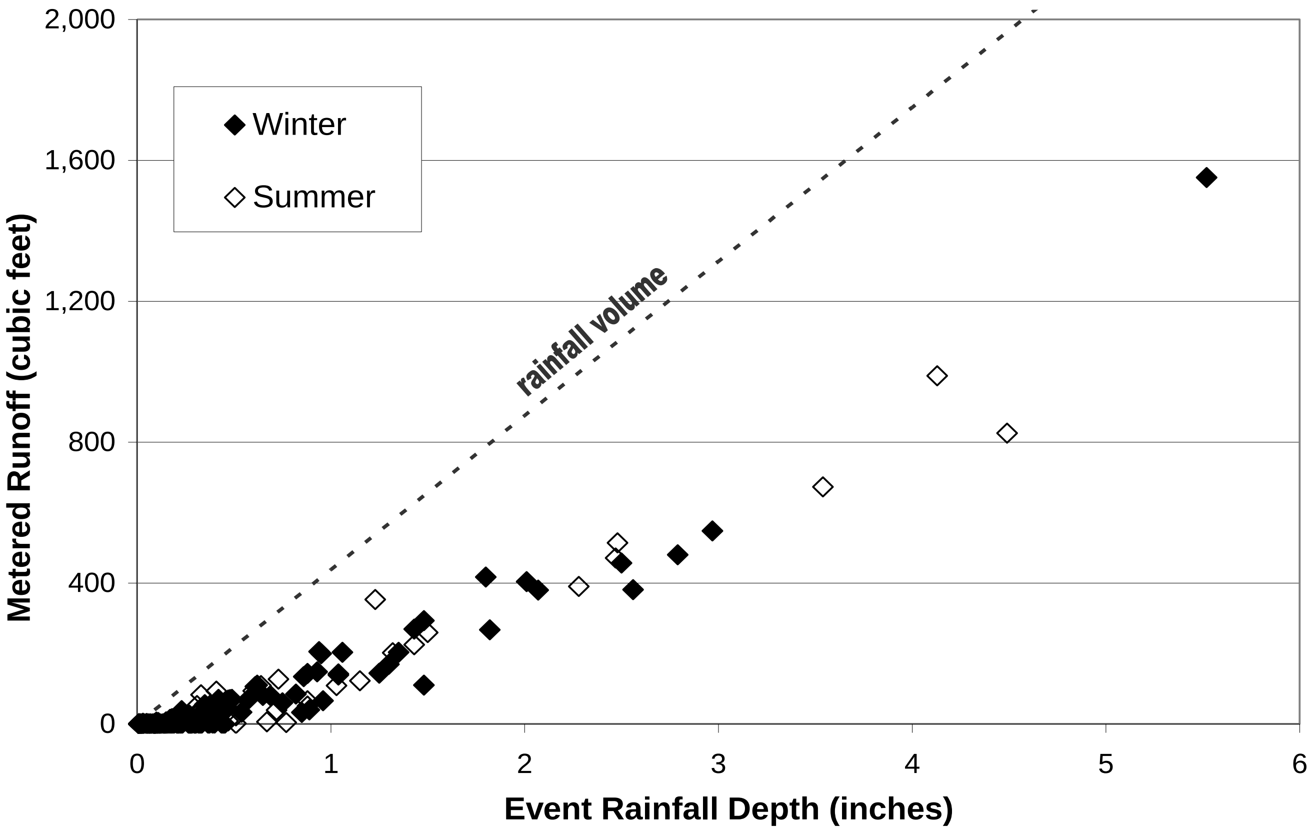


***Figure PB-4*: Seasonal rain event runoff as a function of total storm rainfall, Portland Building**

There have only been two events similar to the CSO Design Storms during the monitoring period. The storm events are summarized in ***Table PB-5*** and ***Figure PB-5***.

***Table PB-5*: Volume retention for storm events**

most similar to CSO Design Storms, Portland Building

Rain Event	(in) Total Rain	(hrs) Duration	(in/hr) Peak Intensity	(ft^3) Potential Runoff	(ft^3) Metered Runoff	Retention
Jun 06 2010	1.28	27	1.08	549	272	**52%**
Oct 09 2010	1.64	35	0.36	703	207	**71%**

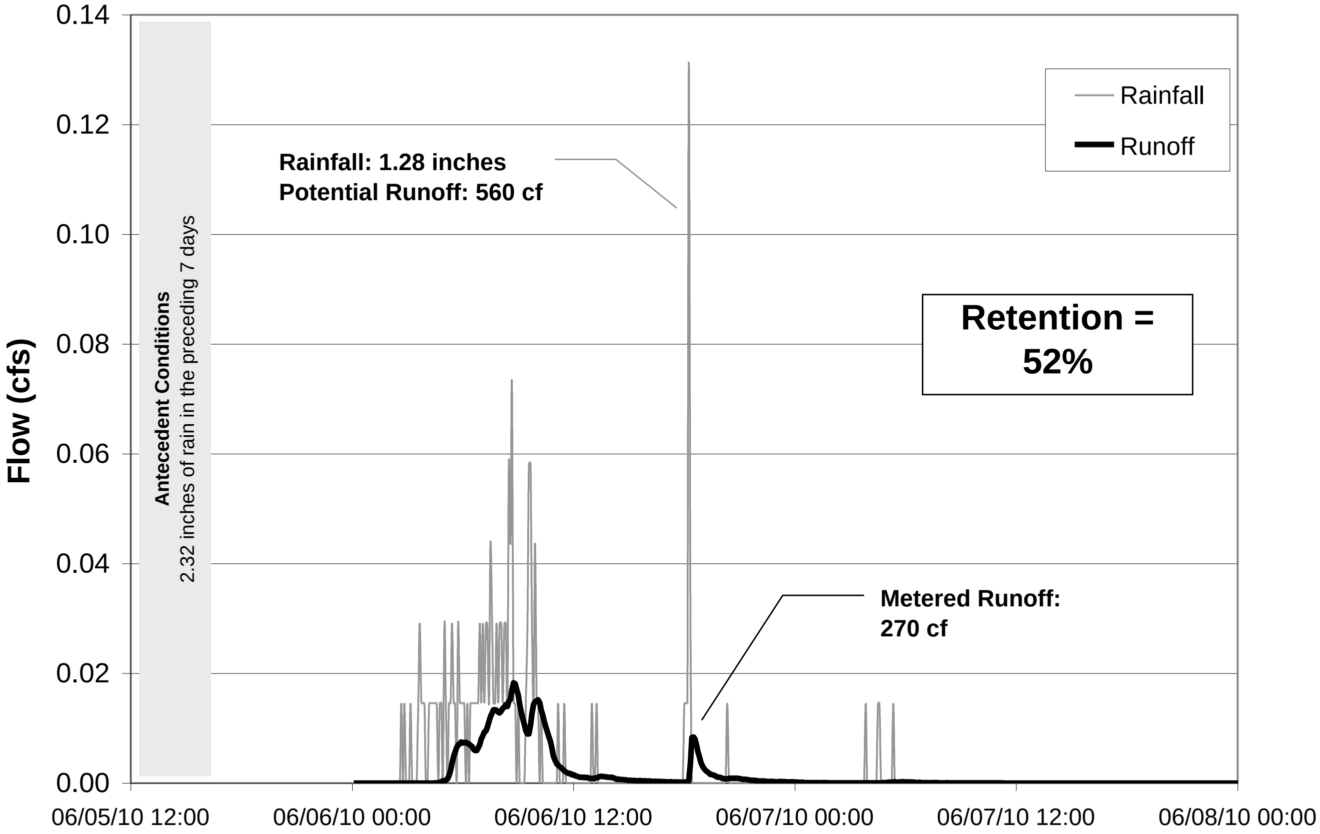


***Figure PB-5*: Volume retention for the June 6, 2010 event, Portland Building**

Water Quality

Fourteen runoff samples were taken over five years. Of particular interest are heavy metals (copper, lead, and zinc) and nutrients (phosphorus and nitrogen), which have regulatory requirements because of potentially adverse watershed health impacts. Metals may be toxic to aquatic organisms while high concentrations of nutrients may lead to algal blooms. While these pollutants can come from rainfall or the breakdown of standard roofing materials, some stormwater facilities have been shown to export some metals and nutrients when runoff washes them from the soil or decaying vegetation.

Metals

Effluent copper and zinc concentrations are somewhat variable, but appear to follow a definite downward trend over time (***Figure PB-6***). This suggests that available metals are being washed from the soil, or that they're becoming stabilized as the plant-soil complex matures.

Dissolved copper levels were initially higher than those seen at Hamilton (maximum of 34.7 µg/L on the Portland Building, versus 26.3 µg/L on Hamilton). This is likely because monitoring on the Portland Building began shortly after construction, while sampling at Hamilton began almost 2 years after its completion. A similar period of stabilization may have occurred during that 2 year period on Hamilton, but it was not monitored. At 5 years of age, effluent dissolved copper levels on the Portland

Building appear to be lower, with the last four samples averaging around 3 µg/L. This is well below the average of 17 µg/L for the four samples taken at a similar age on Hamilton. Of the samples to date, three of the first four dissolved copper levels exceed the acute and chronic water quality criteria for the State of Oregon, but no samples in the past two years have been close to an exceedance (***Table PB-6***).

Dissolved zinc levels were also quite a bit higher than Hamilton levels during the first two years. At 5 years of age, effluent dissolved zinc levels on the Portland Building appear to be lower, with the last four samples averaging around 10 µg/L, as compared to an average of 18 µg/L for the four samples taken at a similar ecoroof age on Hamilton.

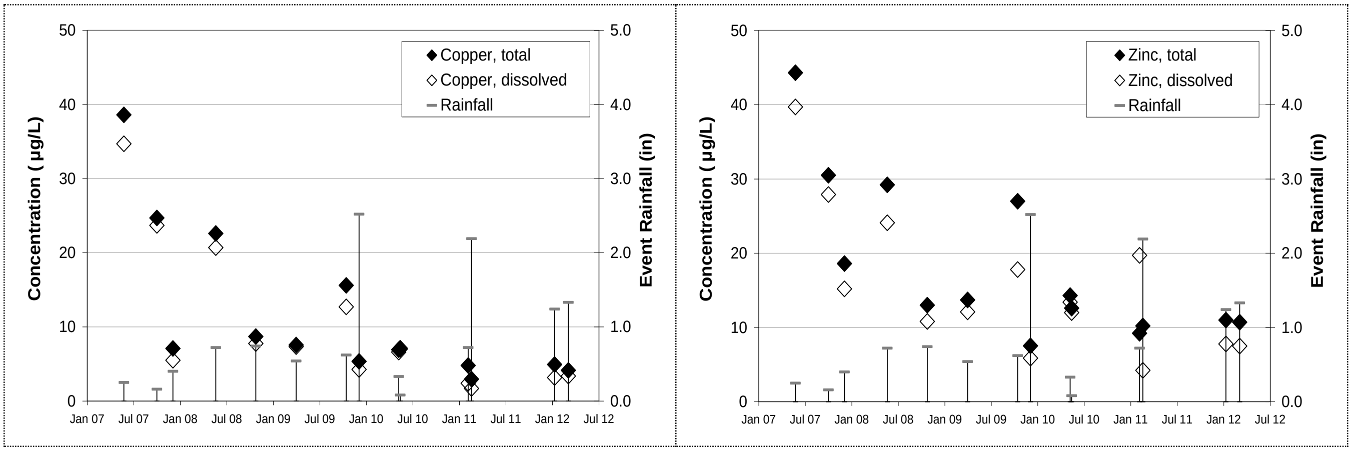


***Figure PB-6*: Ecoroof Runoff Concentrations of Copper and Zinc, Portland Building**

Lead levels, both total and dissolved, have been higher on the Portland Building than on Hamilton, but are still well below health guidelines and water quality criteria.

***Table PB-6*: Dissolved metal concentrations and how they relate to the State of Oregon water quality criteria**

Metal	**Average Concentration (µg/L)**	**Oregon Water Quality Criteria**[1]	
		Acute Exceeded?[2]	Chronic Exceeded?[2]
Copper	10.1	**3 of 14**	**4 of 14**
Lead	0.65	None	None
Zinc	15.6	None	None

[1] Based on values, corrected for hardness levels, as specified in OAR 340-041 Table 20 (OAR = Oregon Administrative Rules).
[2] Number of samples that exceeded water quality criteria.

Nutrients

As with the metals, there appears to be a downward trend in effluent nutrient levels (***Figure PB-7***). Nitrates appeared in three of the first four samples, but have only been above the detection limit once since. Phosphorus levels are more variable, but have still dropped from initial levels of well over 1 mg/L down to an average of 0.22 mg/L for the last six samples. While a significant decrease, this average is still above the benchmark for industrial discharges of 0.16 mg/L (NPDES 1200-COLS).

Phosphorus and nitrate levels were originally higher than Hamilton for the first two years, but have since dropped to levels lower than those at Hamilton at an equivalent ecoroof age of 5 years. All phosphorus levels are high in relation to water quality criteria (***Table PB-7***).

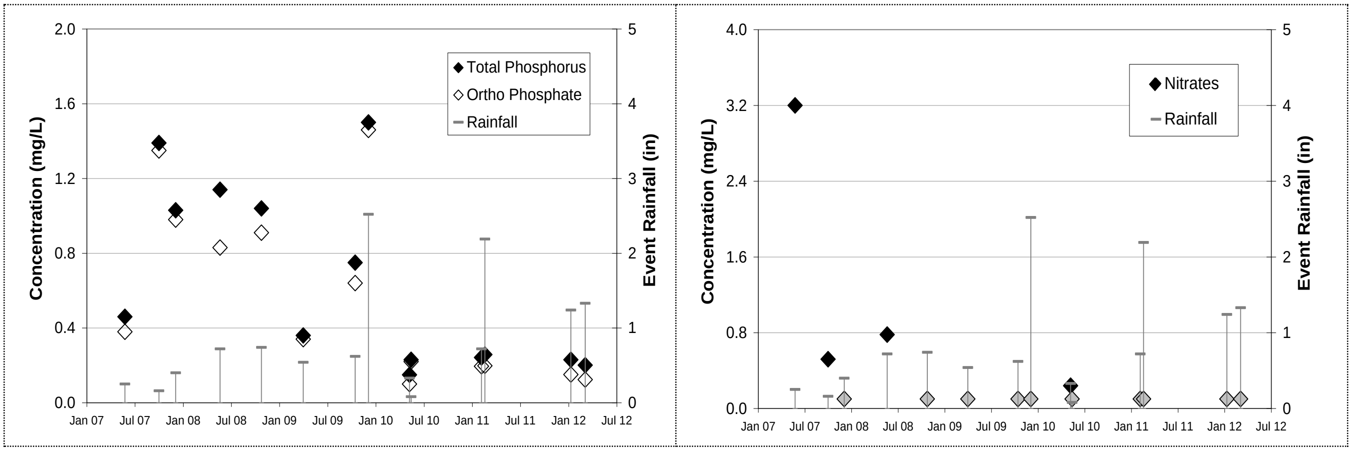


***Figure PB-7*: Phosphorus and nitrogen levels, Portland Building**

(shaded diamonds are the minimum reporting limit for non-detects)

***Table PB-7*: Average nutrient concentrations and how they relate to the State of Oregon water quality criteria**

Parameter	**Avg Runoff Concentration (mg/L)**	**Oregon Water Quality Criteria**	
		mg/L	Exceeded?
Nitrates	0.41[*]	10[+]	None
Ammonia	0.041[*]	3.5[†]	None
Phosphorus, total	**0.64**	0.13-0.16[‡]	**14 of 14**
Ortho Phosphate	0.56	N/A	N/A

[*] Using the conservative substitution of the reporting limit as the concentration for non-detects

[+] Based on drinking water standards (MCL) and human consumption (OAR 340-041 Table 33A)

[†] Average value, corrected for pH, as specified in OAR 340-041 Table 20.

[‡] No values exist in the OAR; the Fanno Creek TMDL is 0.13 mg/L, and the industrial NPDES permit requirement (1200-COLS) is 0.16 mg/L.

Others

Total suspended solids (TSS) levels average a low 4.4 mg/L while total dissolved solids (TDS) levels averaged of 139 mg/L. The TDS level is well below the EPA guideline for drinking water (500 mg/L), and is within the range of average tap water.

Runoff pH averages 7.1, notably higher than Hamilton Apartment ecoroof samples which averages 6.2. Local rainfall has been found to be somewhat acidic (rainfall samples averaged 5.7), so this would suggest the Portland Building soil media is somewhat basic.

Hardness levels have been relatively high averaging 82 mg $CaCO_3$/L (compared to averages of 27 (east) and 35 mg $CaCO_3$/L (west) on the Hamilton Apartments Ecoroof). All values fall into the moderately soft water category. Elevated hardness can be beneficial as higher hardness levels results in lower metal toxicity for aquatic life.

Maintenance

An automated irrigation system is installed on the roof, and is divided into 13 different zones. The system is programmed to run once a day in the morning, but can be shutoff manually. Irrigation usage is metered and tracked via a gage inside the penthouse. Irrigation use to date is summarized in ***Table PB-8***.

Table PB-8: Irrigation applied on the Portland Building Ecoroof

Year	Period	Rainfall (in)	Irrigation (in)
2007	May 17 – Sep 27	2.2	6.5
2008	Jun 19 – Sep 19	1.2	4.5
2009	Jun 17 – Sep 23	2.8	4.3
2010	Jul 6 – Sep 3	0.3	2.8
2011	Jul 7 – Sep 21	1.7	2.5

Periodic irrigation line breaks have been an issue, both from inadvertent damage caused by maintenance workers and from heating / cooling flexing of the irrigation pipes. One such leak in September 2007 was over 38,000 gallons (equivalent to 3.8 inches of irrigation if applied to the whole roof).

Design

After more than 3 years of data collection, the roof appears to be performing very well. Volume retention is higher than the west side of the Hamilton Apartments, despite being thinner and using a lighter weight soil media. The addition of the Stockosorb® polymer may play a role, as well as the use of insulation above the membrane (runoff is forced to flow between, under, or over the foam insulation).

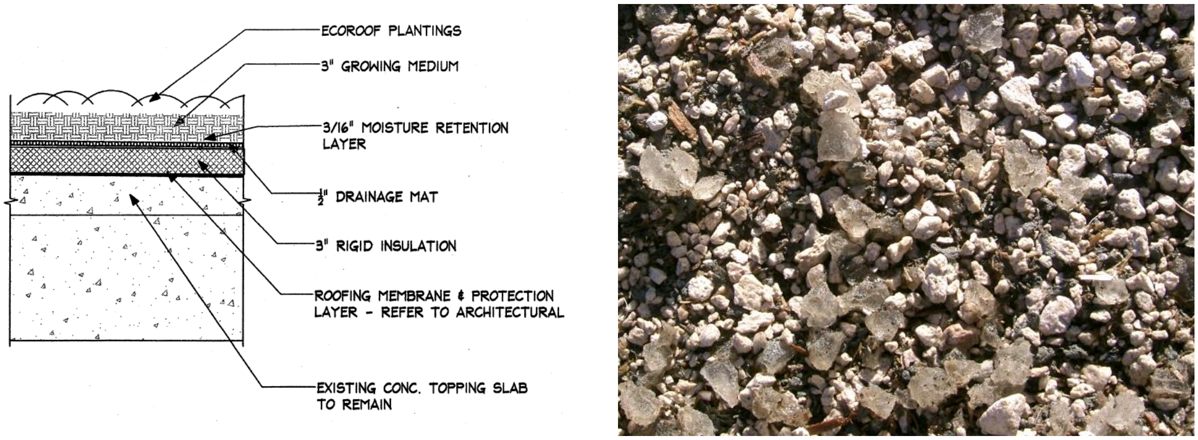


Figure PB-9: Ecoroof cross-section (left) and Stockosorb® gel in the soil media (right)

The irrigation system uses an HDPE pipe system that seems to flex with temperature extremes. With only 3 inches of soil, it is difficult to keep the pipes buried and they are exposed to extremes in temperature (***Figure PB-10***). This is the likely cause of several sprinkler heads popping off their risers and several leaks at pipe joints.

Figure PB-10: Exposed HDPE irrigation lines near the penthouse wall

Vegetation

A large variety of sedum species were planted on the roof and are being evaluated. Coverage after 18 months is good, and while there are weeds on the roof they have not been problematic.

There are clearly numerous climatic zones on the roof – created by air vents, sun exposure, and wind exposure.

Monitoring Summary

- Peak flow reduction has been excellent, but only a limited number of high intensity storms have occurred during the monitoring period.
- Volume retention to date has been excellent – for both summer and winter.
- Effluent copper, lead, and nutrients levels were initially higher than those seen at the Hamilton Apartments Ecoroof, but they have declined substantially since and are now similar.
- Irrigation system has been prone to leaks; likely due to expansion and contraction of HDPE pipe during temperature extremes

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Infiltration Facility Performance

Infiltration facilities have a variety of configurations – including swales, curb extensions, planters, and infiltration basins. They are used to manage both public and private impervious area runoff, and typically pond 6 to 9 inches deep.

Peak Flow Reduction

An evaluation of both flow tests and actual storm events indicate a strong ability to limit peak flows. During flow tests of the most intense design storm (the 25-yr, 6-hr), the peak flow reductions ranged from 62% to 100%, with an average reduction of 90% (**Table IF-1, Figure IF-1**). This would greatly lower or eliminate basement sewer backup risk in the combined sewer under most circumstances, and velocities in open channel systems would be greatly reduced.

Flow Volume Reduction

Infiltration facilities provide a notable reduction in the flow volume (**Table IF-1, Figure IF-1**). For one facility monitored continuously, annual runoff over an eight year period has been reduced by 84%. Flow tests simulating both CSO Design Storms have shown retentions ranging from 12% to 100%, with an average of 71%.

Water quality design storm results range from 61% to 100% retention, with most facilities achieving 100%. Stormwater facilities are typically designed to at least manage the Water Quality Design Storm, so it would be expected that most infiltration facilities would have no outflow during the storm event.

Performance was most greatly impacted by two basic issues:

- flow bypass – inflow did not enter the facility due to inlet design, backflow from check dams or other flow impediments, or flow short-circuited portions of the facility
- local site conditions – facilities on steep slopes, tests during wet antecedent conditions, and facilities in the slower draining soils of outer southwest were typically the poorest performers

Infiltration Rates

Though it was assumed that urban soils may produce highly variable infiltration results, regional results for most locations within the city are generally consistent (**Table IF-2, Figure IF-2**). At this point, that seems to be the case despite differences in facility age, drainage area, and antecedent moisture conditions.

North Portland exhibits substantially higher rates, and this is consistent with sandier soils found in the region. In contrast, some facilities in outer southwest Portland show lower rates, and this is consistent with finer grain soils and underlying impervious layers often found in the region.

The median value is about 3.0 inches per hour for all regions of the city other than the north. This consistency could indicate greater than expected uniformity in urban near-surface soils, or it could reflect generally consistent facility design and construction practices.

Table IF-1: Peak Flow Reduction and Volume Retention of Infiltration Facilities

Facility	Location	Sizing Factor	25-Yr Peak Flow Reduction	Annual Runoff Retention	CSO Flow Volume Retention	WQ Flow Volume Retention
12th & Montgomery	SW	4%	N/A	N/A	73%	N/A
21st & Tibbetts	SE	6%	100% [2]	N/A	89%	N/A
30th & Multnomah	SW	13%	N/A	N/A	N/A	100%
35th & Yeon	NW	3%	N/A	N/A	N/A	100%
56th & Ankeny	SE	6%	N/A	N/A	49%	N/A
92nd & Francis	SE	2%	N/A	N/A	N/A	61%
117th & Holladay	NE	23%	N/A	N/A	100%	100% *
Alameda & Fremont	NE	4%	N/A	N/A	N/A	100%
Albina Triangle	N	8%	N/A	N/A	100%	100% *
Belmont & 42nd	SE	4%	96%	N/A	66%	N/A
Central & St Johns	N	6%	N/A	N/A	46%	N/A
Fremont & 131st	NE	7%	94%	N/A	95%	100% *
Gantenbein & Humboldt	N	5%	100%	N/A	100%	100% *
Glencoe Rain Garden	SE	6%	80% [2]	84%	78% storms 45% tests [2]	100%
Lambert & 17th	SE	6%	100%	N/A	95%	100% *
Mt Tabor Rain Garden	SE	7%	N/A	N/A	68%	N/A
Pettygrove & 26th	NW	3%	N/A	N/A	13%	N/A
Reedway & 90th	SE	5%	N/A	N/A	N/A	100%
Sandy & 21st	NE	9%	100%	N/A	94%	100% *
Sandy & Davis	NE	13%	N/A	N/A	100%	100% *
Siskiyou & 35th	NE	5%	78% [3]	N/A	75%	N/A
Virginia & Florida	SW	12%	N/A	N/A	94%	100%
Tryon Headwaters	SW	20%	N/A	N/A	N/A	72%
Water, S. of Clay	SE	2%	N/A	N/A	68%	N/A
Winchell & Mallory	NE	3%	N/A	N/A	51%	N/A
AVERAGE			**90%**	**N/A**	**71%**	**96%**

* Not tested; assumed based on results of CSO design storm testing

[2,3] Lowest result of multiple tests; number of tests indicated by superscript number

Table IF-2: Infiltration Rate Summary

Facility	Location	Green Street	Private	Minimum Infiltration Rate (in/hr)	Facility	Location	Green Street	Private	Minimum Infiltration Rate (in/hr)
12th & Montgomery	SW	✓		2.8 – 4.7 [5]	Oregon Wild (ONRC)	N		✓	7.0
21st & Tibbetts	SE	✓		3.2 – 4.4 [2]	Page 19 Warehouse	SE		✓	1.5
56th & Ankeny	SE	✓		3.0	Parks Bureau East Side Office	SE		✓	4.2
Alameda & Fremont	NE	✓		50.	Pettygrove & 26th	NW	✓		1.7
Albina Triangle	N	✓		13.	Ramona & 133rd	SE	✓		20.
Belmont & 42nd	SE	✓		3.6	Sandy & 21st	NE	✓		4.6
Central & St Johns	N	✓		1.9	Sandy & Davis	NE	✓		1.0 – 1.4 [2]
Fremont & 131st	NE	✓		7.5	Siskiyou & 35th	NE	✓		1.0 – 2.5 [5]
Glencoe Rain Garden	SE	✓		1.5 – 3.0 [4]	St Andrews Parking Lot	SW		✓	0.6
Glendoveer Commons	NE	✓		2.5	Sylvania & 29th	SW	✓		1.2
Killingsworth	N	✓		30. – 62. [3]	Tryon Headwaters Rain Garden	SW	✓		0.9
Lambert & 17th	SE	✓		4.5	Virginia & Florida	SW	✓		4.6
Mt Tabor Rain Garden	SE		✓	2.1	Willamette & Denver	N	✓		8.8
OMSI Parking Lot	SE	✓		6.0	Winchell & Mallory	NE	✓		3.1
CITYWIDE MEDIAN					**3.2 inches / hour**				

[2,3,4,5] Multiple test results; number of tests indicated by superscript number

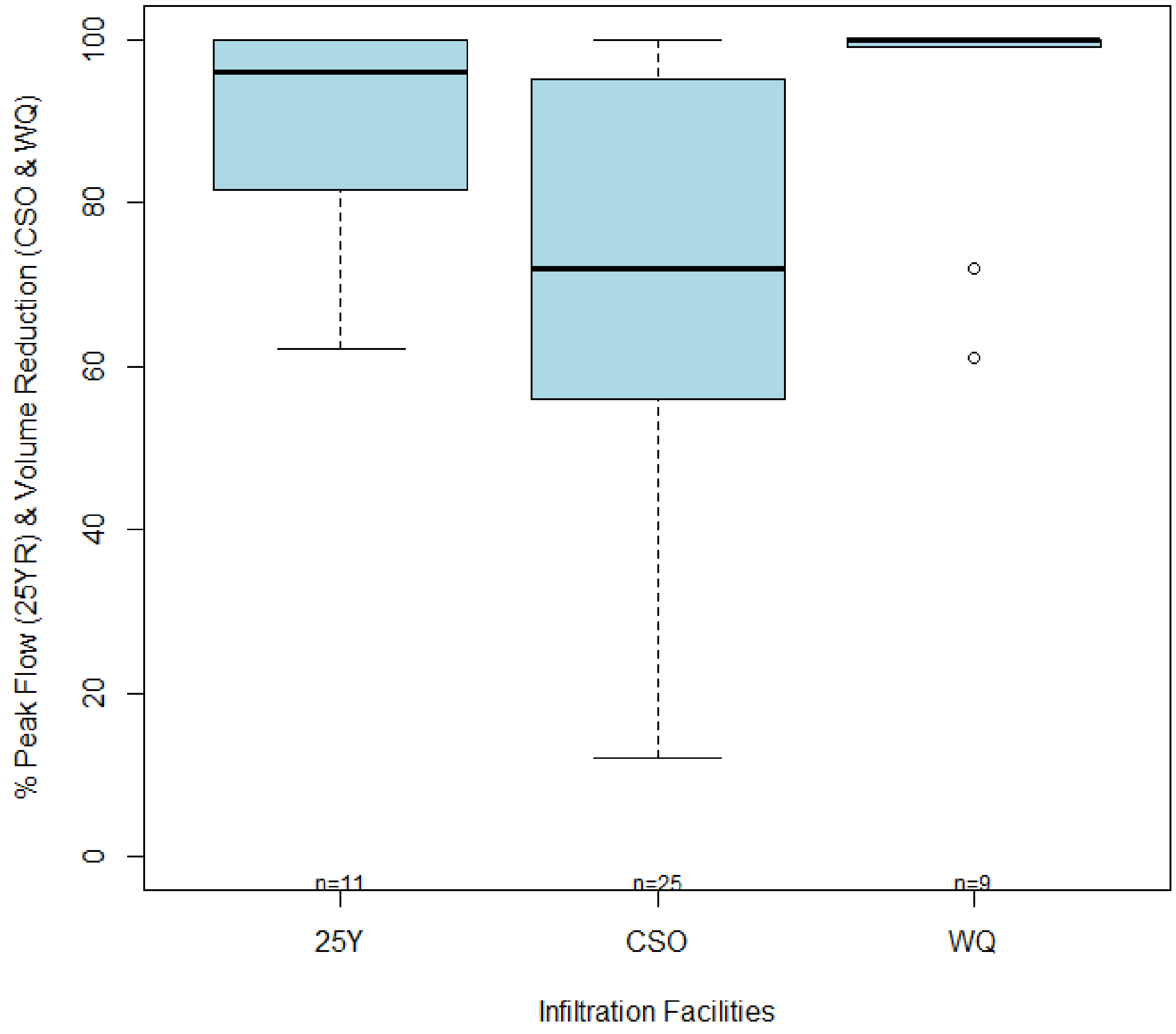

Figure IF-1: Peak Flow Reduction and Volume Reduction for Infiltration Facilities by Design Storm

(box plots: the dashed vertical line represents the range of values, the box is the middle two quartiles, and the black bar in the box is the median value; ° = statistical outliers.)

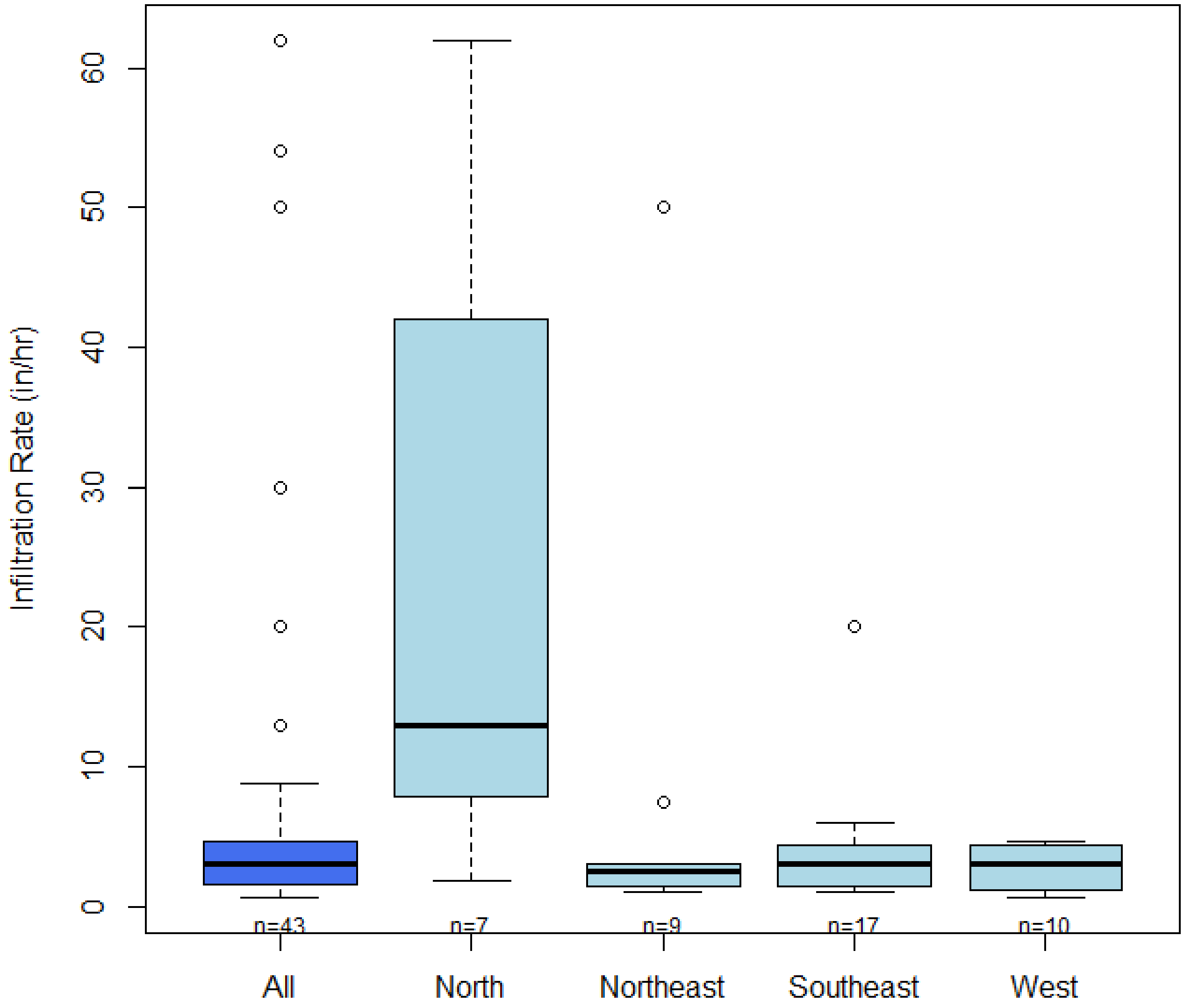

Figure IF-2: Infiltration Rates Result Summary for All Facilities (far left) and then by Subarea of the City

(box plots: the dashed vertical line represents the range of values, the box is the middle two quartiles, and the black bar in the box is the median value; ° = statistical outliers.)

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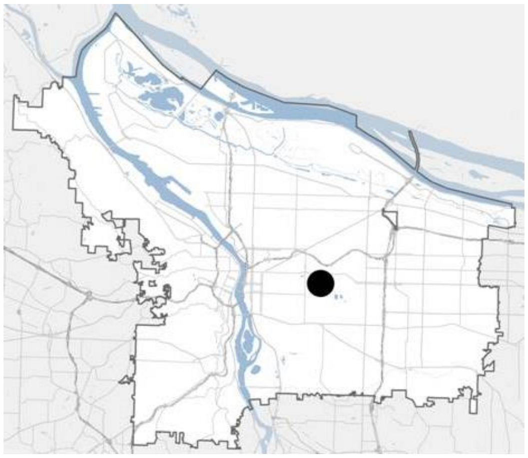
Glencoe Rain Garden

Summary Information		
Evaluation Period:	**9 years** (Jan 2004 – Dec 2012)	**The facility receives runoff from approximately 24,000 ft^2 of heavily used residential right-of-way adjacent to Glencoe Elementary School. It also receives overflow from an infiltration swale that handles runoff from a 10,800 ft^2 parking lot.**
Constructed:	**October 2003**	
Facility Type:	**Vegetated Infiltration Basin**	
Drainage Area:	**34,800 ft^2**	
Facility Area:	**1,975 ft^2**	
Sizing Factor:	**6%**	



Monitoring Result Summary

Peak Flow Reduction	
Continuous Flow Monitoring	**95%**
(2) Flow Tests **[25-yr]**	**80%**

Flow Volume Reduction	
Continuous Flow Monitoring	**84%**
(1) Flow Test **[CSO Summer 6]**	**56%**

Water Quality

Based on continuous monitoring, no overflow expected from facility during a Water Quality design storm.

Soil / Infiltration

- Native soil: silt down to 6 feet, grading into sand
- unamended soil; tilled with a irrigation trencher

1.3 – 3.0 in/hr
(minimum rate)

Design

- Drainfield overflow functions but is more complex than necessary. The filter fabric used between the drainfield rock and soil can clog.
- Sediment accumulation in the forebay is difficult to remove. A sedimentation manhole between the inlets and the forebay may ease sediment removal.

Maintenance

- Forebay: weed grass and sediment accumulation are issues, and it is difficult to remove from around the mature Juncus
- Drainfield: filter fabric was clogged by bark mulch washed in from the main facility
- Plants: *Juncus patens* in the forebay has been very successful – so much so it requires annual pruning
- Plants: *Carex obnupta* took several growing seasons to establish in the main facility but is now growing well

Overview

This facility was constructed in the summer of 2003 in response to chronic basement sewer backups suffered by residents downstream. Its primary mission is to reduce peak flows to the combined sewer.

Continuous flow meters monitor outflow from the Rain Garden, as well as downstream flows in the combined sewer line. Rainfall data is collected from a raingage 400 feet away on the roof of the elementary school (***Figure GL-1***).

Peak Flow

Basement sewer backups are strongly associated with short, intense periods of rainfall. To protect the properties downstream from sewer backups, the Rain Garden outflow is designed to limit peak flows in the sewer to no more than 0.50 cfs.

As shown in ***Figure GL-3***, in the 9 months prior to construction of the Rain Garden, there were 4 events creating runoff flows exceeding the 0.50 cfs design benchmark. In the 9 years after construction, there have only been two events with peak flows near the 0.50 cfs standard. Neither of those events were the result of particularly intense rainfall, but were generated by large volume, multi-day storm events in late fall (November 2006 and December 2010).

During the four most extreme intensity events during the post-construction period – two greater than the 5-year event, one greater than the 10-year, and one greater than the 25-year – none have exceeded 0.50 cfs. There was very little runoff for the highest intensity event, but the next highest event is shown in ***Figure GL-4***.

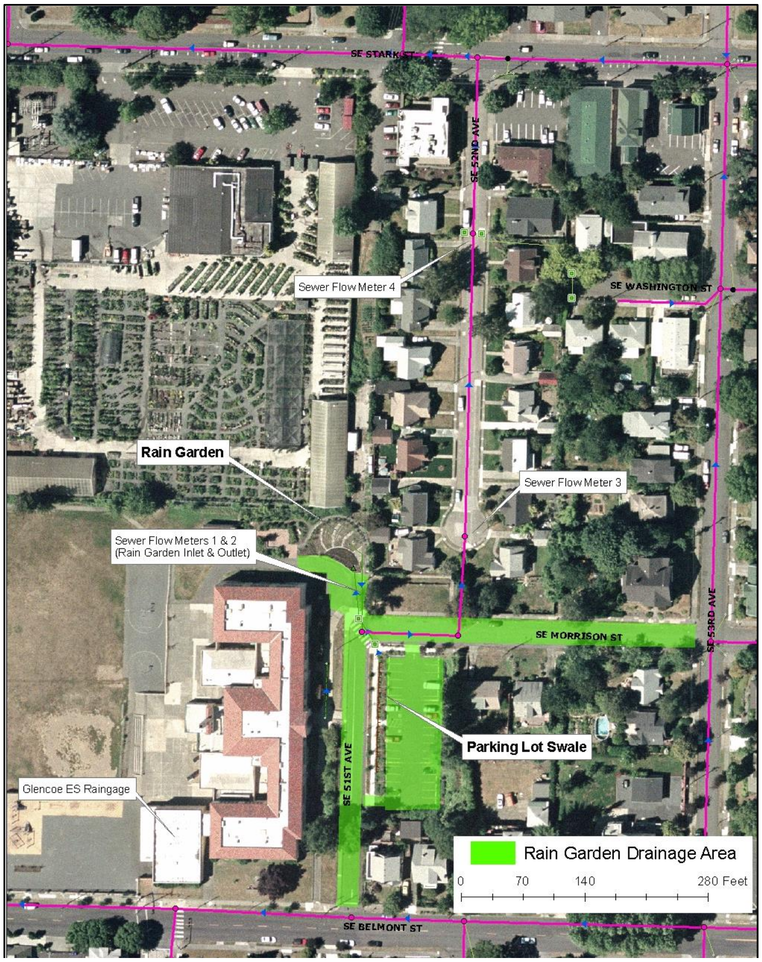


Figure GL-1: **Drainage area and monitoring locations**

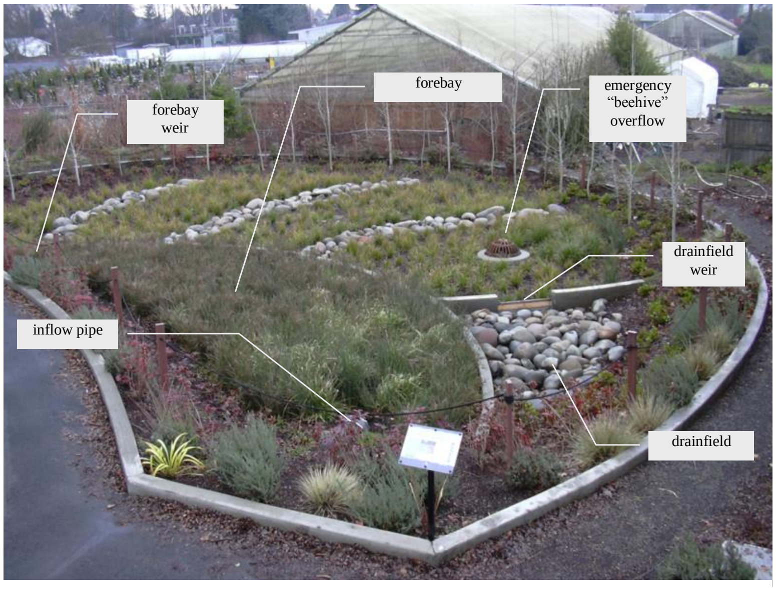


Figure GL-2: **Rain Garden overview**

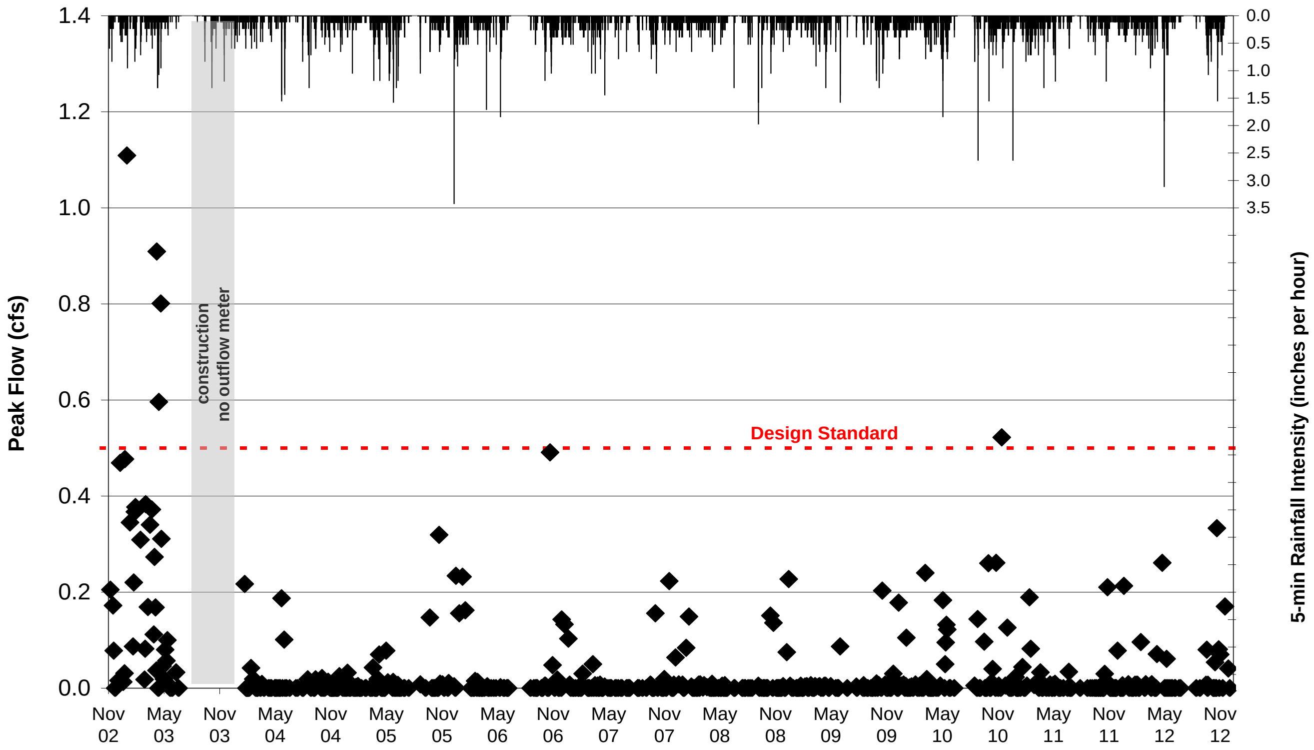


***Figure GL-3*: Peak flows entering the combined sewer before and after Rain Garden construction**

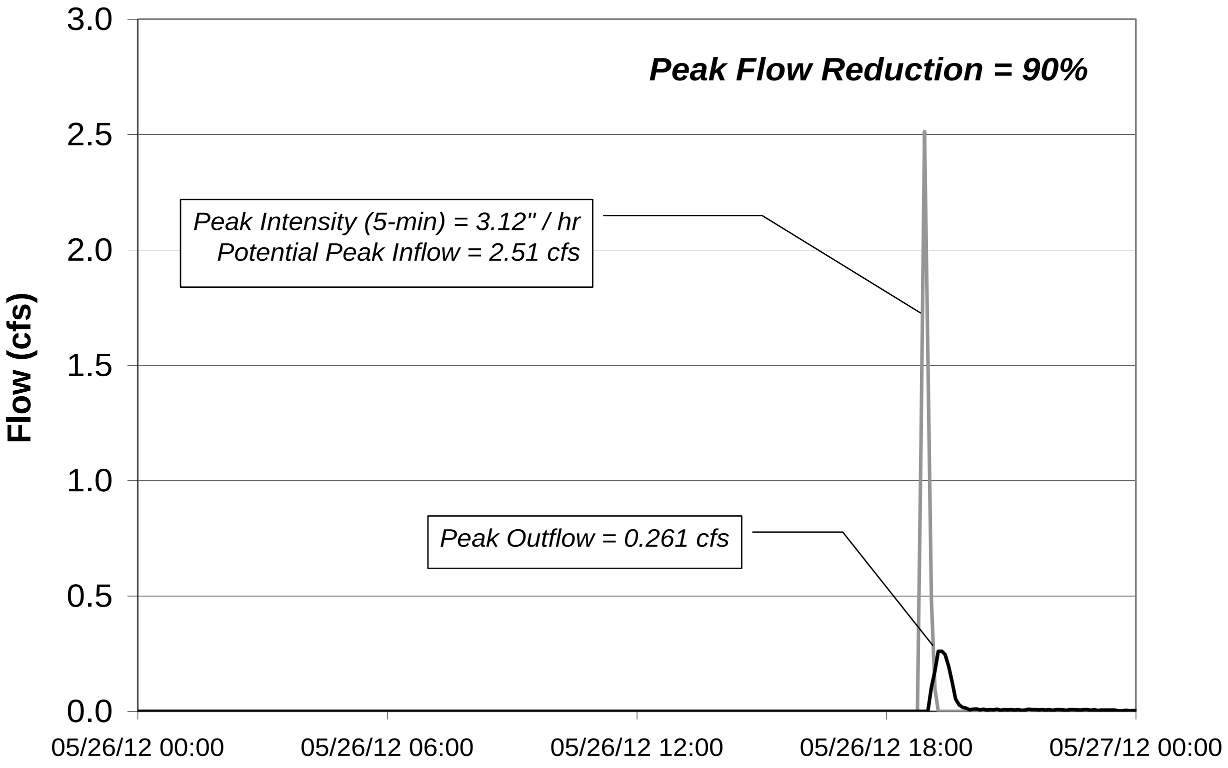


Figure GL-4: Peak flow reduction during an intense rain event, May 2012

Peak flow reduction has been excellent, with two events – December 19, 2005 and May 26, 2012 – close to the intensity of the 25-year Design Storm (3.32 inches per hour) used for basement sewer backup protection.

***Table GL-1*: Peak flow reductions for events with 5-minute peak rainfall intensities >= 1.32 inches per hour**

Event Date	Peak 5-min Rainfall (in/hr)	Potential Peak Flow (cfs)	Rain Garden Outflow		
			Peak Flow (cfs)	Peak Flow Reduction[1]	Average Peak Flow Reduction
05/27/04	1.56	1.26	0.187	85%	**95%**
06/05/04	1.44	1.16	0.101	91%	
08/21/04	1.32	1.06	0.018	98%	
05/31/05	1.58	1.28	0.013	99%	
06/10/05	1.32	1.06	0.006	99%	
12/19/05	3.43[2]	2.76	0.004	100%	
04/05/06	1.72	1.35	0.002	100%	
05/21/06	1.85	1.49	0.002	100%	
05/01/07	1.45	1.17	0.003	100%	
07/03/08	1.32	1.06	0.	100%	
09/21/08	1.98	1.60	0.005	100%	
10/02/08	1.32	1.06	0.	100%	
05/02/09	1.32	1.06	0.005	100%	
06/19/09	1.58	1.28	0.087	93%	
10/26/09	1.32	1.06	0.006	99%	
05/25/10	1.85	1.49	0.183	88%	
09/18/10	2.64[4]	2.13	0.144	93%	
10/24/10	1.56	1.26	0.260	79%	
01/12/11	2.64[4]	2.13	0.001	100%	
04/24/11	1.32	1.06	0.006	99%	
05/26/12	3.12[3]	2.51	0.261	90%	
11/19/12	1.56	1.26	0.333	74%	

[1] Based on runoff expected from 34,800 square feet of impervious area using the maximum 5-min rainfall intensity

[2] Exceeds the 25-year, 5-minute intensity of 3.32 inches per hour

[3] Exceeds the 10-year, 5-minute intensity of 2.86 inches per hour

[4] Exceeds the 5-year, 5-minute intensity of 2.47 inches per hour

The response to the May 2012 event (previously shown in ***Figure GL-4***), is particularly impressive as 0.60 inches of rain fell in 20 minutes during that storm event – equivalent to a 50-year intensity for that time period – and there had been 1.50 inches of rain over the preceding 6 days.

Two 25-year flow tests were also performed – one in August 2004 and another in May 2005. Peak flow reductions were 79% and 81% with a maximum outflow from the facility of 0.56 cfs – just slightly higher than the 0.50 cfs benchmark. This small difference is within the error tolerance of the metering equipment and the operational tolerance of the facility.

Flow data shown in ***Figure GL-5*** indicates that the facility is having a similar effect in the downstream sewer on SE 52nd. This meter includes a larger drainage area with substantial uncontrolled runoff, but there is still a clear reduction in peak flows after the rain garden.

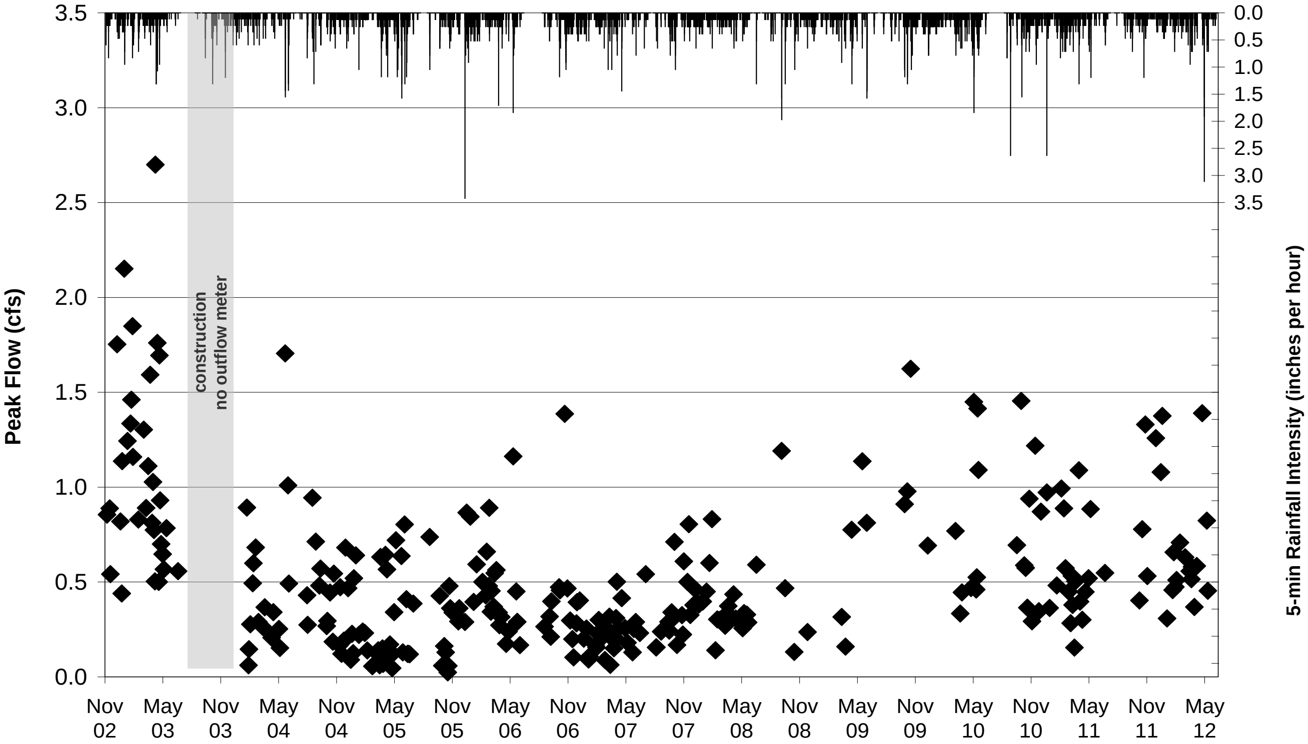


***Figure GL-5*: Peak flows in the SE 52nd Ave sewer before and after Rain Garden construction**

There are seven events which caused peak flows in the sewer greater than 1.5 cfs in the nine months prior to Rain Garden construction. None of these events had particularly high rainfall intensities (the highest was 1.32 inches per hour). In the 9 years of post-construction monitoring, only two events have exceeded 1.5 cfs despite twenty-two events with high peak rainfall intensities (1.32 inches per hour or greater).

The peak flow reductions on 52nd are particularly important because the homes with the highest basement sewer backup risk are located along this street. ***In the nine years since the rain garden was constructed, there have been no basement sewer backups reported.***

Flow Volume

The Glencoe Rain Garden was constructed to reduce peak flows, and not flow volumes. However, this facility, and others like it, can provide substantial benefits to combined sewer overflow (CSO) control.

Runoff data shows that the Rain Garden does a tremendous job of removing flows from the combined sewer system. Based on assumed runoff from the drainage area, the Rain Garden is retaining approximately 86% of the annual runoff.

Retention is similar when comparing runoff generated before and after Rain Garden construction. Prior to the Rain Garden, runoff was recorded for even the smallest rain events. After construction, runoff was largely eliminated for all events with less than 1 inch of rainfall. Aggregate runoff volumes before and after rain garden construction are summarized in ***Table GL-2***.

***Table GL-2*: Flow Volumes Before and After Rain Garden Construction**

Rain Garden	Duration (months)	Rain (in)	Runoff (cu ft)	Runoff (cu ft / in of rain)	Total Runoff Reduction
Before	9	34.3	83,560	2,436	**84%**
After	107	391.8	154,440	394	

Figure GL-6 shows monthly rainfall and runoff values both before and after Rain Garden construction. It is evident that runoff volumes have decreased dramatically. Outflow before construction tracked very closely to the rainfall volumes, while outflow after construction is substantially lower during all times of year.

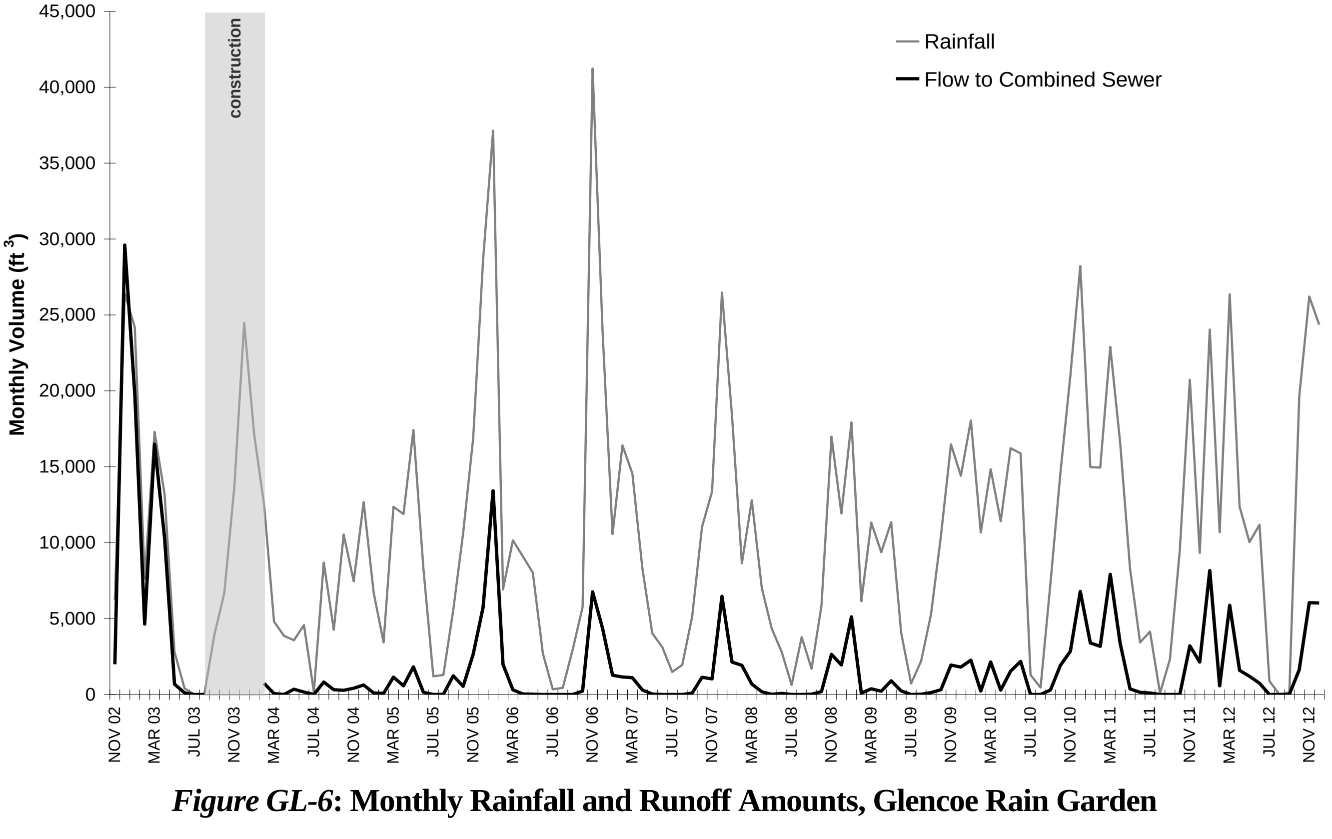


***Figure GL-6*: Monthly Rainfall and Runoff Amounts, Glencoe Rain Garden**

Even the wet winter months show a major decline in volumes. For example, December 2002 (before construction) and December 2005 (after construction) had similar rainfall amounts, but runoff was reduced by nearly 80%. Volumes are summarized in ***Table GL-3***.

***Table GL-3*: Metered runoff for similar Decembers before and after Rain Garden construction**

Month	Rain (in)	Metered Runoff (cubic feet)
December 2002	9.24	29,600
December 2005	10.0	6,580

The runoff reduction is also evident when plotting storm event runoff (***Figure GL-7***). While this doesn't address issues of pattern (a 2-inch rain event over 24 hours is plotted with a 2-inch rain event over 4 days), the trends both before and after construction are fairly evident. Almost all rain events before the rain garden generated significant runoff. After the rain garden was in place, storm events of less than 1 inch generate little or no runoff, while runoff for large storm events are greatly reduced when compared with similar storm depths before construction.

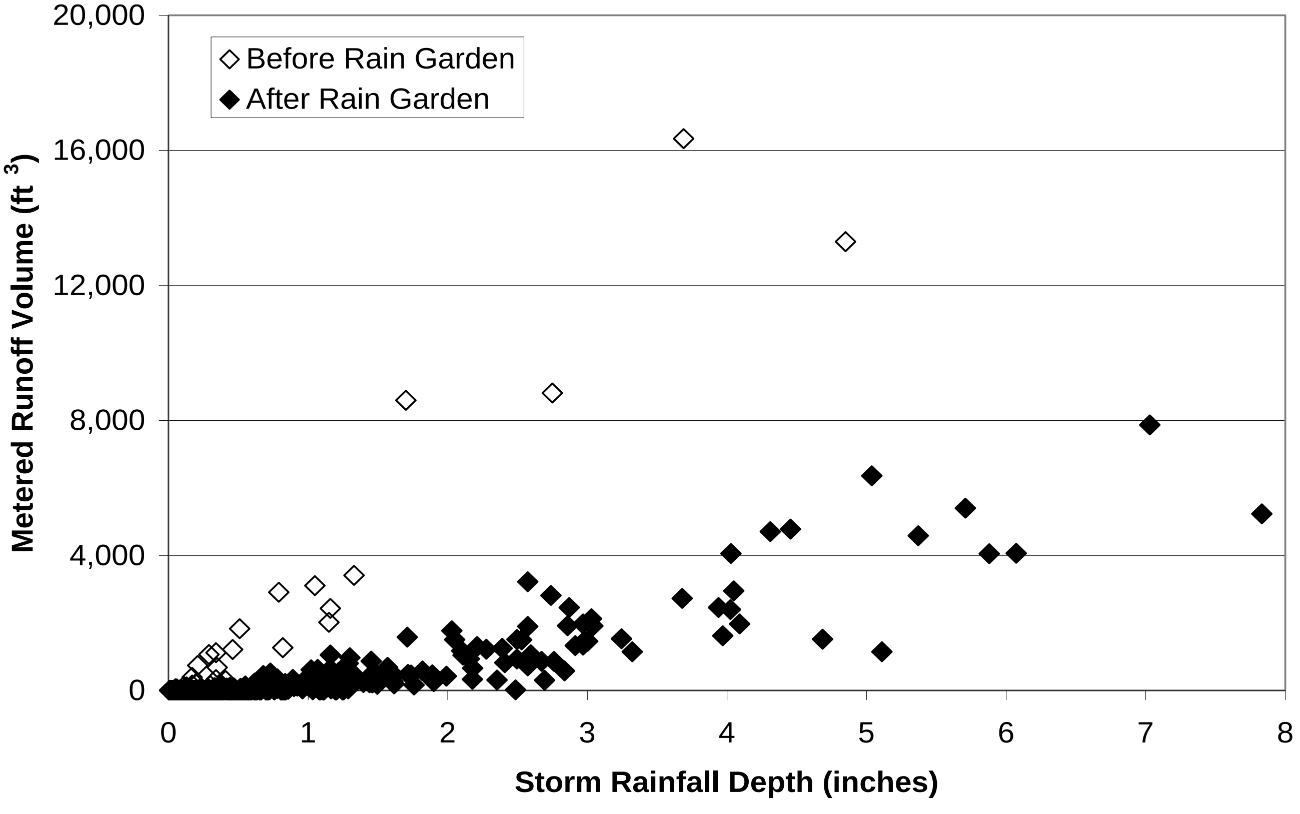


***Figure GL-7*: Rain event[1] runoff compared with total storm rainfall, before** (n=43) **and after** (n=590) **the Glencoe Rain Garden**

[1] *rain events are separated by at least 24 hours of no precipitation*

Annual retentions during the monitoring period are shown in ***Table GL-4***. Retention was highest in 2004 at 94%, but that was also a very low rainfall year. During a very wet 2010, the Rain Garden retained 87%.

***Table GL-4*: Annual Volume retention by the Glencoe Rain Garden**

	2004	**2005**	**2006**	**2007**	**2008**
Rainfall (in)	25.6	43.5	52.0	40.7	33.2
Runoff (cu ft)	3,740	14,000	27,100	12,600	9,800
Retention	**95%**	**89%**	**82%**	**89%**	**90%**
	2009	**2010**	**2011**	**2012**	
Rainfall (in)	38.4	55.9	44.5	58.0	
Runoff (cu ft)	11,100	20,500	23,800	31,800	
Retention	**90%**	**87%**	**81%**	**81%**	

Other than the high retention rate of the first year of operation, retention has varied between 81% and 90% over the past eight years. Annual rainfall is not necessarily a good predictor of annual retention. While low rainfall years generally do have the higher retentions, high rainfall years don't necessarily have lower retentions, such as 2010. In those cases, rainfall pattern can become more important – one inch of rain falling over two days will be managed much better than one inch of rain falling over two hours.

Estimating volume retention for CSO design storm performance is more difficult. Volume retention is generally high, but there are very few storm events during the monitoring period that closely resemble the CSO control storms (ASFO and Summer 6). The events that are most similar are represented in ***Table GL-5***, divided into storms before and after Rain Garden construction.

***Table GL-5*: Average volume reduction for storm events most like the CSO Design Storms before and after Rain Garden construction**

		Duration (hrs)	**Depth (in)**	**Max Intensity (in/hr)**	**Metered Runoff (cf)**	**Average Runoff (cu ft per inch of rainfall)**	**Estimated CSO event Volume Reduction**
ASFO Design Storm		*24*	*1.41*	*0.92*			
Summer 6 Design Storm		*35*	*2.17*	*0.48*			
Pre-construction	04/16/03	24	0.82	1.08	1,270	**2,190**	**78%**
	04/23/03	21	0.79	0.96	2,250		
Post-construction	05/27/04	35	0.78	1.56	340	**475**	
	10/15/06	29	1.12	1.19	130		
	06/19/09	18	0.96	1.58	230		
	06/06/10	26	1.45	0.66	870		
	10/08/10	35	1.82	0.60	580		
	06/04/12	35	1.57	0.72	690		

An aggregate comparison between storms before and after the Rain Garden, indicates a retention on the order of 78%. This is an excellent result, but there are only two pre-construction storms for comparison, and both are just outside the primary May through October compliance window. However, the large difference between before and after volumes strongly suggests there is a very significant reduction in CSO-like event volumes.

A Summer 6 Design Storm flow test was performed in August 2006. The results are shown in ***Figure GL-8***. The retention of 56% is much lower than the reduction estimate of 86% based on real storm events. However, the lower retention is almost certainly the result of compressing the 35-hour design storm into a 6-hour simulation so it could be completed in a single work day. The compression leads to greatly increased flow rates to achieve the same total volume in a shorter period of time. In this case, metering 2.17 inches of rain runoff into the facility over 6 hours is approximately equivalent to a 15-year event – much higher than the intended 3-year return period of the Summer 6 Design Storm.

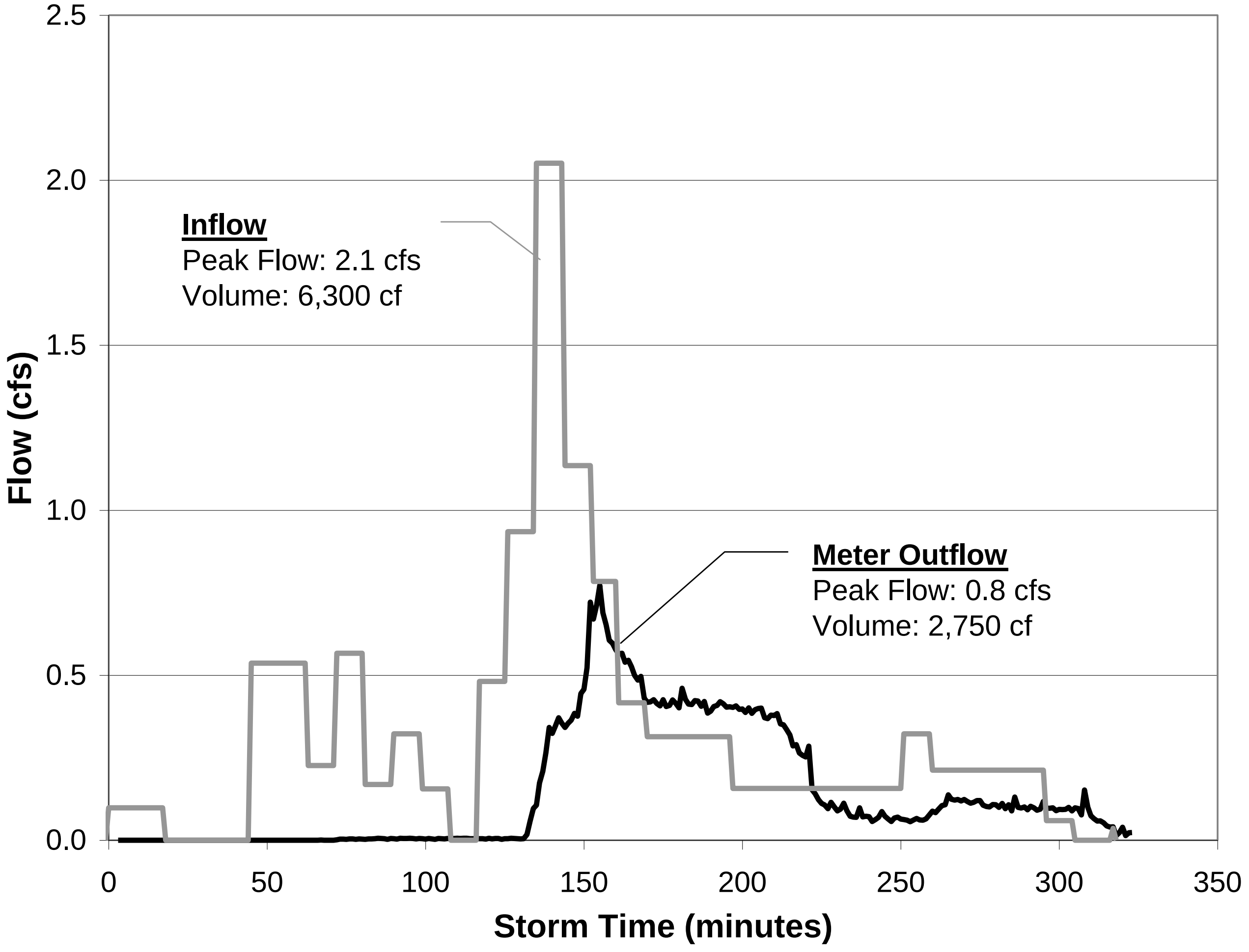


***Figure GL-8*: Flow results for the August 2006 flow test (Summer 6 Design Storm), Glencoe Rain Garden**

Water Quality

No water quality sampling has been done for this facility. Its primary purpose is peak flow control with overflow going to the combined sewer system. However, based on the performance during larger volume tests and infiltration rates observed during those tests, very little overflow would be expected during the Water Quality Design Storm.

Infiltration

During four flow tests, infiltration rates were calculated once overflow to the drainfield ceased. Infiltration rates declined over time while approaching a "saturated" value, summarized in ***Table GL-6***.

***Table GL-6*: Flow Test Infiltration Rates**

Flow Test	Antecedent Conditions	Test Volume (cu ft)	Infiltration Rate
August 2004	damp (0.60" in prior 7 days)	5,950	1.8 in/hr
May 2005	damp (0.30" in prior 4 days)	1,940	3.0 in/hr
August 2006	very dry (0" in prior 7 days)	6,300	1.5 in/hr
July 2011	damp (0.21" in the prior day)	5,080	1.3 in/hr

The May 2005 wet antecedent condition test actually has the highest infiltration rate, but it should be noted that it was a 25-yr peak flow test using a much smaller volume of water. It's also possible that tests with dry antecedent conditions may have hard soil crusts that provide more resistance to infiltration.

Soil Sampling

Soil samples have been taken four years apart in the forebay and main compartment of the rain garden, and results for metals and a representative PAH are compared in ***Table GL-7***. A background sample from an adjacent landscape area was taken in 2012 to establish levels outside the facility.

***Table GL-7*: Average concentrations from soil sampling of the Glencoe Rain Garden (0-6" depth)**

Pollutant	Units	2004	2008	2012	Background
Forebay					
copper	mg/kg	16.5	21.8	49.2	27.2
lead	mg/kg	13.7	20.8	54.9	41.7
mercury	mg/kg	0.023	0.045	0.081	0.058
zinc	mg/kg	83.6	121.	268.	113.
benzo(a)pyrene	mg/kg	N/A	0.015	0.046	0.020
Main Compartment					
copper	mg/kg	18.0	17.1	23.4	27.2
lead	mg/kg	16.7	18.2	20.4	41.7
mercury	mg/kg	0.034	0.035	0.042	0.058

zinc	mg/kg	103.	102.	110.	113.
benzo(a)pyrene	mg/kg	N/A	0.010	0.020	0.020

grey numbers indicate non-detects; the number is the detection limit

Levels do appear to be increasing slowly in the forebay over time, and the sampled facility levels in 2012 are higher than the background levels outside the facility. All levels are well within human health guidelines, but the rising levels are an important issue for facility maintenance, as they are likely the result of incomplete sediment removal during maintenance visits (see below in the *Maintenance* section).

This issue does appear to be confined to the forebay, as the levels in the main compartment are all under background levels and have remained generally stable with only minimal increases over the past 8 years.

Maintenance

Vegetation maintenance is the primary activity at the facility. Weed seeds, especially grasses, are washed into the forebay and have become established despite a successful existing vegetative cover. The rest of the facility has only moderate weeding requirements. The *Juncus patens* in the forebay have been vigorous growers to the point where they need to be trimmed at least once a year.

Sediment accumulation has been significant, and removal is made difficult by the success of the Juncus. There is some evidence that facility performance has decreased in the past four years. The latest CSO design storm flow test in 2011 (33% retention) resulted in a much lower volume reduction compared to the flow test in 2006 (56%). There is also some indication that peak flows leaving the facility are somewhat higher, but there also appears to have been a greater number of high intensity events during that period. It may be time to remove the forebay plants, regrade to the proper elevation, and replant.

During the August 2004 flow test, it was clear that the drainfield had become clogged and was not operating as intended. The drainfield and emergency overflow were reconfigured in April 2005 and appeared to function perfectly during the May 2005 and August 2006 flow tests.

Residents have expressed concern over the facility becoming a breeding area for mosquitoes. Multnomah County Vector Control has visited the facility and believes it does not provide breeding habitat (the facility consistently drains within 24 hours of a large storm event). Results from traps set around the facility did not indicate a problem, but periodic investigation is warranted to ensure that no problem develops over time.

Monitoring Summary

- The facility provides excellent peak flow reduction and flow volume retention.

- Appearance of surface soil and initial infiltration test are not necessarily a predictor of performance. The silty soil reaches 6 feet below the bottom of the facility before it grades into a sandy texture, and the double-ring infiltrometer test indicated minimal infiltration. However, the facility drains very well and never holds water for more than 24 hours.

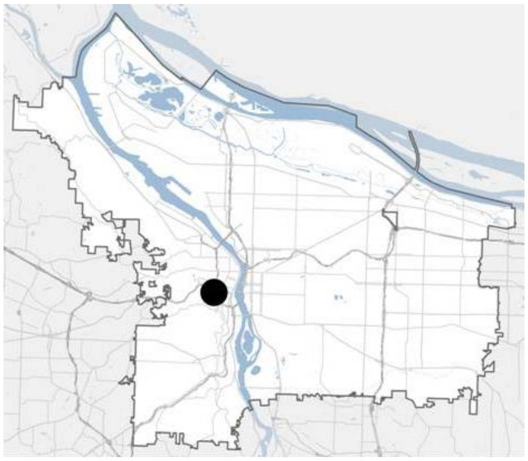
- Use of floatable bark mulch is not compatible with a drainfield overflow.

- Juncus patens (California gray rush) has proved to be a great performer in the facility. However, the rush is growing taller than expected and requires annual trimming. Weeding the grass and removing accumulated sediment from around the juncus in the forebay is extremely difficult.

- Metals do appear to be slowly accumulating in the forebay soil, but are well below human health exposure guidelines. They are not accumulating in the remainder of the facility.

SW 12th & Montgomery Green Street

Summary Information		
Evaluation Period:	**4 years** (Jul 2005 – Jun 2009)	**A series of four planters designed to fit into the urban environment of downtown Portland. Metered parking is accommodated with a step-out area between the street curb and the facility.**
Constructed:	**June 2005**	
Facility Type:	**Street Planter**	
Drainage Area:	**7,000 ft²**	
Facility Area:	**272 ft²**	
Sizing Factor:	**4%**	



Monitoring Result Summary

Peak Flow Reduction
N/A

Flow Volume Reduction	
(3) Flow Tests **[CSO Summer 6]**	**74%**

Water Quality
Based on CSO design storm testing, no overflow expected during WQ design storm.

Soil / Infiltration

- facility soil: 3-way mix (equal parts topsoil, sand, and compost)
- native soil: silty, urban mixture

3.2 – 5.5 in/hr
(minimum rate)

Design

Juncus patens is used throughout the infiltration bays, and each bay has a single Tupelo tree (*Nyssa sylvatica*) in the center. Juncus grows very well and requires trimming once a year.

Maintenance

- Sediment / debris accumulation is significant in the first bay – leaves, sweet gum burrs, and sediment from the upper portion of SW 12th. Must be removed 6 times a year.
- Curb openings are at a 90 degree angle to the gutter. This results in bypass during high intensity storms.

Overview

The facility is divided into four bays - each 17 feet long and 4 feet wide with a maximum ponding depth of 7 inches. To reach the planter bays, curb runoff flows through grate-covered curb openings at the upper end of each bay. Once the bays are full, flow leaves the bay through a downstream curb opening and proceeds into the next bay. Once all bays are filled, the final bay overflows to the existing street inlet.

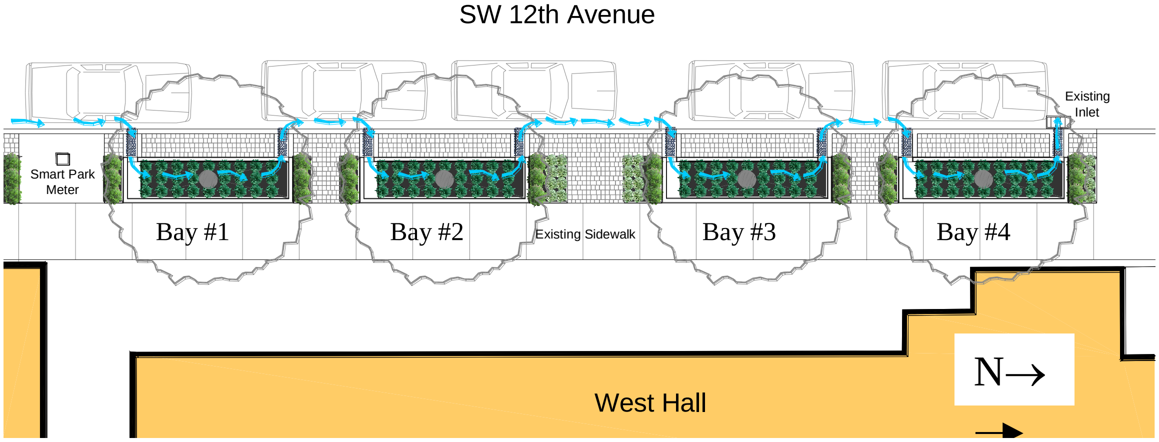


***Figure SW-1*: Plan view of the planters at SW 12th & Montgomery**

***Figure SW-2*: First two bays looking south (left) and the first three bays from above (right) looking east**

The site is not a candidate for continuous flow monitoring because the storm sewer drains substantial impervious area above the facility. Metering flows at this sewer location is also challenging due to a steep slope and variable baseflow from unknown sources. Pre-test flow rate verification and during-test manual verification are both necessary to ensure usable data.

Flow Volume

Flow test data is shown in ***Figures SW-5 and SW-6***, and summarized in ***Table SW-1***.

Retentions for the three tests with usable results were quite consistent – averaging around 74%. Overflow from the fourth bay does not occur until after the peak flow rate is reached, but during the peak flow there is some bypassing that sends flow straight to the inlet.

***Table SW-1*: Volume Retention of CSO Summer 6 Design Storm Flow Tests**

Flow Test	Antecedent Rain (7-days)[1]	Volume In (cu ft)	Volume Out (cu ft)	**Retention**
Jun 2006	Meter Malfunction			
Jul 2006	0.12”	1,265	330	**74%**
Aug 2006	0.15”	1,265	295	**77%**
Sep 2008	0.04”	1.325	375	**72%**

[1] SW 12th & Clay raingage, 700 feet north

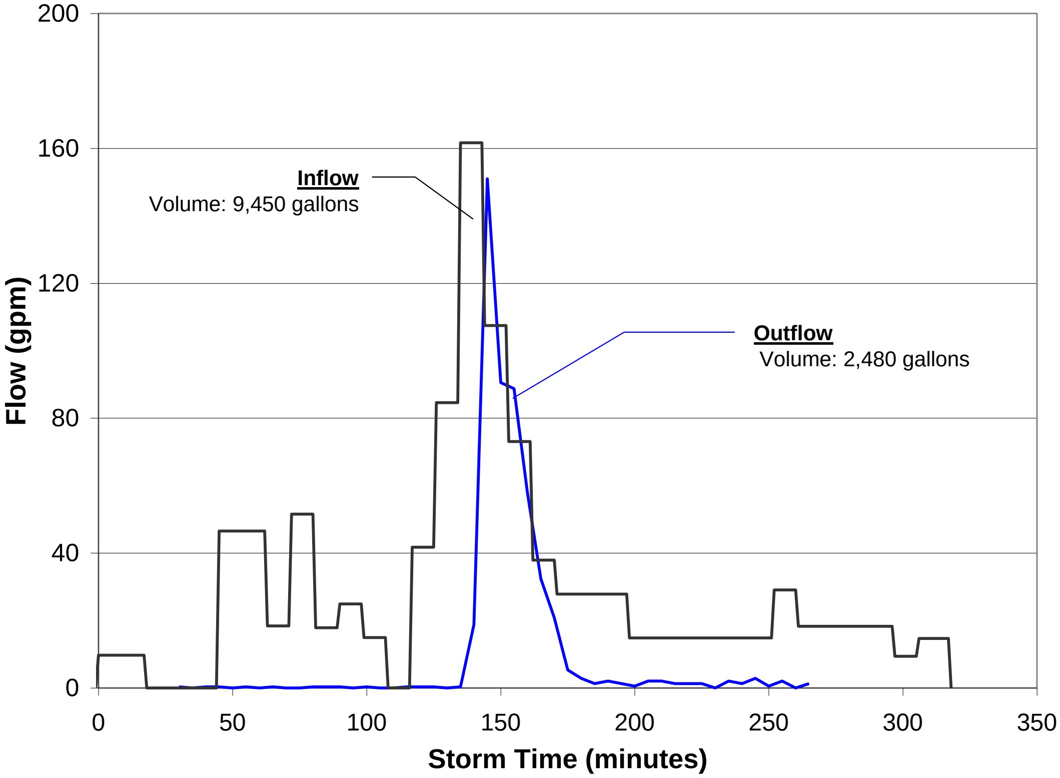


Figure SW-3: July 26, 2006 Flow Test

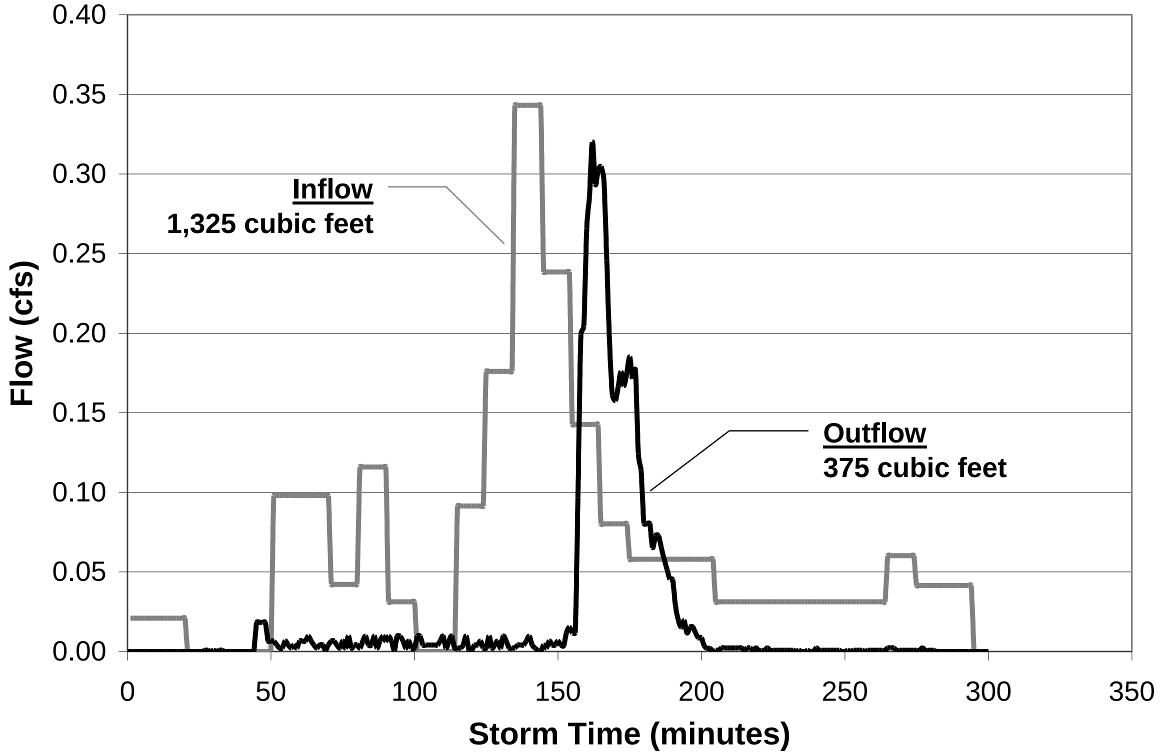


Figure SW-4 September 4, 2008 Flow Test

Given the storm compression required for the flow test (simulation of a 35 hour event in 5½ hours), these results indicate excellent performance.

Infiltration

Infiltration rates were calculated once inflow and overflow from each bay had ceased, and the results are summarized in ***Table SW-2***.

***Table SW-2*: Infiltration rates by planter bay**

Flow Test	Antecedent Rain (7-days)[1]	Test Volume (cu ft)	Minimum Infiltration Rate (inches per hour)[2]			
			Bay 1	Bay 2	Bay 3	Bay 4
Sep 2005 #1	0.08”	355	17.8[3]	8.8[3]	5.5	N/A
Sep 2005 #2		355	10.0	6.7	4.5	9.2
Jun 2006	0.22”	1,270	4.4	5.0	3.2	N/A
Jul 2006	0.12”	1,265	13.0	7.8	4.0	N/A
Sep 2008	0.04”	1,325	4.5	5.3	3.0	N/A

[1] SW 12th & Clay raingage, 700 feet north

[2] Rate during the final 30 minutes; [3] Drained in less than 30 minutes – rate is the average over the entire period

Infiltration rates were higher than anticipated because the native soils are high in silt content and were anticipated to be a barrier to infiltration. Antecedent conditions for the tests were relatively dry.

Generally, infiltration rates decrease from Bay 1 to Bay 3 (moving from south to north). Each bay is identical in design – same geometry, ponding depth, and planting. The first bay does have the largest drainage area, but it fills fast and overflows to the other bays quickly during a large event and they all fill to the maximum ponding depth. The difference may be the result of changing sub-surface conditions, but there were no obvious differences during construction.

The first three bays handle all the flow except during the highest flow rates, so the fourth bay receives less volume than the others. As a result, the water does not pond as deeply in Bay 4, and there is typically no water depth at the tail end of the test – even while flow is still coming in.

Design

At 12th & Montgomery, trench drains are used to move the water under the car step-out area and into the facility. To enter the drains, water is forced to turn 90 degrees and during high flows the momentum in the gutter carries much of the water past the openings. This situation becomes more problematic as the slope of the street increases. Small, asphalt berms have been installed to encourage flow to enter the bays and they appear to be working well. Future facilities would benefit from angled entries, gutter depressions, or other methods to ease the transition of flow from the curb into the facility.

Figure SW-5: **Flow bypassing 90 degree inlet**

This facility also appears to manage much more than the drainage area assumed during design. The inlet at the base of an overpass (***Figure SW-6***), and another just upstream of the facility (***Figure SW-7***), frequently clog with leaves and other debris, resulting in significant additional flow.

Figure SW-6: **Flow bypassing a clogged inlet and crossing the street**

Figure SW-7: **Flow bypassing a clogged inlet just above the facility**

Soil Sampling

Soil sampling began in fall 2005 with analyses for metals and petroleum-based pollutants (heavy oils and polycyclic aromatic hydrocarbons, or PAHs). The maximum results for samples taken at the surface (0 to 6 inch) depth horizon within the facility are summarized in ***Table SW-3***. A more complete data summary is presented in the ***Soil Sampling*** section of the Monitoring Report.

***Table SW-3*:** **Maximum soil pollutant concentrations from the 0 to 6 inch soil horizon, SW 12th & Montgomery Green Street**

Pollutant	Units	2005 [1]	2007 [2]	2010 [2]	Control (2010)
E. coli	mpn/g	7	2	2	
Motor oil	mg/kg	342	257	749	337
pH	Std Units	7.9	6.6	6.2	7.8
copper	mg/kg	30.1	31.2	31.2	26.4
lead	mg/kg	29.9	41.3	51.7	34.3
mercury	mg/kg	0.043	0.125	0.049	0.047
zinc	mg/kg	120	138	233	132
benzo(a)pyrene	ug/kg	61	77	57	52
benzo(b)fluoranthene	ug/kg	65	85	90	71
benzo(g,h,i)perylene	ug/kg	91	107	160	88
chrysene	ug/kg	56	81	52	54
fluoranthene	ug/kg	57	96	77	59
indeno(1,2,3-cd)pyrene	ug/kg	54	65	60	48
pyrene	ug/kg	65	90	110	73

grey numbers indicate non-detects; the number is the detection limit

[1] 0 to 6 inch composite of all bays; [2] 0 to 6 inch sample from Bay 1

In 2010, a control location adjacent to but not part of the stormwater facility was added. This sample was taken from the sidewalk-level landscape buffer at the end of one of the planters.

Some general observations:

- Motor oil levels have been close to the control levels. Though 2010 did have a higher than normal level, oil levels are highly variable and temporary spikes are common.
- pH has dropped noticeably from almost 8 down to just above 6, while the control is still almost 8.
- Metals have been generally consistent with the control, but lead and zinc have shown potential signs of an upward trend. All metal levels are well below concentrations considered a threat to human health.
- PAHs have been generally stable, with many levels dropping between 2007 and 2010. However, benzo(b)fluoranthene, benzo(g,h,i)perylene, and pyrene have increased somewhat with each sample and are somewhat higher than the control levels.

Vegetation & Maintenance

Weeding, garbage removal, leaf removal, and sediment removal are the primary maintenance activities for the facility. Sediment loads have been heavy due to silt soil wash off from the hills above the site and the clogged inlets above. Tree litter just upstream of the facility is also substantial. It's been necessary to cleanout the first bay 4-6 times per year.

California gray rush (*juncus patens*) is the base planting along with one Black Tupelo (*nyssa sylvatica*) in each bay. Both rush and tupelos have done well and appear to handle the wet winter and dry summer cycles well.

The rush has grown quite tall in the facility and must be trimmed at least once a year to prevent it from flopping into the sidewalk and car step-out area. For future facilities, the lower growing *juncus patens* 'Elk's Blue' or another shorter growing carex / juncus species may be a lower maintenance option.

Monitoring Summary

- The facility successfully integrates curbside parking and stormwater management.
- Forcing curb runoff to turn 90 degrees into curb openings is problematic during high flows. The momentum of the runoff is straight down the street. The retrofit of small asphalt check-dams have improved performance, but better gutter depressions and/or angled would be better for new facilities.
- The facility drains a much larger drainage area than it was designed to manage. This is the result of clogged upstream inlets and variations in the street surface that are common throughout the city. At this point, the facility appears to be handling the higher flow rates and flow volumes well
- Sediment and debris accumulation in the first of the four bays has been significant. It is cleaned out at least 4 times per year.

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Lined Facility Summary

Lined facilities contain soil and plants just like infiltration facilities, but are sealed off from the surrounding native soils. The sealing is most often done using an impervious liner or concrete. Water not captured in the soil is collected by an underdrain and connected to a disposal point like a sewer, sump, or surface drainage system.

Lined facilities are especially versatile because they can be used in areas with poorly draining soils or adjacent to building foundations. They provide peak flow reduction and water quality treatment, but because some flow volume passes through the underdrain system, they provide only partial volume retention.

Table FT-1: Peak Flow Reduction and Volume Retention of Lined Facilities

Facility	Location	Sizing Factor	25-Yr Peak Flow Reduction	Annual Runoff Retention	CSO Flow Volume Retention	WQ Flow Volume Retention
32nd & Capitol	SW	2%	N/A	N/A	N/A	20%
Barbur & Glisan	SW	4%	N/A	N/A	26%	N/A
Glisan & 28th	NE	3%	N/A	N/A	55%	N/A
Haven & Cecilia	N	2%	N/A	N/A	N/A	7%
Moody & Abernethy	SW	4%	N/A	N/A	N/A	59%
Oregon Zoo	SW	9%	N/A	N/A	23%	N/A
ReBuilding Center	N	6%	58% [a]	28%	29%	N/A
WPCL Test Planters	N	6%	92% [b]	N/A	26% [c]	N/A
AVERAGE			**90%**	**N/A**	**28%**	**29%**

[a] average continuous and flow test data; [b] average of 7 tests; [c] average of 15 tests

Peak flow reduction was excellent for all configurations of the WPCL test planters, and was adequate at the ReBuilding Center planter. The range of peak flow reduction is similar to that found for infiltration facilities. This would suggest lined facilities are generally equivalent to infiltration facilities in reducing peak flow.

Tests of the CSO design storm at three facilities resulted in very consistent volume retention results averaging 28%. The single tests at the Oregon Zoo and ReBuilding Center, resulted in 23% and 29% retention, respectively. Results for the 15 tests run at the WPCL test planters ranged between 13% and 38% of inflow volume, with an average retention of 26% across all tests and all bays.

Based on those WPCL tests, geometry appears to make a significant difference. The long, skinny planter has an average retention 11 percentage points lower than the shorter, wider planter (31% short/wide versus 20% long/skinny). This is likely due to the greater wall length to surface area ratio. The greater wall length provides more opportunity for water to leak down the side, avoiding most of the soil volume. This is accentuated in the summer when the soil dries and shrinks back from the walls (and when most testing has been done). Differences in the two soils were not significant (only a 3% difference). The soil / rock separator difference of 6% could be somewhat significant (31% filter fabric versus 25% pea gravel). This suggests that filter fabric's greater resistance to the passage of water into the underdrain could be used to increase volume retention. However, if filter fabric is used, it is important to ensure the facility soil and fabric are well matched to prevent clogging.

An effort will be made to test more lined facilities in the future. It is expected that the number of lined facilities will increase in the future as facilities are needed in areas that are not suitable for infiltration.

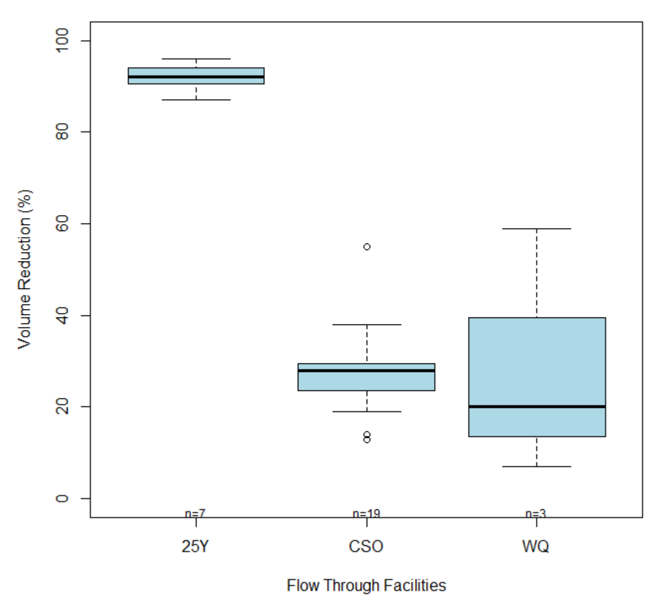


Figure FT-1: Design Storm Performance for Lined Facilities

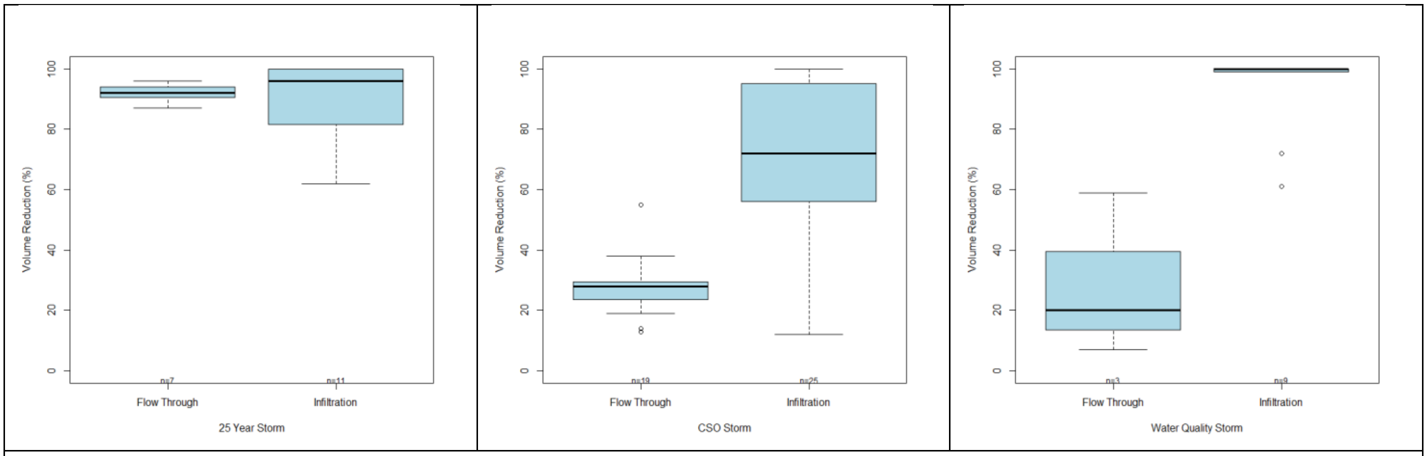
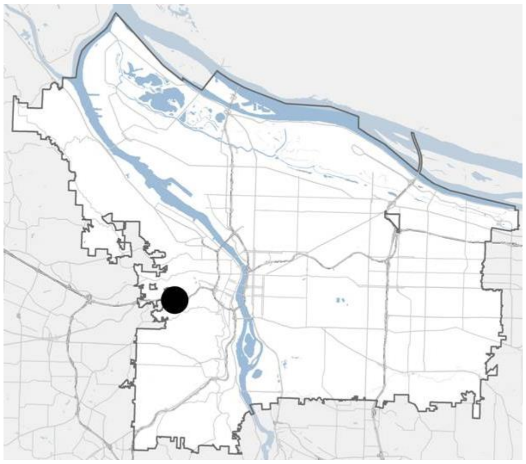


Figure FT-2: Comparison of Design Storm Performance between Lined and Infiltration Facilities

Oregon Zoo Parking Lot Swales

Summary Information		
Evaluation Period:	**12 months** (Dec 2006 – Dec 2007)	**Parking lot retrofit of several parking rows in a large, heavily used parking lot. Swales are fully lined due to location in a slide hazard area.**
Constructed:	**June 2006**	
Facility Type:	**Lined Basin**	
Drainage Area:	**104,000 ft^2**	
Facility Area:	**6,500 ft^2**	
Sizing Factor:	**6%**	



Monitoring Result Summary

Peak Flow Reduction

Flow Volume Reduction

Continuous Flow	**6%**
Flow Test **(CSO Summer 6)**	**23%**

Water Quality

- only 2 storm samples
- removal of metals and oils
- some export of phosphorus and nitrates

Soil / Infiltration

Facility soils:
Row 4 = 55% sandy loam / 45% compost
Row 7 = Sunderland Yard 3-way mix

Vegetation

Maintenance

N/A

Overview

Stormwater facilities were constructed in 2006 to manage runoff from a portion of a large, heavily used parking lot serving the Oregon Zoo, World Forestry Center, and Children's Museum. The lined swales and filter strip manage runoff from approximately 2 acres of pavement in the northeast corner of the parking lot (***Figure OZ-1***).

Runoff from the access road and plaza north of Row 8, flows over the filter strip of vegetation and mulch, but was not designed for retention. Overflow from the Row 8 filter strip is intended to be captured by the Row 7 lined planter where runoff flows over surface vegetation and river rock mulch, and then percolates through approximately 18 inches of soil media (***Figure OZ-2***). Any runoff that passes through the soil media is then collected in a perforated pipe that is connected to the existing storm sewer system running down SW Zoo Rd. If inflow exceeds the capacity of the soil media, runoff flows over a series of check dams and into an overflow connected to the pipe system. The lined swale on Row 4 functions in the same way.

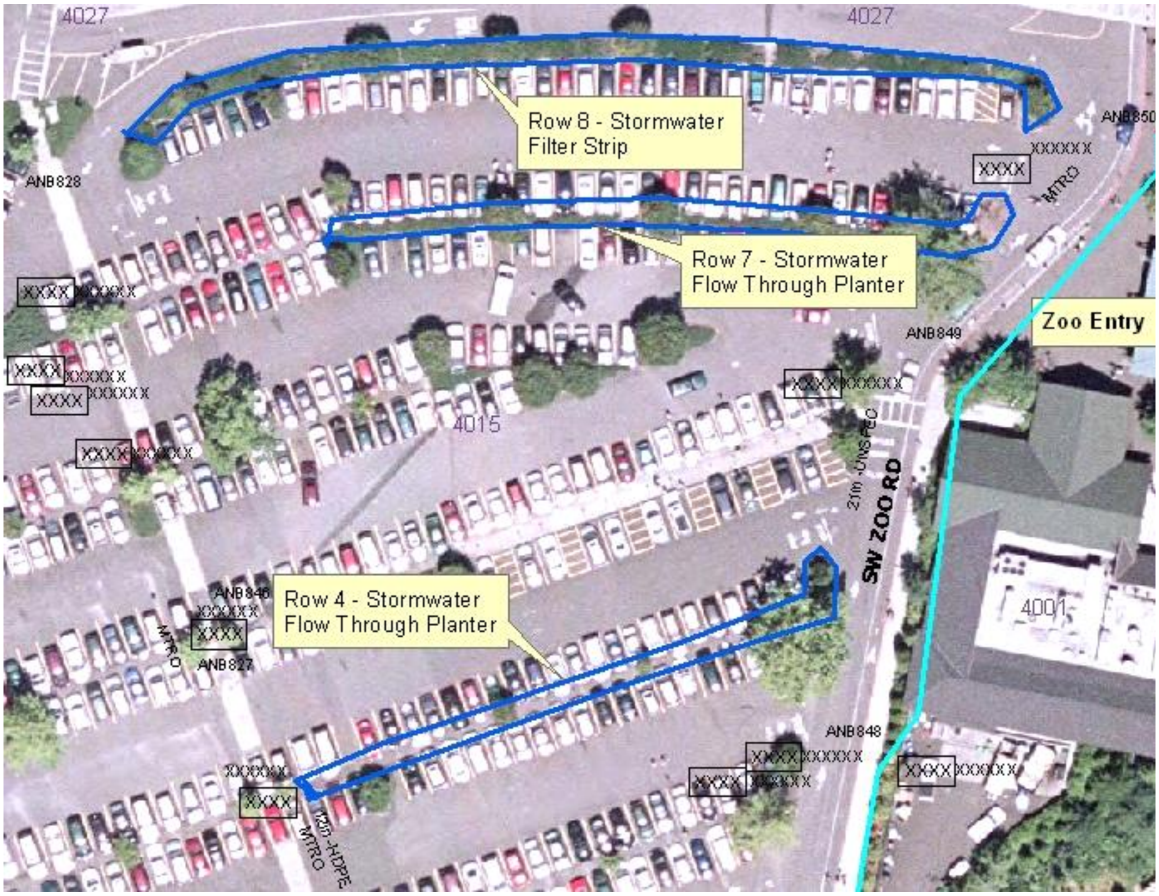


Figure OZ-1 – Facility Overview

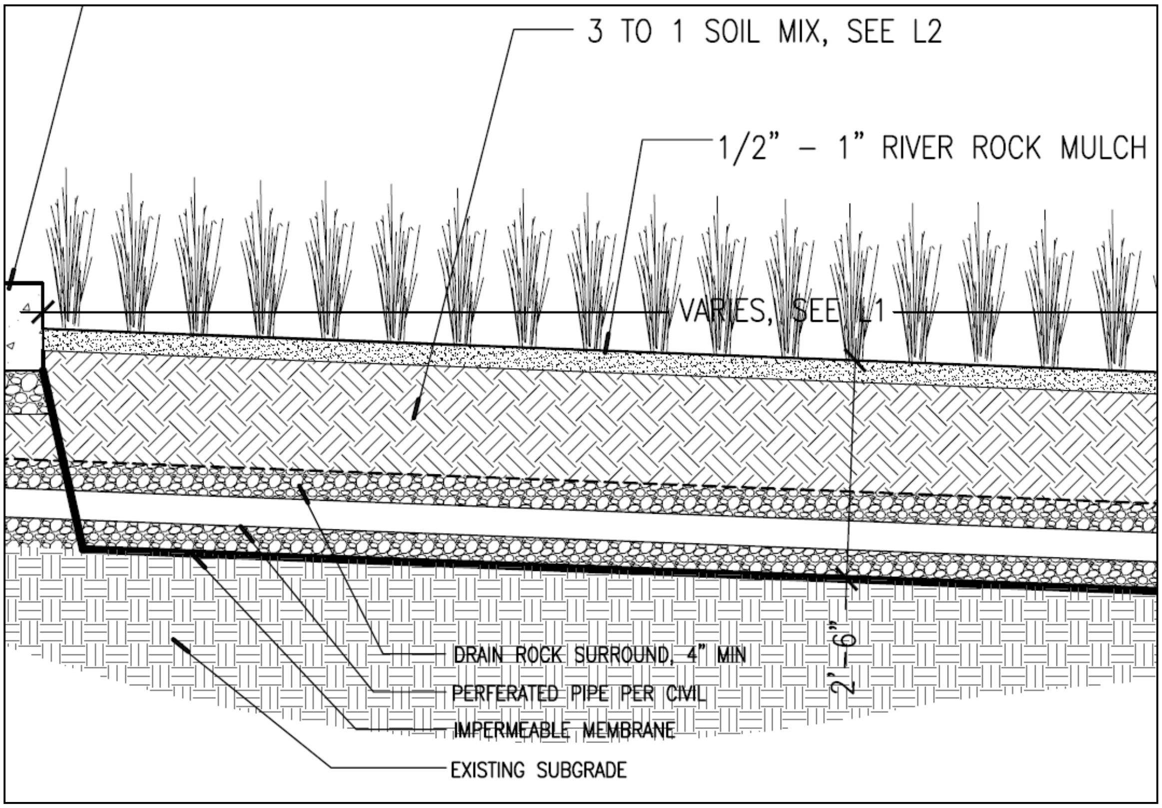


Figure OZ-2 – Cross-section of the lined swales

Flow Volume

Continuous flow meters were installed and flow was monitored during 2007 above and below the project area. The resulting data shows little volume reduction from the lined swales, or at least any difference is masked by the error inherent in environmental monitoring. This error is undoubtedly large due to typically shallow flow depths (less than 2 inches in a 21 inch pipe), the steep slope of the storm sewer, and uncertainties in the delineation of the drainage area.

While lined systems aren't assumed to remove large amounts of runoff from the system, a reduction of at least 15% due to the field capacity of the soil would be expected in the summer months. Similar lined systems being tested at the Bureau of Environmental Services Water Pollution Control Lab have shown retentions between 20 and 40% and the lined planters at the ReBuilding Center have averaged 20%. However, these other sites provide a much more controlled environment for collecting data.

To better control the variables at this site, a flow test was conducted in September 2007. The Row #7 swale was tested using the Summer 6 CSO Design Storm. Antecedent conditions were dry with 0.13 inches of rain in the prior 7 days.

For this test, the swale retained 23% of the inflow volume. This result is consistent with other lined facilities that have been monitored. Retention and attenuation were greatest during the first 150 minutes of the storm event (equivalent to 0.76 inches of rain) which agrees with continuous flow monitoring data which indicates noticeable retention for storm events up to ¾ inches of rainfall, but little retention for the largest events.

Figure OZ-6 – flow test of Row #7 (flow rate approximately 56 gpm)

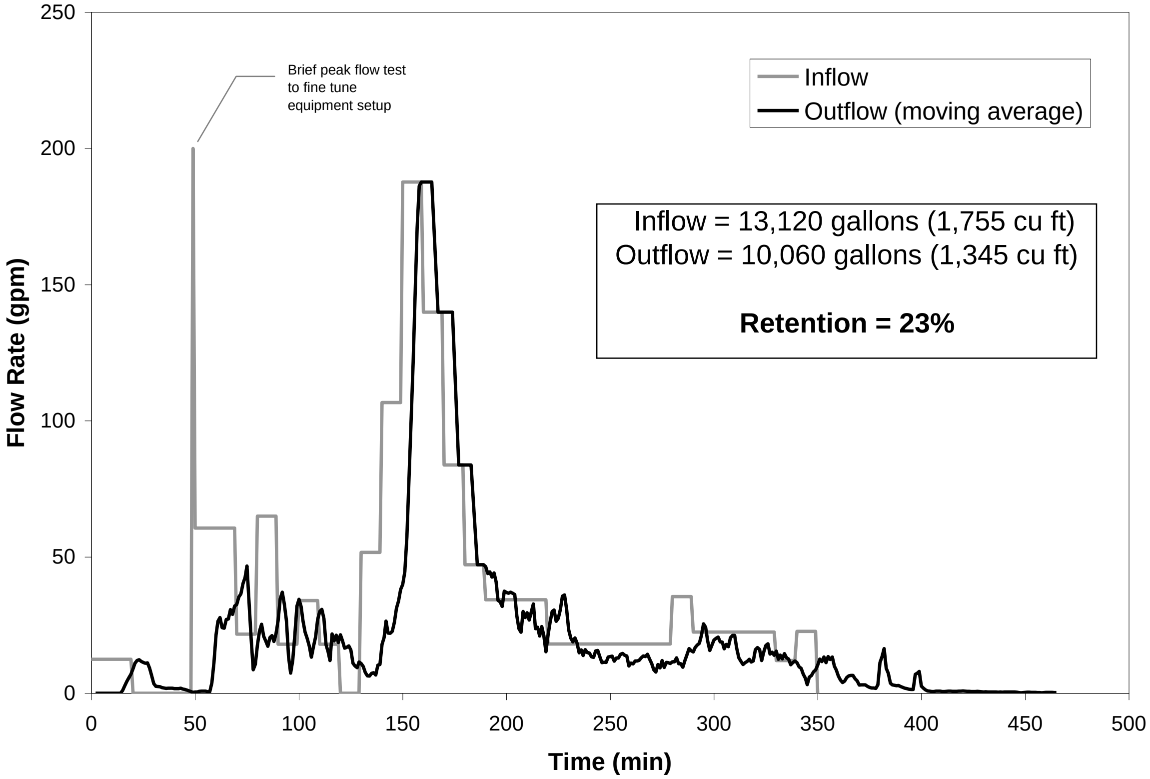


Figure OZ-7 – Row #7 Swale flow test (September 2007) inflow and outflow

After the peak inflow rate was reached, outflow and inflow rates were generally the same. Passage through the facility provided a time delay (about 10 minutes) throughout the simulation between inflow rate change and outflow rate change.

It is also important to note that the lined swales are only intended to manage the smaller Water Quality Design Storm (0.83 inches in 24 hours), but this storm is not ideal for flow testing because the storm's flow rates are low and were not expected to produce significant flow into the sewer. Given the results of this test, it may be prudent to conduct another test of the smaller storm event in the future.

This result should also be considered conservative due to time compression. Compressing longer storm events into a test that can be carried out in a single work day results in an "aggressive" test. In order to maintain the storm volume during a shorter duration, all flow rates must increase providing a much greater challenge than the real storm event would.

The accuracy of this test should be much greater than was achieved for the continuous meter installations. With the pre-test calibration, manual observations during the test, and the consistency between inflow and outflow rates, there is a high degree of confidence in the results.

Water quality samples were also taken at three locations (***Figure OZ-8, Table OZ-2***).

Table OZ-2 – Water Quality Sampling Locations

Sampling Point	Type	Drainage Area
Row #4 Swale Overflow	Lined Swale	15,500 ft^2
Row #7 Swale Overflow	Lined Swale	45,900 ft^2
Row #5 Parking Lot Inlet	Conventional Parking Lot	27,600 ft^2

Row #5 has no stormwater facilities and acts as a control for comparison with the two lined swale facilities. Grab samples for the Row #4 and Row #7 sites were taken by pumping flow from the underdrain system through the overflow structure (***Figures OZ-9 & OZ-10***). Grab samples from Row #5 were taken at the lip of the inlet.

Rainfall event depths, durations, and intensities were recorded at a raingage on the roof of the Children's Museum – approximately 650 feet from the project area.

Water quality sampling took place for two events – December 14th, 2006 and May 2nd, 2007 (results shown in ***Table OZ-3***). The December 2006 event was the tail end of a wet period stretching over 5 days. The total rainfall during that time was 3.09 inches (December 9 – 14). Rainfall for the storm period sampled was 1.33 inches and sampling occurred after 1.26 inches had fallen. The May 2007 event occurred after more than 9 days without rainfall. Total rainfall for the event was 0.42 inches, and sampling took place after 0.40 inches had fallen.

In general, the water quality samples show no significant issues for either the swale effluent or the untreated parking lot runoff. However, with only two samples it will be difficult to draw solid conclusions. In addition, sampling for both events was done towards the end of each storm. This could mean that many pollutants had already washed off the parking lot prior to sampling. This could be especially true of the December 2006 event in which over 3" of rain fell in the 5 days prior to sampling.

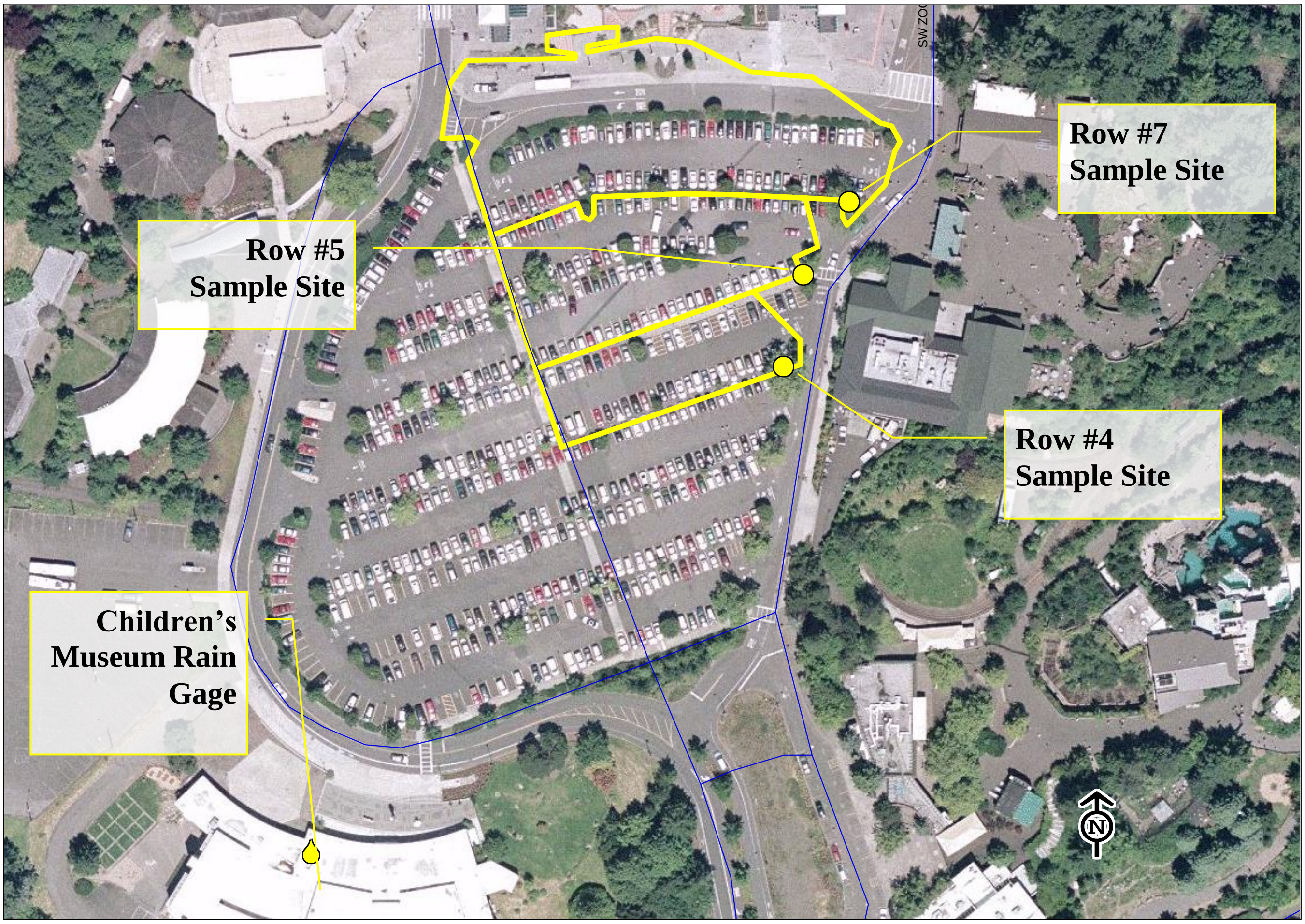


Figure OZ-8 – Water Quality Sampling Overview

Figure OZ-9 – sample points for Row #4 (left), Row #5 (middle), and Row #7 (right) [photos taken during 12/14/06 rain event]

Figure OZ-10 – overflow sampling location (Row 7); flow in underdrain (right) is pumped into a sample container through the overflow dome

Each swale had significant overland flow to the overflow structure during the December 2006 event. This meant that significant amounts of runoff were passing into the underdrain system without being filtered through the soil media. It is unclear whether this was also true during the May 2007 event.

Oils

Small amounts of total oil & grease were present in the untreated parking lot runoff, but were not detected in the swale runoff. The soil media appears to be filtering the oil & grease well.

Solids

Row #7 had much higher total dissolved solids (TDS), conductivity, and hardness when compared with Row #4 for both events. There are three primary differences between the Row #4 and Row #7 swales:

1) different soil mixes were used – Row #4 was approximately 55% sandy loam / 45% compost; Row #7 was approximately 67% sandy loam / 33% compost. Soil sources were also different – Row #4 was provided by the contractor from an unknown vendor, and Row #7 was provided by Sunderland Yard.
2) the drainage area of Row #7 is three times larger than Row #4 (45,900 sq ft to 15,500 sq ft) and includes overflow for the Row #8 filter strip.
3) Row #7 included reconstruction of a concrete light pole foundation.
4) a mastic adhesive was used to attach the impermeable liner on Row #7. Bentonite clay was used to seal the liner in Row #4.
5) mechanical compaction was mistakenly used on Row #4 but only manual compaction on Row #7.

The soil source and composition, as well as the mechanical versus manual compaction could be big influences. Differences in particularly the compost fraction – source stock and maturity – can certainly influence TDS. Well compacted soils are also likely more stable during the early years of the facility, and it may be difficult for particulates in the soil to become mobile. There is no indication that the high TDS and hardness levels are problematic for plant health or water quality. However, follow-up soil tests would determine if the trend continues.

***Table OZ-3*: Water Quality Sampling Results**

Analytes		Units	12/14/2006 (1.33" in 28 hrs)			5/2/2007 (0.42" in 19 hrs)		
			ROW 5	ROW 4	ROW 7	ROW 5	ROW 4	ROW 7
General	conductivity - specific	umhos/cm	18	29	206	26	76	370
	dissolved oxygen	mg/L	8.0	10.3	10.1	9.3	7.0	7.0
	e. coli	mpn/100 ml	98	340	200	52	120	10
	hardness, total	mg CaCO3/L	6.3	9.6	***101.0***	9.5	27.7	***219.0***
	oil/grease - nonpolar	mg/L	6.6	N/A	N/A	N/A		
	oil/grease - total	mg/L	12.8	ND	ND	6.1	ND	ND
	pH	std units	6.9	6.7	6.9	6.4	6.0	6.9
	temperature	deg C	11.9	9.7	8.9	11.6	12.0	12.1
Solids	solids - total	mg/L	8	36	152	53	76	277
	solids - total dissolved @180C		13	31	***153***	40	80	***281***
	solids - total suspended		2	13	3	18	2	2
Nutrients	nitrogen - ammonia	mg/L	ND	ND	ND	0.02	ND	ND
	nitrogen - nitrate		ND	ND	0.48	ND	0.18	1.80
	phosphorus - ortho phosphate (dissolved)		ND	0.05	0.53	0.02	0.08	0.40
	phosphorus - total		ND	0.08	0.57	0.13	0.14	0.45
Metals	arsenic	ug/L	N/A			0.66	0.48	1.37
	arsenic, dissolved		N/A			0.35	0.48	1.42
	chromium		N/A			4.20	1.16	0.75
	copper		2.84	3.07	6.25	***17.5***	8.07	6.37
	copper, dissolved		2.75	2.71	5.07	9.06	6.78	5.59
	lead		0.81	0.77	3.24	***19.7***	1.06	0.78
	lead, dissolved		0.17	ND	ND	1.17	0.33	0.11
	zinc		9.75	11.9	8.57	79.3	14.0	10.4
	zinc, dissolved		9.01	8.48	1.28	33.5	10.7	3.63
	PAHs	ug/L	ND	ND	ND	ND	ND	ND

Row 5 = control (standard pavement runoff); Rows 4 & 7 = flow-through swale effluent
ND = non-detect; ***Bold Italic*** = values of interest

Nutrients

Nutrients levels were not detected or were very low for the untreated parking lot runoff. Values for Row #4 effluent were also quite low while much higher levels of phosphorus and nitrate nitrogen were found in Row #7. As mentioned, Row #7 used a different soil mix than Row #4 but was not thought to differ substantially.

The compaction of Row #4 may also have an impact by limiting the passage of water through the soil and therefore the subsequent leaching of nutrients. More standing water is noted in Row #4 bays when compared to those in Row #7. It may also be possible that the Row #7 soil mix contains more available nutrients. One possible source is the leaf compost in the Sunderland Yard mix used in Row #7 compared to the compost used in the Row #4 soil mix. Follow-up soil tests should be able to determine if this is the case.

Metals

Unlike the results for TDS and nutrients, Row #4 and Row #7 effluents do not appear to differ greatly in metal concentrations. Levels are generally low in relation to aquatic health benchmarks.

There were few significant differences between the untreated parking lot runoff (Row #5) and the two lined swales for the December 2006 event. However, for the May 2007 event chromium, copper, lead, and zinc were all notable higher for the untreated Row #5 than for the swale effluent. Copper and lead values for Row #5 exceeded benchmarks for chronic impacts on fresh water aquatic life, while effluent from the swales for the same event were well below those benchmarks. Swale effluent concentrations for the two storm events are similar, but the Row #5 metal levels were much higher for this event than they were in December 2006. This could suggest the swales do an excellent job managing higher concentrations associated with first flush events, but it is also possible that there were higher influent levels due to point sources in the Row #5 drainage area.

Monitoring Summary

- Low retentions for storm events with total rainfall depths over ¾ of an inch.
- Total and dissolved metal levels in the swale effluent were much lower than in the untreated parking lot runoff for one of the two events.
- Phosphorus and nitrate concentrations are notably higher for Row 7. This may be due to less compaction in Row 7 resulting in more soil particle movement than in Row 4, or it could be a result of the leaf compost fraction in the Row 7 soil when compared with the compost used in the Row 4 soil.

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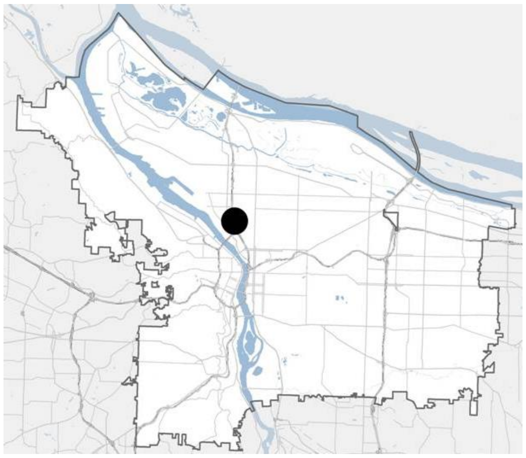
ReBuilding Center Planters

Summary Information		
Evaluation Period:	**6 years** (Jul 2006 – Jun 2012)	**Lined planters placed against the building which manage runoff from a 8,400 sq ft section of roof. Underflow and overflow are piped to a drywell.**
Constructed:	**September 2005**	
Facility Type:	**Lined Planter**	
Drainage Area:	**8,400 ft^2**	
Facility Area:	**480 ft^2 (2 planters)**	
Sizing Factor:	**6%**	



Monitoring Result Summary

Peak Flow Reduction	
Continuous Storm Event Monitoring	**54%**
ASFO CSO Design Storm Flow Test	**61%**

Flow Volume Reduction	
Annual Retention	**28%**

Water Quality

N/A

Soil / Infiltration

- facility soil: 65% sandy loam, 15% digested paper fiber, 10% coconut coir, 10% compost

Vegetation

Maintenance

- irrigation: drip irrigation activated during summer months. No significant irrigation runoff after summer 2006, but results in consistently moist soils in the summer.

Overview

The ReBuilding Center site was redeveloped in 2005 and 2006 and stormwater planters were installed to manage runoff from the roof area. The two lined planters monitored take runoff from 8,400 square feet of roof. The planter underdrains and overflows flow to a drywell located under the parking lot.

The original soil placed within the planters was tested and did not infiltrate at the 2 inches per hour specified by the designer. It was then removed and replaced with a freer-draining soil.

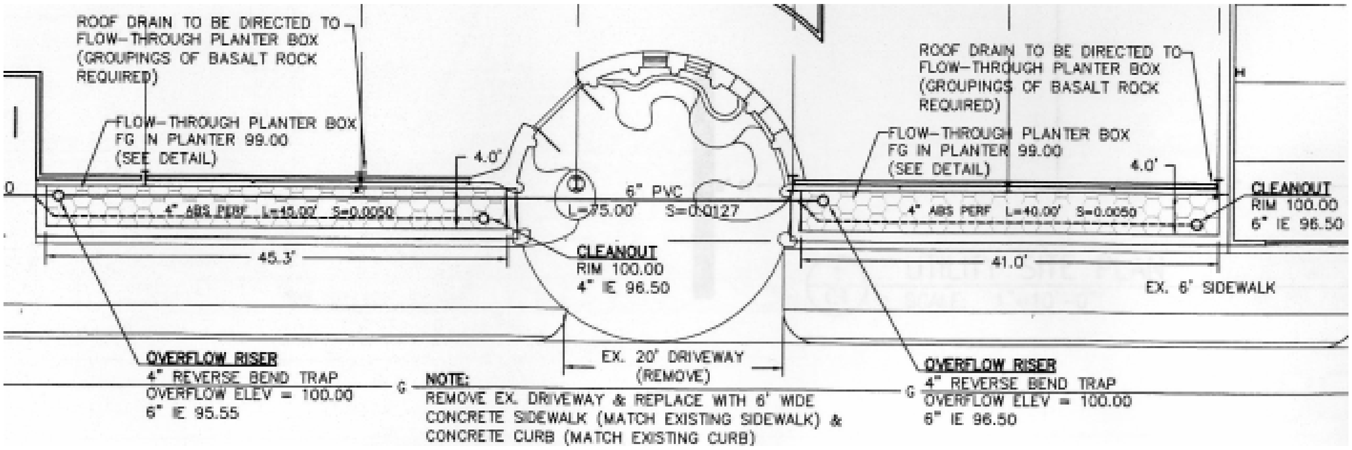


***Figure RC-1*: Plan view of the ReBuilding Center Planters along Mississippi Ave.**

To monitor outflow, a monitoring manhole with a v-notch flume in the bottom (***Figure RC-2***) was installed between the planters and the drywell. Rainfall data is collected from the Albina Pump Station raingage, approximately 0.25 miles away.

Figure RC-2: Monitoring manhole

Figure RC-3: Roof area draining to planters

Peak Flow Reduction

Peak flow reductions were variable depending on rainfall pattern, overall storm depth, and summer irrigation. These planters do provide a good peak flow reduction benefit, but the benefit does appear to be lower than that seen for typical infiltration facilities.

***Table RC-1*: Peak flow reduction for storms with intensities >= 1 inch per hour**

Start Time	Duration (hrs)	Storm Depth (in)	MAX Intensity (in/hr)	Est. Peak (cfs)	Act. Peak (cfs)	Peak Reduction
01/17/07	3	0.30	1.98	0.3850	0.0000	100%
09/28/07	153	2.17	1.06	0.2053	0.0676	67%
05/24/08	37	1.56	3.96	0.7700	#N/A	
10/04/08	47	0.98	1.06	0.2053	#N/A	
05/02/09	25	0.82	1.72	0.3337	0.1688	49%
05/04/09	75	2.04	1.06	0.2053	#N/A	
06/19/09	17	0.51	1.32	0.2567	0.1997	22%
10/17/09	30	0.43	1.19	0.2310	0.1163	50%
10/26/09	45	0.63	1.85	0.3593	0.1972	45%
05/23/10	161	2.56	1.06	0.2053	0.0402	80%
06/06/10	26	1.83	1.06	0.2053	#N/A	
09/07/10	34	0.83	1.08	0.2100	0.1477	30%
09/18/10	61	1.14	1.32	0.2567	#N/A	
10/24/10	90	2.88	1.20	0.2333	0.0835	64%
05/27/11	86	1.11	1.56	0.3033	0.1688	44%
09/25/11	50	0.53	1.20	0.2333	0.2037	13%
10/05/11	144	0.94	1.20	0.2333	0.0358	85%
05/26/12	154	1.88	3.24	0.6300	#N/A	
06/08/12	44	1.06	1.20	0.2333	0.1134	51%
					AVERAGE =	**54%**
ASFO CSO Design Storm Flow Test						
08/28/08	6	1.41	3.75	0.3654	0.1410	61%

#N/A peaks are unavailable due to flume backwatering during that event

Substantial leakage down the seam between the planter walls and the soil has been observed during rain events. In addition, the freely draining soil mix allows water to drain quickly to the perforated pipe. Because of this short-circuiting, the full facility capacity is rarely utilized, and antecedent conditions and rainfall patterns have a larger impact on peak flow reduction.

Flow Volume Retention

Outflow is metered continuously, and volume retention is summarized in ***Table RC-2*** and ***Figure RC-2***.

***Table RC-2*: Overall volume retention**

Period	(in) Total Rainfall	(ft^3) Potential Runoff	(ft^3) Metered Runoff	Retention
July 2006 – June 2012	256.8	179,800	130,300	**28%**
Winter months (NOV-APR)	197.4	138,200	100,200	**28%**
Summer months (MAY-OCT)	59.4	41,550	30,090	**28%**

Large storm events can surcharge the 12 inch flume because of backflow from the disposal drywell located in the adjacent parking lot. This results in unusable flow data. Days during which the flume is backwatered are assumed to have 0% retention and runoff is made equivalent to the runon.

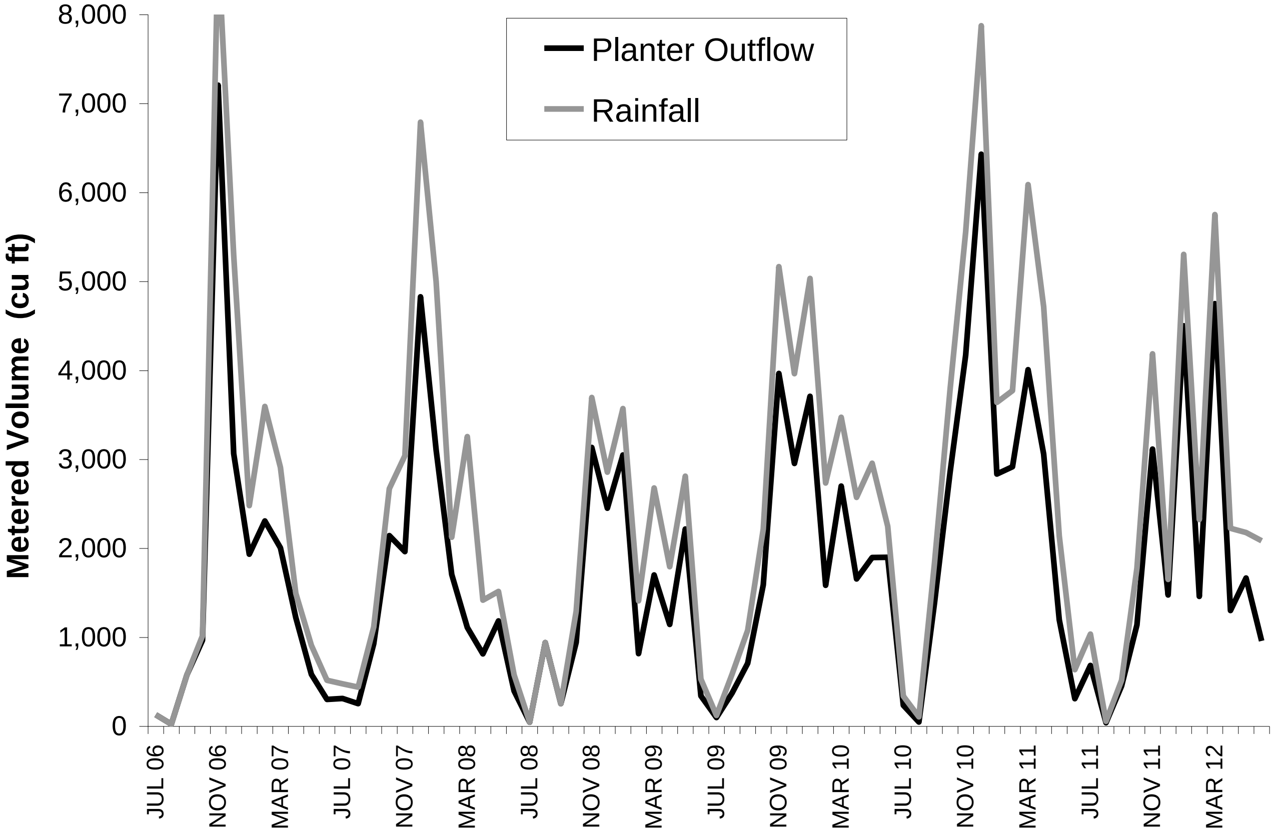


***Figure RC-2*: Monthly volume retention, ReBuilding Center Planters**

While summer retention is typically higher than winter for most facilities, this facility shows a constant retention year round for this facility. The lack of higher summer retention is likely due to the use of irrigation within the planters which keeps the planter soils in a wet season condition.

Storm event retention appears strongly influenced by the overall storm depth, as shown in Figure RC-3. For storms greater than 0.10 inches in depth, retentions typically ranged from 60% to 0%. The planters were most effective at retaining volume for storms less than 0.50 inches. Antecedent conditions did not appear to be a major influence, though low depth storms following high depth storms would often have minimal retention.

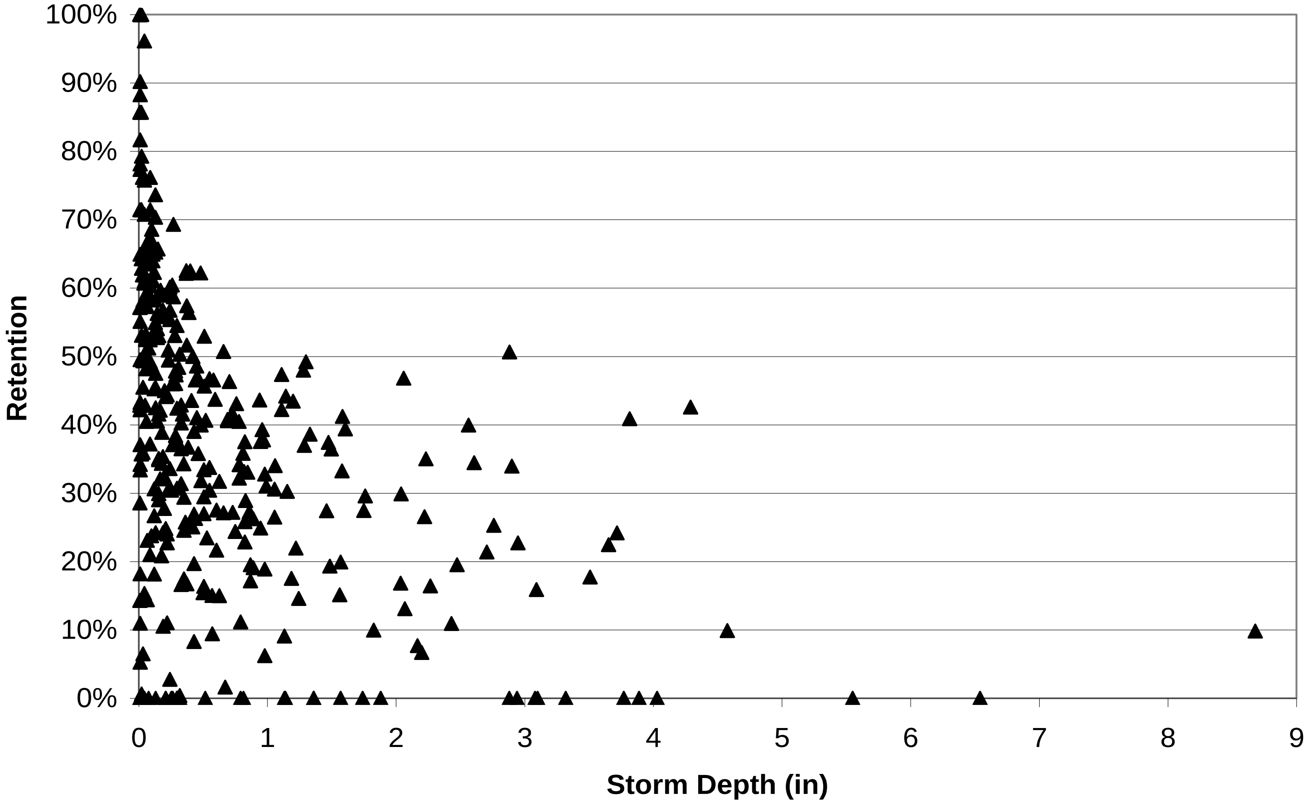


***Figure RC-3*: Rain event retention by event depth**

An ASFO CSO Design Storm flow test was performed on the north planter in August 2008. Water infiltrated quickly through the soil and typically did not extend more than one-third of the way down the horizontal length of the planter. Only during the highest inflow rates did ponding occur – to a maximum depth of 2 to 3 inches.

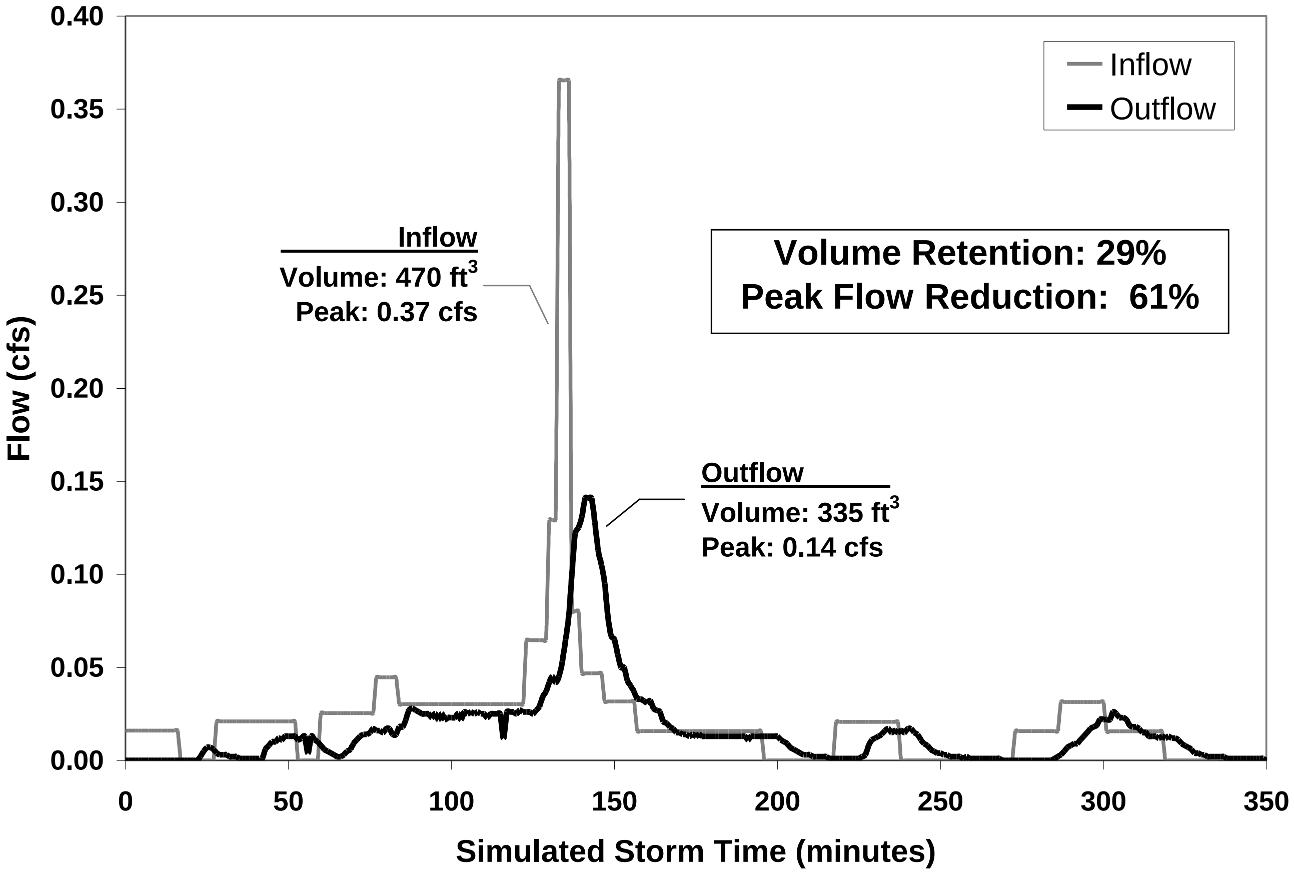


***Figure RC-4*: ASFO CSO Design Storm Flow Test, August 2008**

Design / Maintenance / Vegetation

The planter soil drains so well that there is very little ponding within the planters. During most events, only a small portion of the planter near the downspouts is actually wet on the surface.

Faster draining soils may be appropriate for infiltration facilities where water will continue to infiltrate through underlying native soil. However, lined planters need to pond so they can use their entire soil volume for filtering pollutants, storing water, and reducing outflow rates. When only a small portion is active, the planter's effectiveness is reduced.

Results to date indicate that the existing soil is too porous. It was hoped the soil complex would mature and retention would increase over time, but there is no evidence this is occurring after 4 years. Studies looking at soil specifications and other design variables are under way to determine changes to lined facilities that will maximize their performance.

Vegetation is surviving but struggles for full coverage. Weed numbers are modest throughout most of the facility, but increase near the downspouts – likely because wind-borne seeds wash down from the roof and because of the greater water availability in the soil near the downspouts.

There is some evidence of very minimal irrigation runoff during the summer months (daily peaks of well under 0.1 gpm). While irrigation overflow volume is negligible, the irrigation does keep the soil wet and likely reduces overall retention during the summer.

Monitoring Summary

- Peak flow reduction is generally good, but can be variable based on antecedent conditions.
- Volume retention is similar for both summer and winter seasons. This is likely due to summer irrigation which keeps the soil moist.
- Soil selection for flow-through facilities is very important. Soils that drain too well may not provide the expected benefits for water quality, volume retention, and peak flow reduction.

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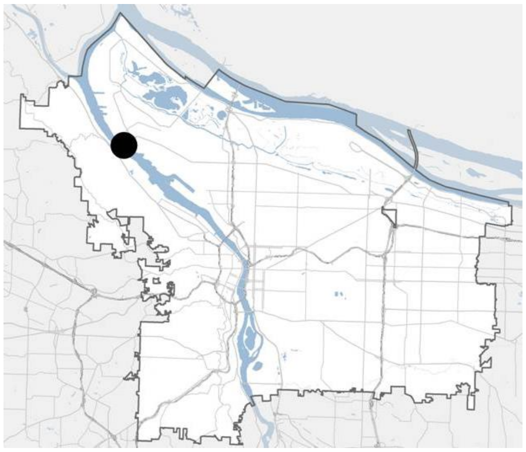
WPCL Test Planters

Summary Information		
Evaluation Period:	**4 years** (Aug 2005 – Jun 2009)	**Facility built to test the impact of three design variables – soil type, geometry, and filter fabric. This is purely a test facility and receives no runoff other than rainfall and the test flows.**
Constructed:	**February 2005**	
Facility Type:	**Lined Planter**	
Drainage Area:	**2,000 ft^2 (each bay)**	
Facility Area:	**120 ft^2 (each bay)**	
Sizing Factor:	**6%**	



Monitoring Result Summary

Peak Flow Reduction

90-97%

(25-yr flow test)

Flow Volume Reduction

Flow Tests	**30%** **(ranges from 14-47%)**

Water Quality

N/A

Soil / Infiltration

- facility soils: proprietary blend of sandy loam, digested paper fiber, coconut coir (top-dressed with compost but not mixed in)

Vegetation

Plants were slow to establish – perhaps due to limited early summer irrigation and/or nutrient deficiency in the soil – but are doing well now. Growing conditions differ from a real planter which receives larger quantities of runoff.

Maintenance

- Plants have been slow to establish, which may indicate more nutrients are necessary. For potential use in a nutrient restricted watershed, the soils had minimal nutrients to reduce export, and a top dressing of mulch was used to provide for plant health. This may be inadequate or the plants may require a longer period of time to establish.
- Some hand watering is necessary during the hottest part of the summer. This would not be as necessary if roof runoff were flowing into the planters.

Overview

To better understand how well lined planters perform, a system of four stormwater planters was constructed at the Water Pollution Control Lab (WPCL). Each of the four planter "bays" are sized to handle runoff from 2,000 square feet of impervious area, based on the SIM sizing standard (6%) in the Stormwater Management Manual.

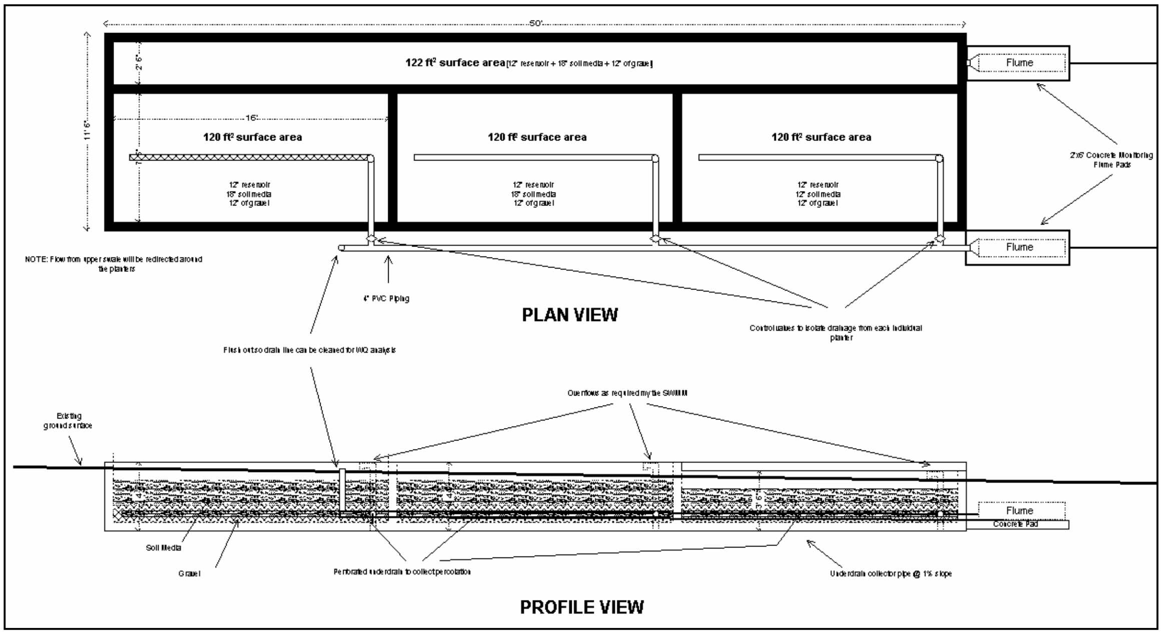


***Figure WP-1*: Plan and profile views of the WPCL Test Planters**

As shown in ***Figure WP-1***, three of the bays are 16 feet long and 7½ feet wide, while the fourth bay is 49 feet long and 2½ feet wide. Each planter has 1 foot of drain rock surrounding a perforated drain pipe, 18 inches of soil, and 1 foot of reservoir space. The flow collected by the perforated pipes daylights into flumes that concentrate the low flow rates and allow them to be accurately measured by flow meters. If the incoming flow is greater than the rate it can filter through the soil, the reservoir begins to fill until it reaches the level of an overflow 8 inches above the soil surface.

The four bays are configured to compare three design variables, as summarized in ***Table WP-1***.

***Figure WP-2:* Flow testing Bay 1**

***Figure WP-3:* Outflow flume**

***Table WP-1*: Design variables currently under investigation at the WPCL Test Planters**

Comparison	Issue	Design Variation
Soil Type	Currently “topsoil” is the only guidance used for lined planter construction. This results in highly variable soil types being used – some of which provide poor plant support and are ineffective for stormwater management. A soil type that can balance volume retention, pollutant removal, and plant health is needed.	• Soil 1 (70% sandy loam + 30% digested paper fiber) • Soil 2 (55% sandy loam + 25% digested paper fiber + 20% coconut coir)
Geometry	A higher surface area to wetted perimeter ratio may lead to more short-circuiting of flow between the planter walls and the soil. This is especially true in dry weather when the soil shrinks away from the concrete walls and forms preferential flow paths directly to the drainage layer.	• Shorter / Wider ratio = 2.6 • Narrower / Longer ratio = 1.2
Filter Fabric	Clogging of filter fabric has been deemed problematic by some regions of the country, and is suspected to have caused facility failure	• filter fabric (80 gal/min/ft2) • 4” pea gravel lens (as recommended by Prince Georges County, Maryland [Prince Georges, 1998])

Bay 1 was chosen to be the reference condition. The other three bays were configured to have only one design difference with respect to the reference bay. ***Figure WP-4*** shows the relative layout of the 4 bays and the design variables used in each one.

<table>
<tr><td colspan="3">BAY 4
Soil 1; Filter Fabric; “limited space” geometry</td></tr>
<tr><td>BAY 1
Soil 1
Filter Fabric
<i>[Reference]</i></td><td>BAY 2
Soil 2
Filter Fabric
“Soil Comparison”</td><td>BAY 3
Soil 1
Pea Gravel
“No Fabric”</td></tr>
</table>

***Figure WP-4*: Design configurations of the lined planters at the WPCL**

Bay 1 was considered the reference condition, because it was the configuration thought to have the best potential to retain flow volume, a shape that reduces potential wall leakage effects, and uses filter fabric as currently specified in the Stormwater Management Manual.

The testing focused on the ability of stormwater planters to:

1) **reduce / delay peak flows**;
2) **reduce / delay runoff volumes**; and
3) **reduce concentrations of stormwater pollutants**.

Peak Flow Reduction

One peak flow test using the 25-year Design Storm was run in August 2005. Response of the four bays is summarized in ***Figure WP-5*** and ***Table WP-2***.

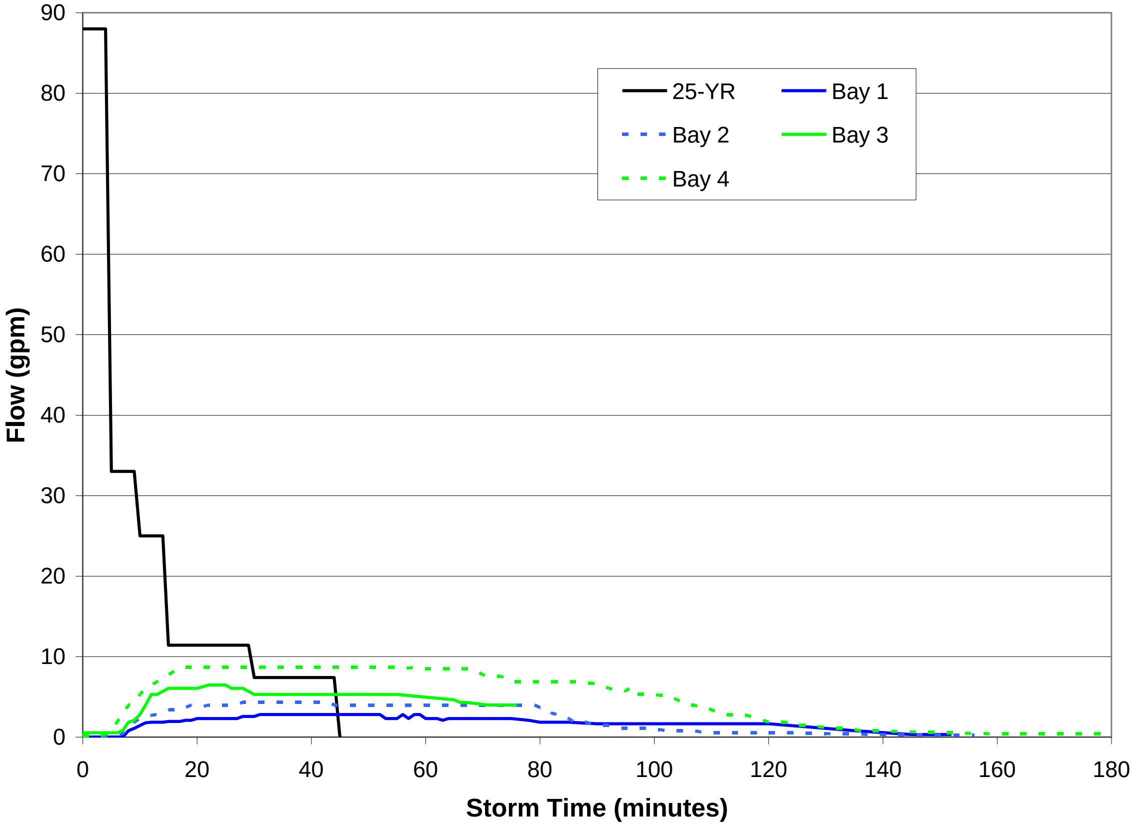


***Figure WP-5*: Peak flow reduction during August 30, 2005 test**

	Bay 1	Bay 2	Bay 3	Bay 4
Peak Flow	3.1	4.9	6.7	8.3
Reduction	96%	94%	92%	91%

Table WP-2: Peak flow reduction for all bays, 25-yr Design Storm

All bays show an excellent ability to lower peak flow, though there are differences in the peak flow rate from each bay. Bay 4 had the highest peak flow, followed by Bay 3, Bay 2, and Bay 1. Given the very similar reductions, the three configurations tested here do not vary significantly for peak flow control.

Flow Volume Retention

Bay 4 has an outflow pipe of its own, but Bays 1, 2, & 3 all share a single outflow pipe. This means that measuring long-term outflow can only be done on one of those three bays at a time. As a result, CSO design storm tests require one day per bay to ensure complete drainage out of the bay so it will not influence volumes for the next test.

Six test series have been conducted in the past two years using the ASFO and Summer 6 CSO Design Storms. Volume retention for each test is summarized in ***Table WP-3***.

***Table WP-3*: Volume retention for flow tests**

	Test	Bay 1	Bay 2	Bay 3	Bay 4
Apr 06 2006	Summer 6	**38%**			**24%**
Jul 16 2007	Summer 6	**34%**	**28%**	**28%**	**14%**
Aug 06 2007	ASFO	**30%**	**30%**	**28%**	**29%**
Jul 23 2008	Summer 6	**21%**	**27%**	**19%**	**13%**
Average		**31%**	**28%**	**25%**	**20%**

Bays 1, 2, and 3 typically have similar retentions. Bay 4 has typically shown the least retention.

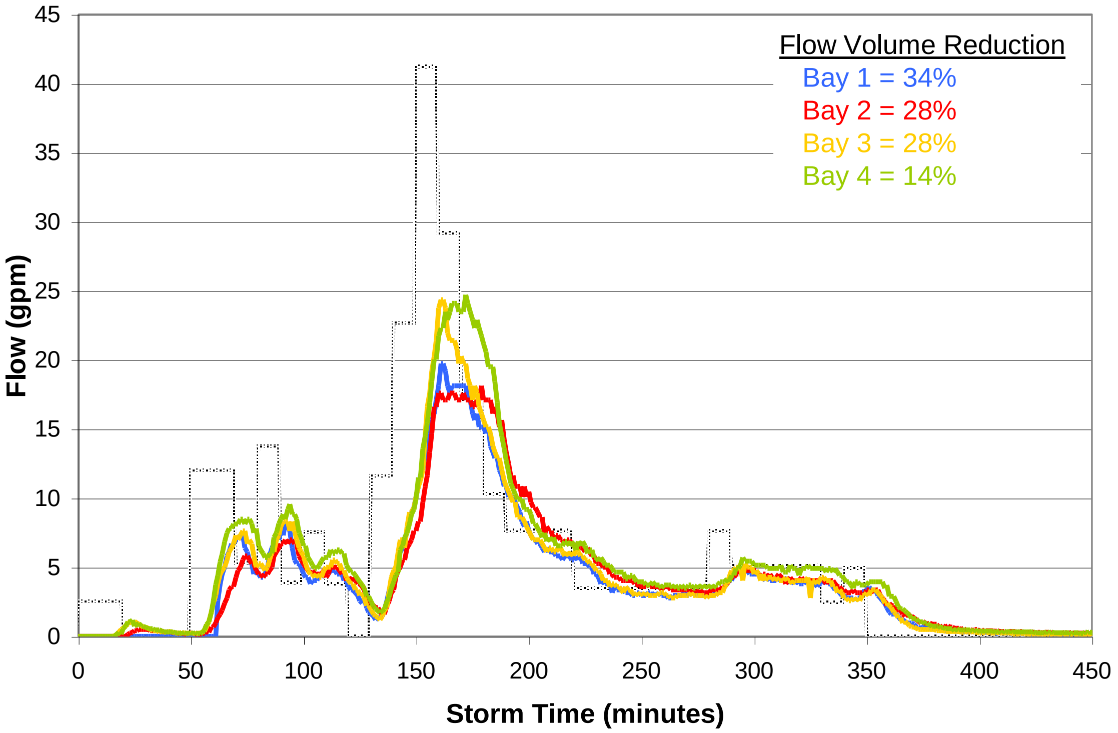


***Figure WP-2*: Outflows for ball bays during July 2007 test**
(faded grey line represents design storm inflow)

Based upon assumptions about the design variables, this would make sense:

- the pea gravel layer used in Bay 3 would provide less resistance to water entering the drainage pipe than the filter fabric. The openings in the filter fabric are far smaller and the route more tortuous. This results in less retention and higher peak outflow.

- Bay 4 has the same soil and filter fabric as Bay 1, but the extensive amount of wetted perimeter – 103 feet for Bay 4 compared to 47 feet in Bay 1 – would provide more opportunity for leakage between the wall and soil. This would be especially true for dry soil conditions when the loss of moisture causes the soil to "shrink" and pull away from the walls. This would decrease retention and increase peak outflow.

There does not appear to be a difference between the soil types. This might indicate that the soil / drain rock separator and wall length / surface area ratio are the most important factors. If so, this would suggest that:

1) shorter, wider facilities retain better than longer narrower ones; and
2) filter fabric separator facilitates volume retention more than a gravel separator

However, the last two test series which compared all the configurations show more parity between the configurations. In particular, the August 2007 tests showed little difference between the bays – with all retentions very close to 30%. At this point, it is unclear if this is a unique occurrence or if it represents a shift in performance over time.

Certainly, a retention in the range of 30% seems reasonable given the field capacity of a sandy loam soil (10-15%) added to the retention capacity of the surface compost and soil amendments.

Design / Maintenance / Vegetation

The planters receive some irrigation from the well system that waters the adjacent ecolawn, but it is of short duration and happens only 3 times per weeks. Supplemental hand watering is carried out by the Parks Bureau as needed. Manual weeding is done several times a year by Parks and by BES staff during flow tests.

Compost was not mixed into either soil mix in the hopes that nutrient export from the planters could be limited. A compost tea was added to the surface after planting along with a layer of composted leaf mulch. Plants were slow to establish, perhaps the result of low nutrients, but are now doing well.

Potential leakage from the drainage system could also be a problem. Flow testing on the test swales above the planters was still occurring, and the construction of the planters would have blocked their drainage path. To facilitate swale drainage, a connection was made from the swale drains to the upper end of the drain pipe for Bays 1, 2, & 3.

Given the shallow slope of the drain pipe (0.5%), this creates the possibility of flow backing out the upper end of the planter instead of draining through the flume. It is important that the planter drainage system be as sealed as much as possible, and a make-shift stopper is placed into the upper cleanout during testing to block backflow. In retrospect, installation of an upper valve that could be closed except during a swale test would have been wise.

The goose-neck overflow suggested in the Stormwater Management Manual were modified because on two occasions, a siphon was created when the reservoir level rose above the overflow elevation causing the drainage system to pressurize and water to be sucked out at a rapid rate. A more open overflow design may allow for better aesthetics and better function.

Monitoring Summary

- Peak flow reduction was excellent for all configurations.

- Shorter, wider facilities may retain flow better than longer, narrower facilities. This could be due to the leakage that can occur along facility walls. Longer, narrower facilities have more wall length per surface area.

- Use of filter fabric as the separator between soil and drain rock may increase the ability to retain volume.

- To establish proper plant health, it is important that irrigation be provided during the hottest parts of the summer. In addition, top dressing with mulch may not provide sufficient nutrients for plant health. Engineered soils are relatively sterile.

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Soil Sampling

In an effort to ensure that surface stormwater management facilities are not receiving significant pollutant concentrations from adjoining drainage areas, BES began periodic soil sampling of some facilities in 2005. Facilities were selected to provide a sampling of facility types, age, and land uses, but were not randomly selected for true statistical robustness.

Samples are tested for oils, metals, polycyclic aromatic hydrocarbons (PAHs), and phthalates. Additional funding was available in 2011 and 2012, and this allowed pesticides and PCBs to be added for those cycles.

Samples were initially taken at three different depth horizons at several locations within each facility. Horizons were 6 inches thick representing the surface (0 to 6 inches), upper root zone (6 to 12 inches), and lower root zone / native soil interface (12 to 18 inches). Levels were found to be highest in the surface layer in almost all sample locations. As this 0 to 6 inch surface layer is the layer most likely to come into contact with humans and other organisms, sampling shifted in 2011 to focus on the surface layer and allow a larger number of facilities to be sampled and compared.

Beginning in 2010, background samples were also taken in locations close to the stormwater facilities, typically in planting strips or landscape areas. The chosen areas are not subject to runoff from parking lot and street surfaces, and would receive loading from aerial deposition and minimal runoff from adjacent areas like sidewalks. This allows for comparison of soils exposed to concentrated stormwater runoff versus those exposed to ambient conditions.

As a broad means of assessing the human health significance of levels found in the soils, regional screening levels (RSLs) provided by EPA Regions 3, 6, & 9 (and accepted by EPA Region 10) are used as guidelines [USEPA 2013]. The two RSLs used are: 1) soil levels for industrial use, and 2) soil levels for residential use. ***RSL values are not regulatory levels, but are intended to provide an initial screen to determine if further soil investigation is warranted.***

As most sampled facilities are green streets in the right-of-way, they do not fit in either the industrial or residential category. If levels exceed the industrial use RSL, actions should be taken to clean out the facility and follow-up sampling should be done the following year. If levels exceed the residential use RSL, results should be monitored for increasing trends.

Facility and background data were pooled into two populations for comparative purposes. It should be noted that only some facility samples have a corresponding background samples (roughly 25% of the samples are paired for metals and PAHs). This could introduce bias in the comparison if there are area-specific conditions, such as air deposition from a nearby source that would not be accounted for without the collection of a paired background sample.

Unlike metals, which are present in all facility and background samples, the majority of organic compounds results (PAHs, PCBs, pesticides, and phthalates) are “non-detects.” This means the compound was not found above a minimum reporting limit (MRL), and the compound may or may not be present at a concentration below the MRL. This makes comparison of sampling data difficult because the non-detects must be accounted for numerically. There is no perfect way to do this, but given the large percentage of non-detects, and a comparison of substitution and regression on order statistics (ROS) methods, the ½*MRL substitution was chosen. This means non-detects were statistically replaced with a numeric value equal to half the MRL for that sample. ***While this approach is reasonable, it does mean that any comparison of data sets with large percentages of non-detects carries the potential for a high level of uncertainty.***

Heavy Oil

Facility concentrations (median of 340 mg/kg) were higher than the background samples (median of 68 mg/kg), and this difference was significant (Mann-Whitney, p<0.01). However, it should be noted that results were variable, and the lab test was found to be potentially influenced by the organic compost portion of the soil mixture. The organic components would sometimes falsely read as a heavy oil result.

As for build-up over time, consecutive samples taken at SW 12th & Montgomery and other facilities, have not shown accumulation. A high concentration during the 2010 sample cycle was followed by a lower concentration in the 2011 cycle, that coincided with a substantial cleanout of the facility in-between. Concentration spikes may be the result of discrete events, such as a vehicle oil leak, adjacent to the facility. As time passes, volatilization and microbial breakdown occur resulting in lower concentrations. Routine maintenance which includes removal of built-up sediment also contributes to keeping concentrations low.

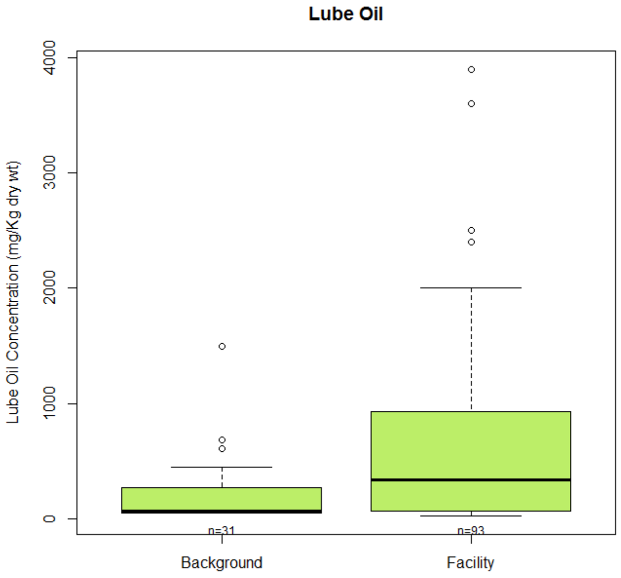


***Figure SS-1*: Comparison of heavy oils in facility and background surface soils (0 to 6 inches)**

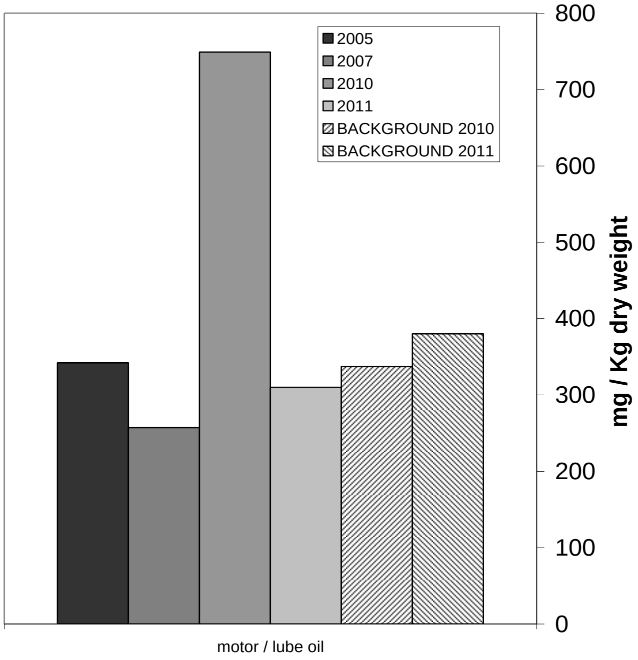
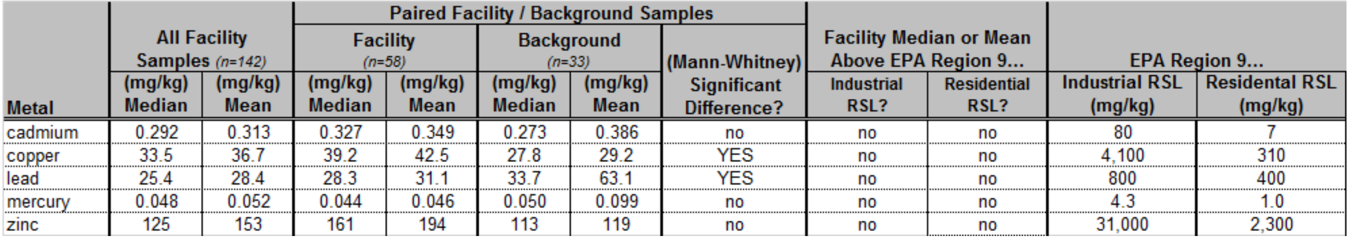


***Figure SS-2*: Comparison of heavy oils in surface soils (0 to 6 inches) over time at SW 12th & Montgomery, Bay 1**

Metals

A summary of facility levels are shown in ***Table SS-1*** and ***Figure SS-3***, and paired facility and background levels are shown in ***Figure SS-4***. All metal levels are well below both RSLs.

Table SS-1**: Metal levels in surface soils (0 to 6 inches)**



	All Facility Samples *(n=142)*		Paired Facility / Background Samples					Facility Median or Mean Above EPA Region 9...		EPA Region 9...	
			Facility *(n=58)*		Background *(n=33)*		(Mann-Whitney)				
Metal	(mg/kg) Median	(mg/kg) Mean	(mg/kg) Median	(mg/kg) Mean	(mg/kg) Median	(mg/kg) Mean	Significant Difference?	Industrial RSL?	Residential RSL?	Industrial RSL (mg/kg)	Residental RSL (mg/kg)
cadmium	0.292	0.313	0.327	0.349	0.273	0.386	no	no	no	80	7
copper	33.5	36.7	39.2	42.5	27.8	29.2	YES	no	no	4,100	310
lead	25.4	28.4	28.3	31.1	33.7	63.1	YES	no	no	800	400
mercury	0.048	0.052	0.044	0.046	0.050	0.099	no	no	no	4.3	1.0
zinc	125	153	161	194	113	119	no	no	no	31,000	2,300

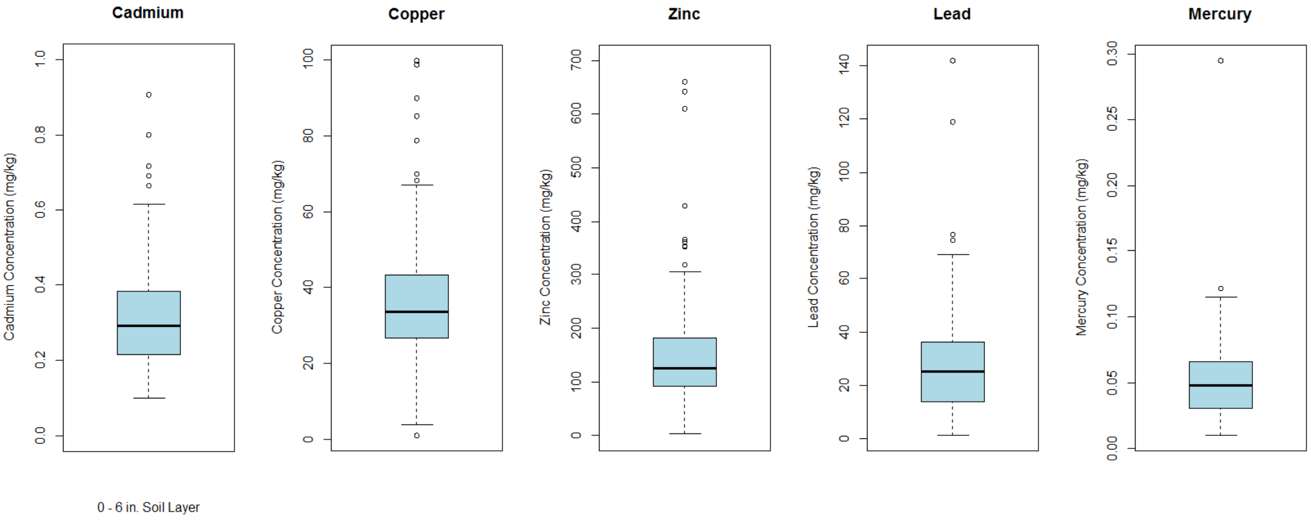


Figure SS-3**: Metal levels in surface soils (0 to 6 inches)**
(stormwater facility: n = 142)

Metal levels are generally consistent between facility and background samples, though copper levels are significantly higher in the facilities ($p<0.01$, Mann-Whitney), while lead levels are significantly higher in background samples ($p<0.05$, Mann-Whitney). The higher lead levels in the background samples is not surprising given years of exposure to ambient legacy sources like leaded gasoline and paint, while the facility soils would be relatively clean when installed.

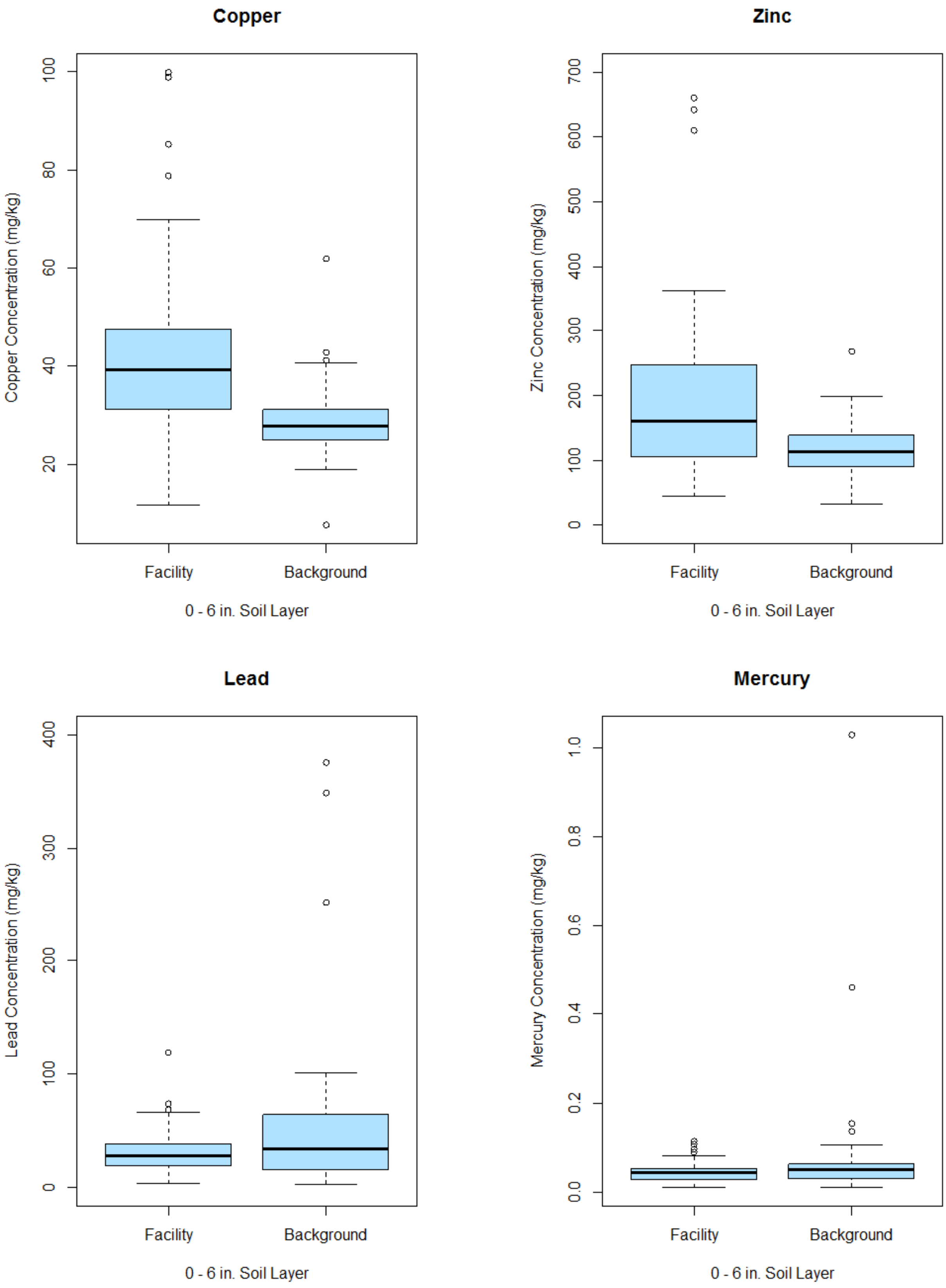


***Figure SS-4*: Comparison of metal levels in surface soils (0 to 6 inches)**
[Sites with paired facility / background data only; stormwater facility: n = 58; Background: n = 33]

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Samples were also grouped by the age of the facility when it was sampled, to determine if any obvious trends related to age were evident (***Figure SS-4***). All metals followed the same general pattern of a slow increase up to 6-7 years, and then a slight dropoff for the oldest facilities. This may simply be due to the relatively small number samples for facilities aged 8 years or more (16 versus 128 for facilities up to 7 years old), so the pattern will be watched for trend changes in the future. In addition, maintenance data for individual facilities is being tracked more closely moving forward, and it may be possible to look at details like the impacts of maintenance frequency, types of maintenance, design variables (e.g. mulch), and drainage area characteristics.

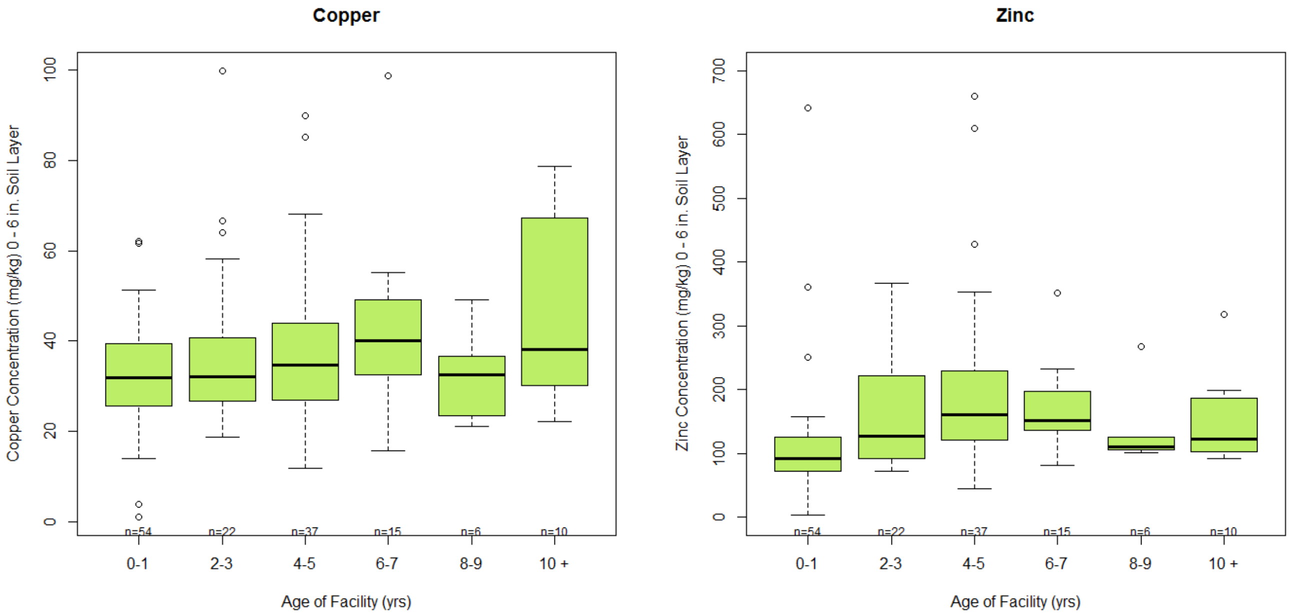


***Figure SS-5*: Comparison of metal levels in surface soils (0 to 6 inches) by age of facility**

Based on samples taken at the SW 12th & Montgomery green street facility over successive sampling cycles (***Figure SS-6***), it does appear that maintenance can play a significant role for some pollutants.

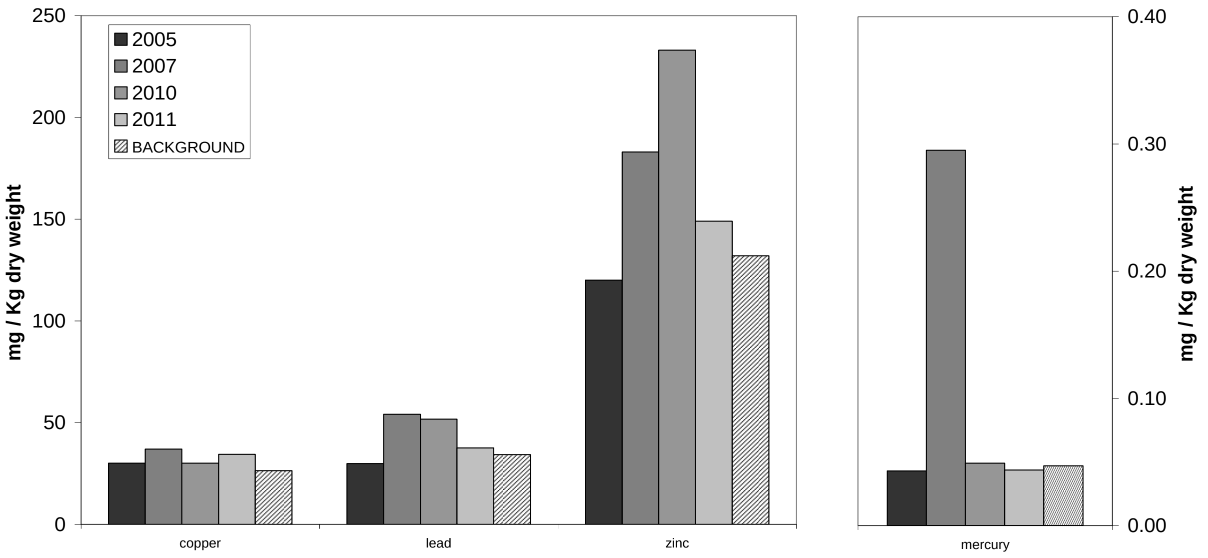


***Figure SS-6*: Changes in metal levels over time at SW 12th & Montgomery**

Metal levels at SW 12th & Montgomery appear to be generally stable. Copper and lead have remained fairly constant and are similar to background levels. Mercury has also been stable, though the 2007 sample shows a spike in concentration not seen since. Zinc levels did show a step increase over the first 5 years, but after the major facility clean-out between the 2010 and 2011 samples, the zinc levels dropped back towards background level. Failure to properly remove sediment allowed for continual accumulation of the zinc which was only lowered when the surface sediment material was removed.

PAHs

Initial sampling included multiple depth horizons. The pattern for PAHs was similar to metals, with the 0-6" horizon consistently having the highest levels. Benzo(g,h,i)perylene is shown as an example in ***Figure SS-7***.

The majority (65%) of the PAH results were below the MRL and recorded as non-detects. One or more PAHs were found at levels above their MRL in almost all facilities, but the levels did not significantly differ from levels found in background samples (***Table SS-2***).

No facility PAH levels exceed the RSLs for industrial use. The two PAHs with the lowest residential use RSLs (15 µg/kg) were exceeded in both the facility and background samples, and the background levels were slightly higher (***Figure SS-8***).

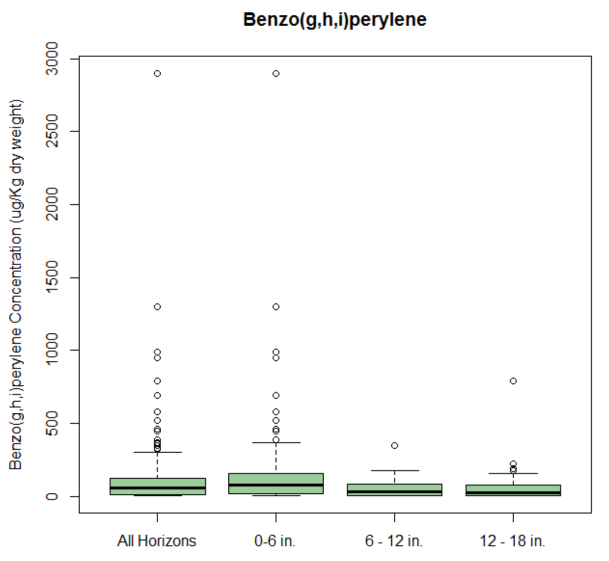


***Figure SS-7*: Comparison of Benzo(g,h,i)perylene levels by soil horizon**

Data broken down by facility age at the time of sampling show a pattern similar to that seen for metals – some slight increases in concentrations over the first 7 years, followed by a modest drop-off for facilities 8 or more years old. ***Figure SS-9*** highlights the data for benzo(a)pyrene which is representative of the other PAHs sampled. Again, it is possible this drop-off could just be the result of a smaller number of samples for older facilities, and there are other variables (maintenance, facility sizing, facility drainage area characteristics) that also impact levels over time.

Table SS-2: Relative Comparison of PAH levels in surface soils (0 to 6 inches) in stormwater facilities and background locations

	Facility Samples *(n=58)*			Background Samples *(n=33)*			Facility Median or Mean Above EPA Region 9...		EPA Region 9...	
PAH	% Detects	(µg/kg) Median	(µg/kg) Mean	% Detects	(µg/kg) Median	(µg/kg) Mean	Industrial RSL?	Residential RSL?	Industrial RSL (µg/kg)	Residential RSL (µg/kg)
acenaphthene	0%	20.0	28.0	9%	20.0	28.7	no	no	3,300,000	340,000
acenaphthylene	17%	20.0	46.7	24%	20.0	74.0	n/a	n/a	n/a	n/a
anthracene	10%	20.0	36.1	24%	20.0	85.6	no	no	17,000,000	1,700,000
benz(a)anthracene	53%	25.0	45.6	55%	20.0	150	no	no	2,100	150
benzo(a)pyrene	72%	46.5	81.8	67%	38.0	205	no	YES	210	15
benzo(b)fluoranthene	74%	73.0	102	76%	55.0	203	no	no	2,100	150
benzo(g,h,i)perylene	81%	94.0	143	79%	56.0	220	n/a	n/a	n/a	n/a
benzo(k)fluoranthene	34%	22.5	30.6	52%	20.0	70.5	no	no	21,000	1,500
chrysene	60%	31.0	65	64%	34.0	169	no	no	210,000	15,000
dibenz(a,h)anthracene	17%	10.0	21.3	27%	10.0	32.3	no	YES	210	15
fluoranthene	81%	70.5	103	76%	47.0	449	no	no	2,200,000	230,000
fluorene	0%	20.0	28.0	6%	20.0	28.8	no	no	2,200,000	230,000
indeno (1,2,3-cd) pyrene	71%	39.0	68.7	67%	36.0	141	no	no	2,100	150
naphthalene	3%	40.0	54.3	3%	40.0	36.5	no	no	18,000	3,600
phenanthrene	26%	20.0	45.6	42%	20.0	251	n/a	n/a	n/a	n/a
pyrene	81%	83.5	140	76%	51.0	494	no	no	1,700,000	170,000

(medians and means calculated using ½*MRL for replacement of non-detects;
light grey indicates median or mean is at or below the detection limit)

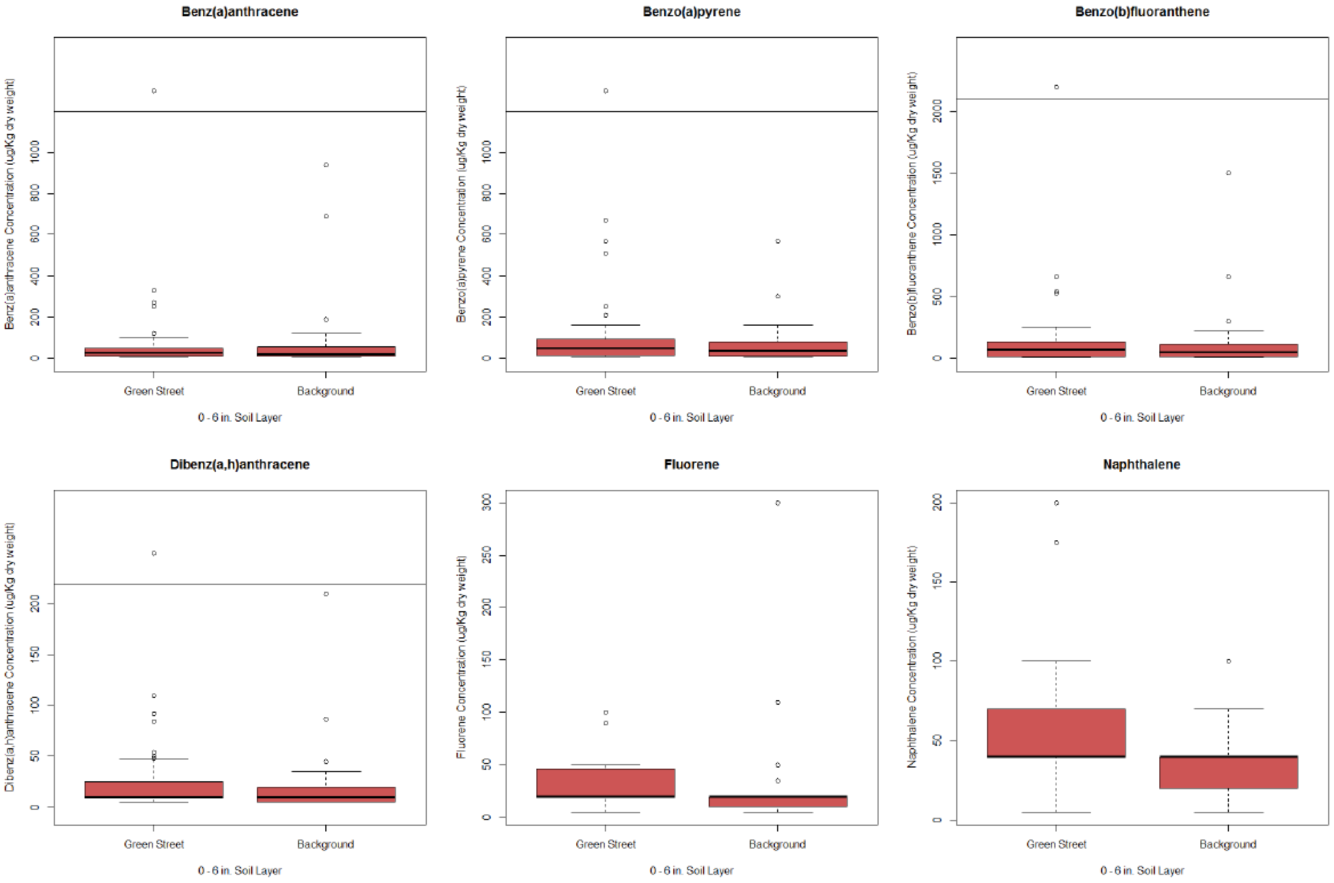


***Figure SS-8*: Comparison of select PAH levels in facility surface soils and background soils**

(box plots: the vertical line represents the range of values, the box is the middle two quartiles, and the black bar in the box is the median value; ° = statistical outliers. Paired facility / background data only; facility n=58, background n=33)

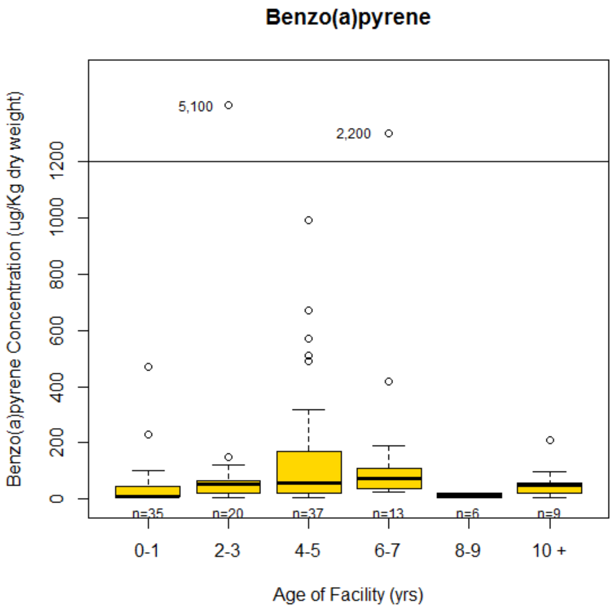


Figure SS-9**: Comparison of benzo(a)pyrene levels by facility age**

Looking at PAH concentrations over time at the SW 12th & Montgomery location (***Figure SS-10***), PAH levels at SW 12th & Montgomery are generally variable. A few – benzo(b)fluoranthene, benzo(g,h,i)perylene, and pyrene – climbed above background levels over time. Similar to the pattern seen with zinc levels, all PAH levels dropped back down below background levels after an extensive facility clean-out between the 2010 and 2011 samples. This suggests that proper maintenance is an important factor in keeping some PAH levels low over time.

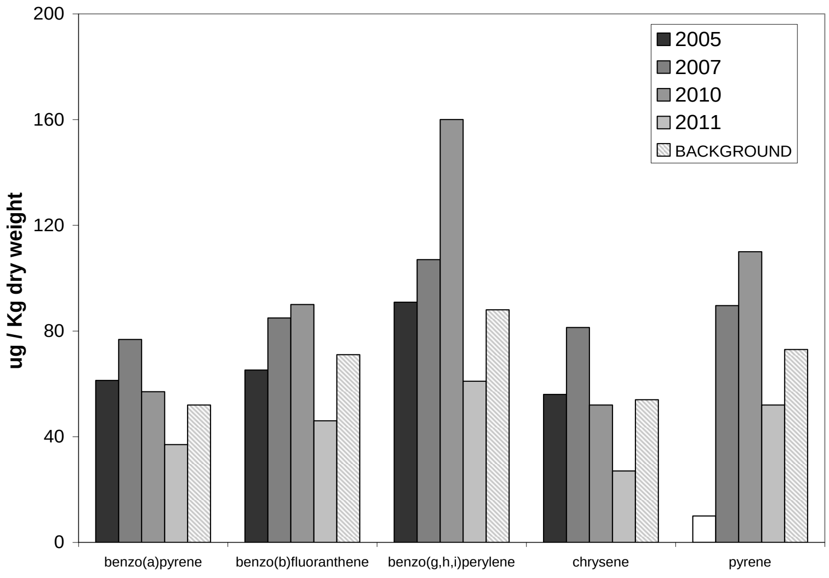


Figure SS-10**: Comparison of PAH levels over time at SW 12th & Montgomery**
(unfilled bars are non-detects)

Pesticides

Sixty-eight percent (68%) of the facility samples had results below the MRL, and were reported as non-detects. Variability can be high based on adjacent land uses like golf courses.

***Table SS-3*: Relative Comparison of Pesticide levels in surface soils (0 to 6 inches) in stormwater facilities and background locations**

	Facility Samples *(n=42)*			Background Samples *(n=26)*			Facility Median or Mean Above EPA Region 9…		EPA Region 9…	
PAH	% Detects	(µg/kg) Median	(µg/kg) Mean	% Detects	(µg/kg) Median	(µg/kg) Mean	Industrial RSL?	Residential RSL?	Industrial RSL (µg/kg)	Residental RSL (µg/kg)
4,4'-ddd (p,p'-tde)	57%	0.50	1.1	46%	0.52	1.2	no	no	7,200	2,000
4,4'-dde (p,p'-ddx)	81%	0.90	1.6	81%	1.7	2.7	no	no	5,100	1,400
4,4'-ddt	29%	0.50	3.0	54%	1.6	7.4	no	no	7,000	1,700
aldrin	14%	0.50	0.86	4%	0.50	1.06	no	no	100	29
bhc, alpha	5%	0.50	0.88	0%	0.50	1.0	no	no	270	77
bhc, beta	17%	0.50	0.91	12%	0.50	1.15	no	no	960	270
bhc, delta	5%	0.50	0.89	8%	0.50	1.04	N/A		n/a	n/a
bhc, gamma (lindane)	21%	0.50	0.85	15%	0.50	1.00	no	no	2,100	520
chlordane, alpha	64%	0.56	1.2	54%	0.75	10	no	no	6,500	1,600
chlordane, gamma	81%	0.84	1.4	54%	0.60	9.9	no	no	6,500	1,600
dieldrin	60%	0.62	1.2	54%	1.6	10	no	no	110	30
endosulfan I	33%	0.50	1.0	31%	0.50	1.3	no	no	370,000	37,000
endosulfan II	14%	0.50	1.4	23%	0.50	2.0	no	no	370,000	37,000
endosulfan sulfate	52%	0.58	1.6	31%	0.50	1.6	N/A		n/a	n/a
endrin	10%	0.50	0.87	8%	0.50	1.16	no	no	18,000	1,800
endrin aldehyde	19%	0.50	0.96	15%	0.50	1.09	N/A		n/a	n/a
endrin ketone	38%	0.44	0.85	23%	0.50	1.23	N/A		n/a	n/a
heptachlor	14%	0.50	1.18	4%	0.50	1.04	no	no	380	110
heptachlor epoxide	24%	0.43	0.83	23%	0.50	1.6	no	no	190	53
methoxychlor	7%	0.50	1.11	12%	0.50	1.3	no	no	310,000	31,000
toxaphene	2%	25	43	0%	25	50	no	no	1,600	440

(medians and means calculated using ½*MRL for replacement of non-detects;
light grey indicates median or mean is at or below the detection limit)

The standard MRL for pesticides is 1 µg/kg. However, because it was believed that pesticide levels would generally be low, labs were instructed to return results for anything above the minimum detection limit (MDL), which is 0.1 µg/kg. Any values below 1 µg/kg should be considered as relative estimates only.

Mean levels were higher in the background samples for all but heptachlor, which had only a small difference. No pesticides exceeded industrial or residential use RSLs, and these screening levels are higher than the typical MRLs of 1 µg/kg.

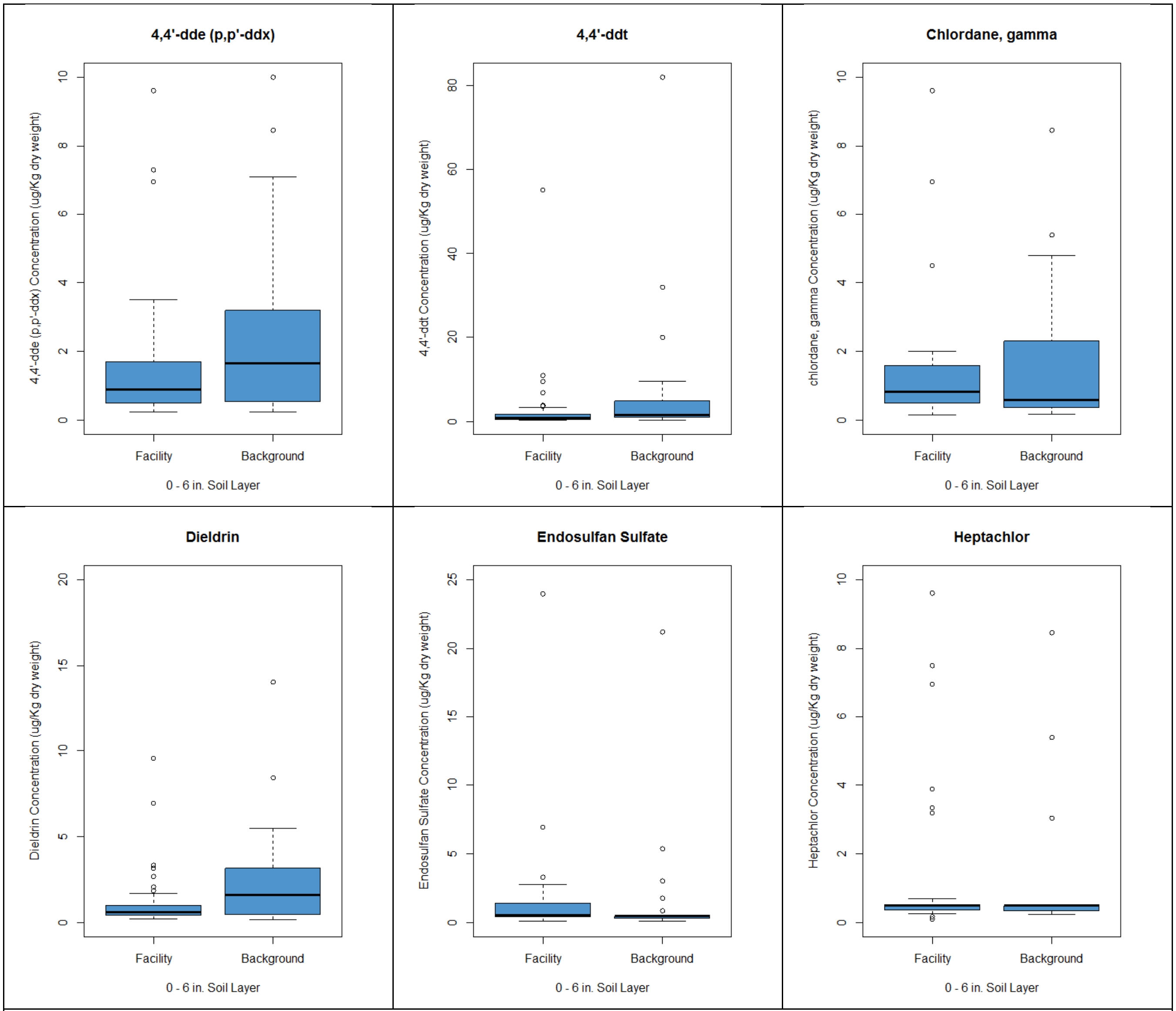


***Figure SS-11*: Comparison of selected Pesticides in facility and background soils**
(paired facility / background data only; facility n=42, background n=26)

PCBs

Ninety-six percent (96%) of the facility samples had results below the MRL, and were reported as non-detects. Only three PCBs were reported with concentrations above the MRL, and values were typically very close to the MRL. Typical MRLs were 5 or 10 µg/kg, and all results fell well below residential and industrial soil RSLs.

***Table SS-4*: Relative Comparison of PCB levels in surface soils (0 to 6 inches) in stormwater facilities and background locations**

	Facility Samples *(n=42)*			Background Samples *(n=26)*			Facility Median or Mean Above EPA Region 9...		EPA Region 9...	
PCB	% Detects	(µg/kg) Median	(µg/kg) Mean	% Detects	(µg/kg) Median	(µg/kg) Mean	Industrial RSL?	Residential RSL?	Industrial RSL (µg/kg)	Residental RSL (µg/kg)
Aroclor 1016/1242	0%	5.0	6.0	0%	5.0	6.5	no	no	740	220
Aroclor 1221	0%	10	12	0%	10	11	no	no	540	140
Aroclor 1232	0%	5.0	6.0	0%	5.0	5.7	no	no	540	140
Aroclor 1248	10%	5.0	9.6	0%	5.0	6.5	no	no	740	220
Aroclor 1254	12%	5.0	10.8	0%	5.0	8.5	no	no	740	110
Aroclor 1260	5%	5.0	8	31%	5.0	16	no	no	740	220
Aroclor 1262	0%	5.0	6.0	0%	5.0	5.7	n/a	n/a	n/a	n/a
Aroclor 1268	0%	5.0	6.0	0%	5.0	5.7	n/a	n/a	n/a	n/a

(medians and means calculated using ½*MRL for replacement of non-detects;
light grey indicates median or mean is at or below the detection limit)

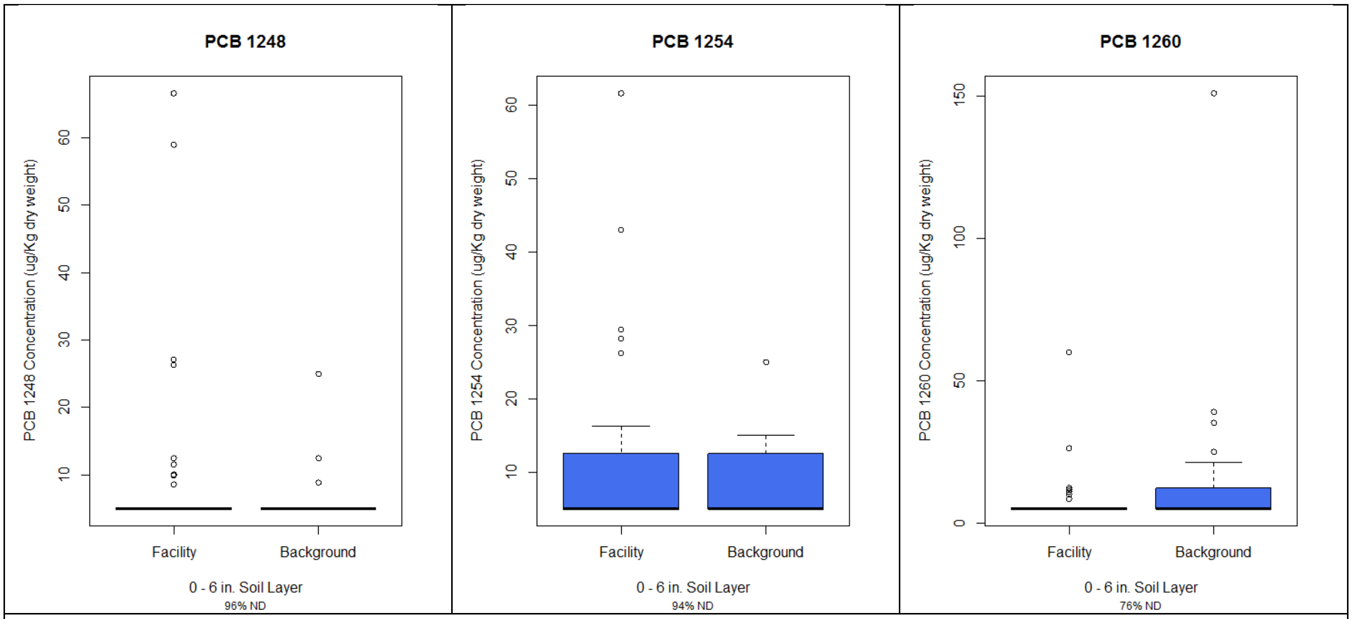
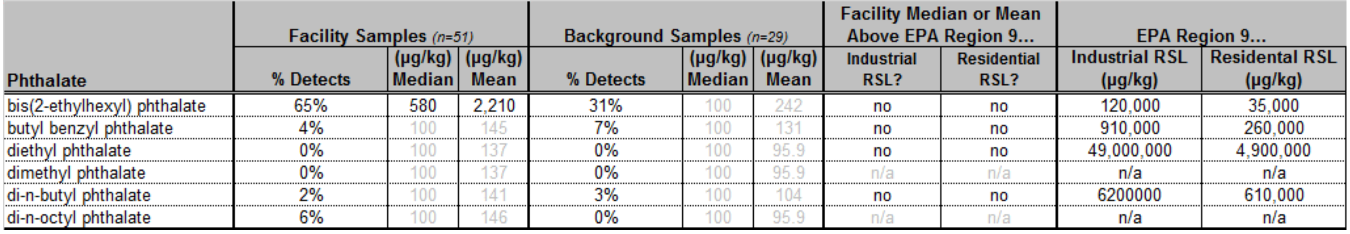


***Figure SS-12*: Comparison of selected PCBs in facility and background soils**
(paired facility / background data only; facility n=42, background n=26)

Phthalates

Eighty-seven percent (87%) of the facility samples had results below the MRL, and were reported as non-detects. Only bis(2-ethylhexyl) phthalate (BEHP) was detected with any frequency, and it is the only phthalate with median and mean levels above the MRL. Facility median and mean values for BEHP data collected to-date are higher than the background values.

***Table SS-5*: Relative Comparison of Phthalate levels in surface soils (0 to 6 inches) in stormwater facilities and background locations**



	Facility Samples *(n=51)*			Background Samples *(n=29)*			Facility Median or Mean Above EPA Region 9...		EPA Region 9...	
Phthalate	**% Detects**	**(µg/kg) Median**	**(µg/kg) Mean**	**% Detects**	**(µg/kg) Median**	**(µg/kg) Mean**	**Industrial RSL?**	**Residential RSL?**	**Industrial RSL (µg/kg)**	**Residental RSL (µg/kg)**
bis(2-ethylhexyl) phthalate	65%	580	2,210	31%	100	242	no	no	120,000	35,000
butyl benzyl phthalate	4%	100	145	7%	100	131	no	no	910,000	260,000
diethyl phthalate	0%	100	137	0%	100	95.9	no	no	49,000,000	4,900,000
dimethyl phthalate	0%	100	137	0%	100	95.9	n/a	n/a	n/a	n/a
di-n-butyl phthalate	2%	100	141	3%	100	104	no	no	6200000	610,000
di-n-octyl phthalate	6%	100	146	0%	100	95.9	n/a	n/a	n/a	n/a

(medians and means calculated using ½*MRL for replacement of non-detects;
light grey indicates median or mean is at or below the detection limit)

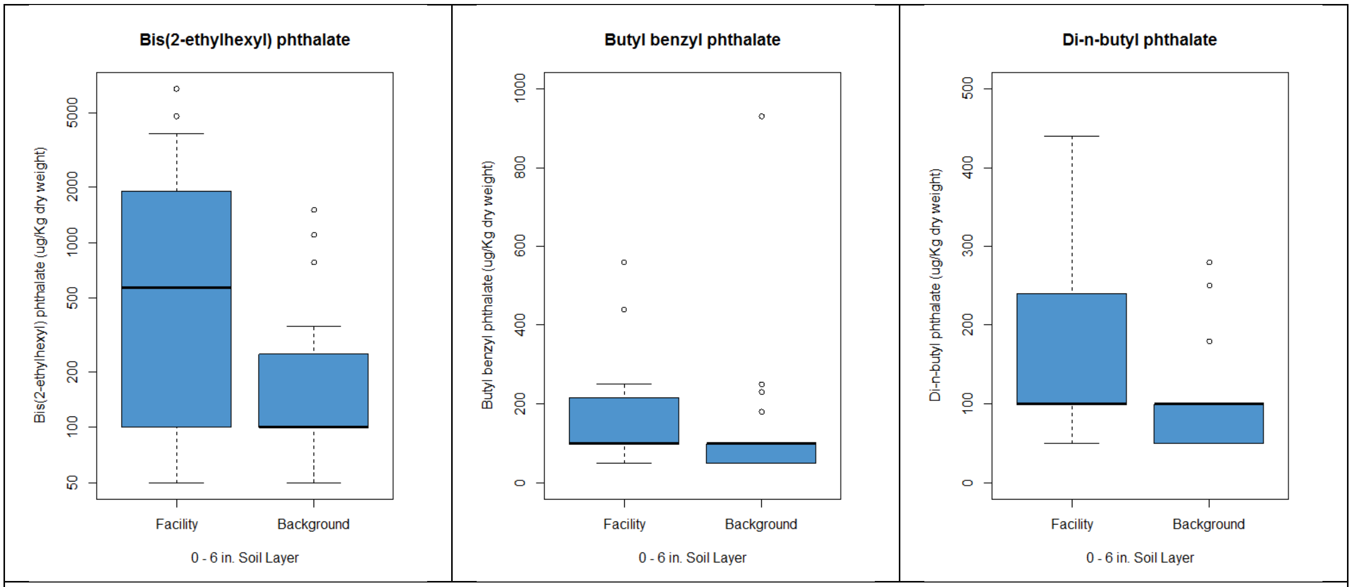


***Figure SS-13*: Comparison of selected phthalates in facility and background soils**
(paired facility / background data only; facility n=51, background n=29)

No phthalates exceeded industrial or residential use RSLs.

Monitoring Summary

- With the exception of two PAHs, soil concentrations were below the conservative EPA Residential Regional Screening Levels (RSLs); for those two PAHs, the background concentrations were also over the RSL and were similar to the facility levels.

- Metal, PAH, PCB, and Pesticide levels in stormwater facilities are generally similar to those found in background samples from sites located outside of the stormwater facilities.

- Because the vast majority of PCBs, pesticides, and phthalates were non-detects and below screening levels, they are not good candidates for frequent sampling.

- Additional sampling is recommended to verify the observed trends. Constituents that could be evaluated over time include: copper, endosulfan sulfate (pesticide), and bis(2-ethylhexyl) phthalate.

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References

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Appendix

Pollution Reduction Facility Monitoring Criteria

FY 2005-06

Environmental Investigations Division
City of Portland, Bureau of Environmental Services

These criteria are ONLY applicable if pollution reduction effectiveness is being determined for bioswales, ponds, manufactured treatment technologies, and filters.

I. General

A. Goals and Objectives

- Estimate the efficiency of a PRF in reducing pollutant loading from stormwater runoff.
- Determine if the mean TSS concentration in the PRF effluent is less than or equal to 20 ppm at a 95 percent confidence level.
- Compare effluent concentration of pollutants of concern to instream water quality criteria.

B. Total Project Cost

Approximately $100,000 for 15 storm events sampled over 3 to 5 years (based on FY 2004-05 costs)

II. Sampling and Analysis

	Stormwater		**Sediment**
Number of Events:	Minimum of 15		Minimum of 3
Frequency:	3-5 per fiscal year		1 per fiscal year
Sample Sites:	Inlet and Outlet		Treatment facility
Sample Type:	Grab	Flow-weighted Composite	Composite
Analytes: *(additional analytes can be added to meet site specific objectives)*	•pH •Temperature •Conductivity •Total/Nonpolar Oil and Grease •*E. coli*	•TSS/TDS/TS • Total Metals (Cu, Cr, Pb, Zn) •Dissolved Metals (Cu, Pb, Zn) •Hardness •Total Phosphorus •Orthophosphate phosphorus •Ammonia-nitrogen •Nitrate-nitrogen	•Total Solids •Grain Size •HCID/TPH •Total Metals (Cd, Cr, Cu, Pb, Hg, Zn)
Quality Control:	Annual field blank and duplicate		N/A

III. Data Evaluation and Reporting

A. IMS Deliverables

- Annual Monitoring Summary
- Preliminary Data Evaluation and Summary after 10 events
- Final Data Evaluation and Summary after 15 events

B. Customer Responsibility

- Overall BMP evaluation including construction, and maintenance costs, design specs, pollutant removal performance, and maintenance issues.
- Action plan for making management decisions based on BMP evaluation data and information.

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WS 1393