# Bioretention Research and Demonstration Project

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## Abstract

Stormmwater runoff from impervious urban surfaces causes localized flooding and combined sewer overflows. Bioretention (rain gardens, bioswales, etc.) is a form of green infrastructure for stormwater treatment that reduces runoff volume, peak flows, and pollutant loads. Most of the research in bioretention has been within the last decade, and there have been few studies of more than a couple of years in length. Several bioretention models exist to assist in estimating hydrologic performance for individual site design, however, there has been a lack of follow-up field monitoring to compare with the model estimations. In this field scale study, four newly constructed bioretention cells will be intensely monitored and compared side by side for the long term. The 4,000 $ft^2$ site will be instrumented for continuous flow rate, evapotranspiration, soil water storage, matric potential, and hydraulic conductivity for a real time water budget and hydrologic analysis. Additionally, the facility's data will be streamed live onto our website for public access.

As of May 2014, this collaborative project is being funded by the Oregon Water Resources Department, Benton County, the City of Corvallis, and Oregon State University. The project is currently in the planning and design phase. The 100,000 $ft^2$ acre drainage basin was delineated using lidar data and confirmed with field evaluation. Hec-HMS was used to model the project site's runoff volume and peak flow rate. A soil analysis that included a literature review and professional interviews was conducted to investigate soil media mixes for use in the facility. Current research efforts are focused on reviewing existing bioretention hydrologic and water quality models. Site excavation and construction is expected to begin in June 2014.

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## Introduction

Fully urbanized landscapes can increase stormwater runoff by as much as ninety percent compared to pre-development conditions, (FEMA, 2005). Conventional urban stormwater practices increase hydraulic efficiency of stormwater conveyance networks which increases the potential for flooding downstream by, for example, causing a 10-year storm to produce the runoff equivalent of a 25-year storm (FEMA, 2005), (Meierdiercks, 2010), (Fletcher et al., 2013). Runoff from urban impervious surfaces are frequently contaminated with a slew of pollutants, including heavy metals, nutrients, pesticides, bacteria, hydrocarbons, and vehicle combustion byproducts, that are harmful to downstream water users and to aquatic ecosystems (Passeport et al., 2009). At its worst, this has been described as the "pave it, pipe it, pollute it paradigm" of stormwater management, (Dolman, 2012).

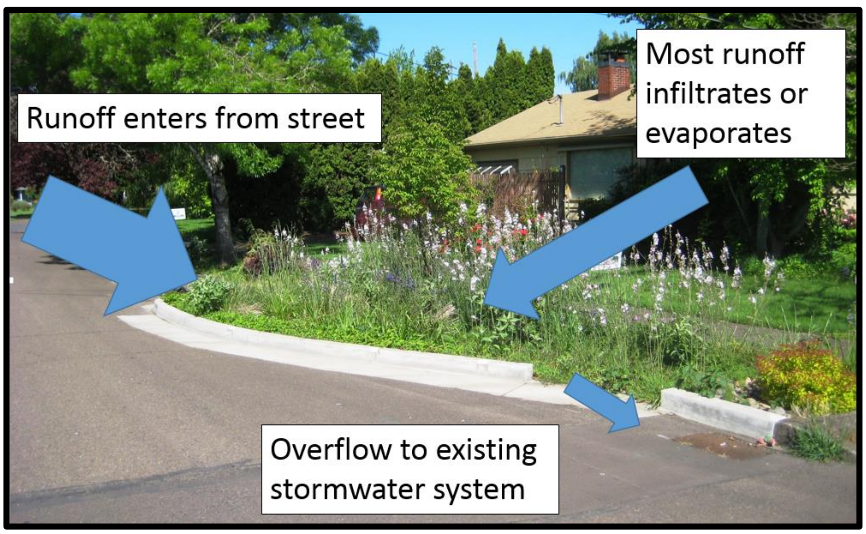


*Figure 1: Bioretention rain garden in Corvallis, Oregon*

Low impact development, (LID), is the hydrologic component of green infrastructure that was born in the early 1990s in Prince George's County, Maryland. LID is defined as "a land planning and engineering design approach that implements small-scale hydrologic controls with integrated pollutant treatment to compensate for land development impacts on hydrology and water quality," (Liu et al., 2014). Bioretention is a promising LID structural tool and best management practice (BMP) for mitigating the negative impacts of urban runoff quantity and quality. Bioretention is a stormwater treatment practiced defined as "a landscaped depression that receives runoff from upgradient impervious surfaces, and consists of several layers of filter media, vegetation, an overflow weir, and an optional underdrain," (Liu et al., 2014). At its best, this stormwater management strategy has been described as the "solution-based system of slow it, spread it, sink it," (Dolman, 2012).

However, this does not mean that LID and bioretention can replace conventional stormwater management. Rather, a synergistic approach that utilizes the most beneficial aspects of each practice can achieve the most economically and ecologically efficient outcome. For example, in Portland, Oregon, the Big Pipe Project completed in November of 2011 has reduced combined sewer overflows (CSOs) by more than 99% and 94% in the Columbia River Slough and the Willamette River, respectively (Portland Tribune, 2014), (NRDC, 2013). Portland was initially going to use a 28 ft diameter pipe for $865 million to solve their CSO issue, but the city was able to reduce the pipe size to 23 ft at a price tag of $625 million by utilizing LID practices in its Grey to Green Initiative. Portland's Bureau of Environmental Services estimates that the use of green infrastructure will save $65 to $145 million over time.

Several field studies have showed that bioretention facilities are able to minimize impervious surface hydrology impacts by significantly reducing runoff volumes, peak flows, and the time to peak. In a 2 year study that monitored two lined bioretention facilities over the course 49 runoff events from a parking lot, runoff volume was reduced to zero for 18% of the events, peak flows were reduced by 44-63%, and the time to peak was delayed by a factor of 2 or more (Davis, 2008). In another study with a retrofit bioretention cell in a parking lot, 28 precipitation events were monitored over the course of 10 months; runoff volumes and peak flow rates were reduced by 97% and 99%, respectively (DeBusk and Wynn, 2011). In a third study that monitored 16 events ranging in size from 2 to 40 mm (0.08-1.6 in.) over the course of 2 years, the mean peak flow reduction was 99%, with the time to peak delayed by ~3 hours, (Hunt et al., 2008). A study that compared bioretention outflow to an undeveloped meadow's groundwater outflow to a stream found that there was no statistical difference between the storm event interflow from the urban bioretention facility and the undeveloped watershed (DeBusk et al., 2011). This indicates that bioretention facilities can help to restore predevelopment groundwater recharge to provide for stream base flow. Additionally, bioretention has successful removed a wide range of pollutants from urban runoff. In a literature review by Leu, the studies showed removal of 58-100% of TSS, 13-99% of

TN, 12-99% of TP, 71-100% of coliform, 60-99% of Zn, 65-98% of Cu, and 32 to 100% of Pb, (Liu et al., 2014).

At least three public domain bioretention tools have been developed specifically to assist in the design of individual bioretention facilities to estimate hydrologic performance. They are the University of Wisconsin's RECARGA (Atchison and Severson, 2004), Oregon State University's Rain Garden Sizing Spreadsheet (OSU Extension, 2014), and the Low Impact Development Center's Urban Design Tool's Bioretention Calculator (LID Center, 2007). Several hydrologic models, including Hec-HMS, SWMM, DRAINMOD, and SUSTAIN have also been used to model bioretention. However, there is a lack of field research that evaluates how well these tools and models predicted bioretention hydrologic and water quality performance. Additionally, several short term (2 years or less) field scale bioretention studies have been completed, but there is a lack of long term bioretention monitoring. To the best of this author's knowledge, the longest time that a bioretention system has been scientifically studied is only 9 years (Komlos and Traver, 2012). The objectives of this research and demonstration project are:

1. Design, construct, and instrument four bioretention cells for long term scientific research and demonstration
2. Evaluate existing tools and models for their ability to accurately estimate bioretention hydrologic performance using collected data
3. Educate the public through signage, a website, and conferences about the use of bioretention as a BMP for stormwater management

## Methodology

### Site Description

The Benton County Public Works Office is a six acre property yard located adjacent to Avery Park in Corvallis, Oregon. There is significant pedestrian traffic near the site due to the proximity to the park and developers applying for construction permits at the county office. Everything needed to build roads is stored on the yard including tractors, above ground gasoline and diesel tanks, raw asphalt mixture, road base/fill, and road paint. Additionally, the site contains several parking lots. When it rains on this site, numerous petroleum based and heavy metal pollutants are mobilized in runoff that flows without treatment directly into Mill Race Creek, the last tributary to the Mary's River before it runs into the Willamette River. Localized flooding at the Mill Race Creek outfall on Crystal Lake Ave. has isolated southern Corvallis from the downtown area, as well as closed the major highway through town, Hwy 99. See Figure 2.

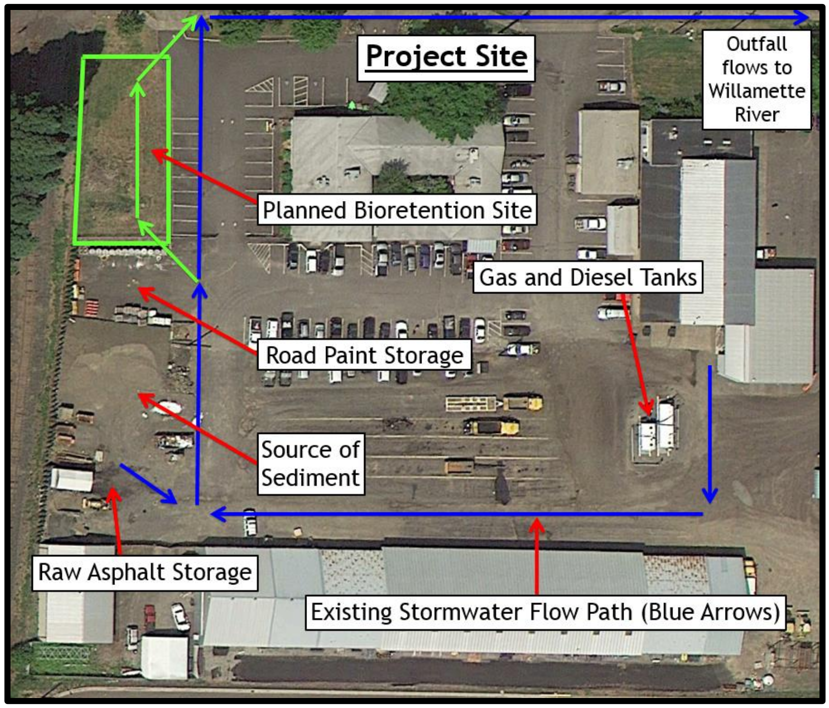


*Figure 2: Project Site.*

Catchment Basin Delineation

Using lidar data and ArcGIS 10.1, the bioretention facility's catchment basin was delineated. An initial attempt at using the ArcMap's built in watershed delineation tools, as well as the ArcHydro add on tools, failed to accurately delineate the basin. This is because these tools did not model the main storm line's subsurface 12" concrete pipe. To solve this issue, LiDar data was used to compute 0.25 ft contour lines, and a classic watershed delineation approach was used to trace the 'ridgelines' of the site using a polygon. The site was visited during a storm event to confirm the accuracy of the watershed delineation. Using ArcMap's polygon featire, the catchment basin area was calculated as approximately 100,000 ft$^2$.

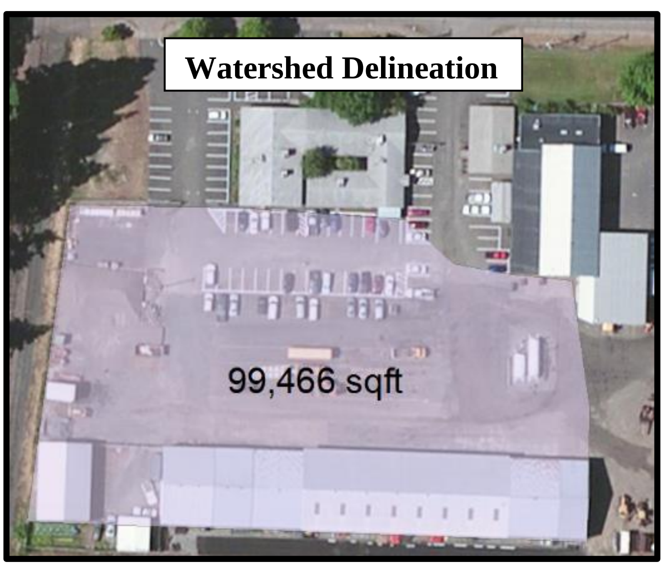


*Figure 3: Catchment basin delineation in ArcMap 10.1.*

Runoff Analysis

The SCS Curve Number Method (NRCS 1986), the Rational Method (Davis 2005), and Hec-HMS 4.0 (US Army Corps 2013) were used to estimate runoff volumes and peak flows for the 2 year, 24 hour NRCS Type 1A design storm of 2.5 in. A composite curve number of 94 was computed based on the different surfaces (rooftop, pavement, gravel, and dirt) at the site. The runoff coefficient used was 0.75, which corresponds to heavy industrial surface (Davis and McCuen, 2005). The runoff results are summarized in Table 1. Based on these results, the conservative values of 17,000 $ft^3$ of runoff and 1.14 cfs peak flow were used to assist in bioretention facility design.

| Method | Runoff Volume ($ft^3$) | Peak Flowrate (cfs) |
|---|---|---|
| SCS CN Method | 15600 | n/a |
| Rational Method | n/a | 0.76 |
| Hec-HMS | 17000 | 1.14 |

*Table 1: 2 year, 24 hour design storm runoff volume and peak flow rate.*

Soil Analysis:

The desirable characteristics in a bioretention soil media are

- Capacity for soil water storage to buffer peak flows
- Balanced amount of nutrients to minimize export of nutrients while also allowing for plant growth
- High cation exchange capacity (like most clays) to remove heavy metals
- High organic matter content (saw dust, compost, leaf mulch, etc.) to facilitate microorganism growth to break down petroleum hydrocarbons

Most of the bioretention research studies have used a soil media containing 80% or more sand mixed with organic matter, native soil, loam, and other soil mixes with decent hydrologic and water quality results (Brown and Hunt, 2008), (Brown and Hunt, 2011), (DeBusk and Wynn, 2011), (Hathaway et al., 2011), (Li and Davis, 2008). Personal interview with a green infrastructure consultant, horticulturalist, and two soil scientists at Oregon State University were conducted for professional soil media advice. They recommended the use of a soil media that is high in clay and organic matter conent due to the high cation exchange capacity for heavy metal removal, and high microorganism content for hydrocarbon treatment. Additionally, they recommended the use native soils because they will be a better for native plant growth. A study that compared vegetated and non-vegetated bioretention mesocosms found that vegetation helped to maintain soil hydraulic conductivity with time through preferential flow paths (Le

Coustumer et al., 2012), indicating that a soil with a higher clay content and organic matter content has the potential to both increase pollutant treatment and maintain beneficial hydrologic function without clogging the facility.

The United States Department of Agriculture's Web Soil Survey was used to investigate the native soils at the site, see Table 2.

| Soil Type: Malabon silty clay loam | | | |
|---|---|---|---|
| **Soil Property** | **Site Rating** | **Units** | **Comments** |
| Cation Exchange Capacity | 30.2 | mEq./100g | Typical for silty clays |
| Organic Matter Content | 3.31 | % | Moderate value, higher is better |
| $K_{sat}$ (0 to 15 inches) | 1.2 | in/hr | Saturated hydraulic conductivity |
| $K_{sat}$ (15 to 40 inches) | 0.41 | in/hr | Saturated hydraulic conductivity |
| Depth to water table | 6.5 | ft | Infiltration is an option |

*Table 2: USDA Web Soil Survey Results*

The native soil at the site has favorable characteristics for bioretention. It will be used at our site in a 2:1:1 mix of native soil**:**compost**:**biologically rich organic soil. Additional soil media types that are higher in sand will be tested at the facility to compare their hydrologic and pollutant removal performance.

## Results and Discussion

<u>Facility Design and Sizing</u>

The University of Wisconsin's RECARGA, Oregon State University Rain Garden Calculator, the Low Impact Development Center Filtration Urban Design Tools Filtration Calculator, and Bioretention Sizing Program (Figure) were used to assist in the sizing of the facility. These tools estimate the amount of runoff from the catchment basin, the volume of water stored, and the amount of infiltration. According to the models,

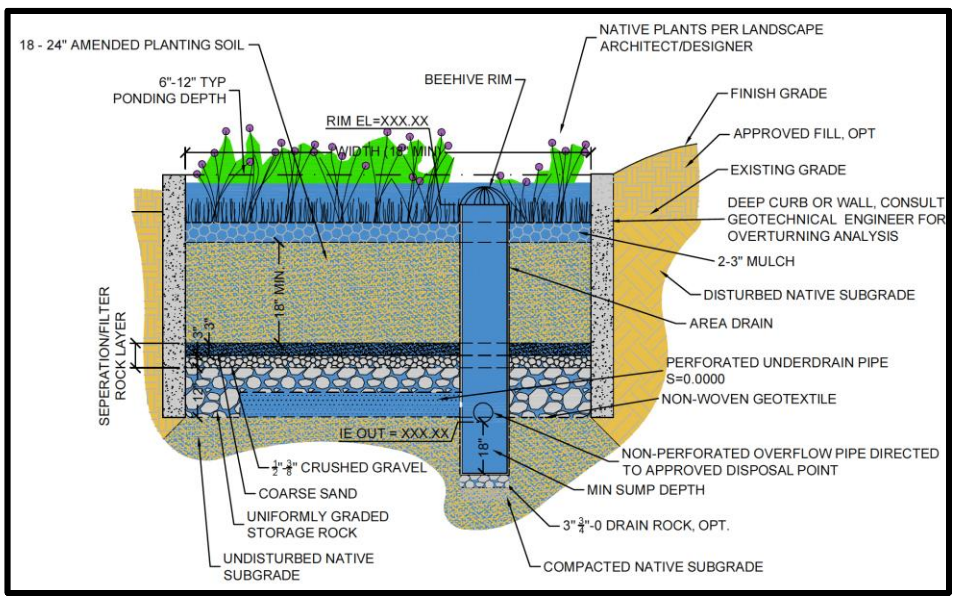


*Figure 4: Conceptual Bioretention Facility (OSU Extension 2014)*

approximately 7 acre feet of runoff will be treated in the facility on an annual basis. Unfortunately, these models lack the ability to estimate peak flow mitigation and runoff volume attenuation. A conceptual design of the facility is provided in Figure 4.

## Conclusions and Next Steps

A bioretention research and demonstration facility will be constructed for long term monitoring of hydrologic and pollutant removal performance. A pre-bioretention hydrological and soil analysis at the Benton County Public Works Project Site for has been completed. Results show that approximately 7 acre feet of runoff will be treated in the facility on an annual basis. As of 5/15/14, design details are nearly finalized, and will be presented at the ASFPM Conference June 5th, 2014.

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