Greening the Streets: A Comparison of Sustainable Stormwater Management in Portland, Oregon and Los Angeles, California

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GREENING THE STREETS:
A COMPARISON OF SUSTAINABLE STORMWATER MANAGEMENT IN PORTLAND, OREGON AND LOS ANGELES, CALIFORNIA

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In partial fulfillment of a Bachelor of Arts Degree in Environmental Analysis, 2012-13 academic year, Pomona College, Claremont, California

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ABSTRACT

Stormwater runoff is one of the main sources of pollution for urban waterways. Stormwater has traditionally been managed through concrete-based storm drainage systems, but the past twenty years have introduced an alternative in the form of green infrastructure. Green infrastructure for stormwater management involves the use of low impact development (LID), often vegetated facilities to mimic natural hydrologic systems that capture and allow infiltration of rainwater where it falls and from impervious surfaces upstream, before entering the drainage system. Portland, Oregon and Los Angeles, California have adopted green infrastructure into their stormwater management plans. For this project, bioswales, a form of vegetated LID facility, were tested in each city to determine their pollutant retention capabilities. Results from Portland show that bioswales filter out heavy metals effectively, and results from Los Angeles show that bioswales accumulate heavy metals in the soil over the course of the year (also due to filtering out metals from the stormwater). These results raise the question of whether accumulation can reach dangerous levels or saturate the soil with pollutants so that removal efficiency is diminished, indicating a need for further monitoring. However, the success of bioswales up to this point is encouraging and indicates that this method should continue to be employed.
Chapter 1

INTRODUCTION

“Portland’s waterway
Lifeblood of our fine city
Greener and freer”
–Nancy Sabin

Water is an essential resource, but one that we are still learning to manage. We utilize water for almost everything we do; we need it to be clean yet all our uses of it contaminate it; it is difficult to transport, and we haven’t figured out how to value it economically. We have built an incredible amount of infrastructure surrounding water in an attempt to capture, clean, manage, and distribute it, particularly in urban areas.

The aim of this thesis is to investigate the stormwater management efforts, particularly the emergence of green infrastructure in Portland and Los Angeles. The focus is an analysis of their policies and the effectiveness of the facilities implemented for pollution reduction.

The Problem: Stormwater as a Source of Pollution

One of the water-related problems that presents a particular challenge to large urban areas is stormwater runoff. Large areas of impervious surfaces prevent rainwater from percolating into the ground. As this rainwater accumulates it collect pollutants that

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have deposited on roads or other impervious surfaces\(^2\), primarily by vehicle traffic and dry deposition.\(^3\) Dry atmospheric deposition is the “direct transfer of dust, aerosols, and gas from the atmosphere to the ground and plant surfaces” during dry weather periods, resulting in accumulation of these particles.\(^4\) During storms, water carries these particles off the impervious surfaces, leading to concentration of the pollutants in the stormwater.\(^5\) Pollutants in stormwater include various heavy metals (primarily copper, zinc, and lead),\(^6\) polycyclic aromatic hydrocarbons (PAH), mineral oil hydrocarbons (MOH), and readily soluble salts.\(^7\) Metals in tires (zinc) and brake pads (copper) cause the majority of vehicle-induced road pollution.\(^8\) Tire abrasion and brake pad abrasion are linked to zinc, lead, chromium, copper, and nickel deposition.\(^9\)

Stormwater runoff bearing these various pollutants frequently flows untreated into rivers and streams, polluting these major bodies of water.\(^10\) Such contamination is in the category of nonpoint source pollution, defined as “water from diffuse sources such as agricultural runoff, street or urban runoff, and malfunctioning septic systems.”\(^11\) All of the pollutants that run off in stormwater, including heavy metals, are harmful to the

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\(^3\) United States Environmental Protection Agency (1983), *Results of the nationwide urban runoff program: Volume 1 – Final report*.


\(^5\) Gobel et al., 2007

\(^6\) From Ball et al., as cited by I. Gnecco, C. Berretta, L.G. Lanza, & P. La Barbera (2005), Storm water pollution in the urban environment of Genoa, Italy, *Atmospheric Research*.

\(^7\) Gobel et al., 2007

\(^8\) D. Wicke, T.A. Cochrane, & A. D. O’Sullivan (2012), Atmospheric deposition and storm induced runoff of heavy metals from different impermeable urban surfaces, *Journal of Environmental Monitoring*.

\(^9\) From Muschack, 1989 as cited in Gobel et al., 2007


health of the rivers and streams,\textsuperscript{12} with copper, lead, and zinc specifically identified by the Environmental Protection Agency (EPA) as toxic heavy metals found in road runoff.\textsuperscript{13} For example, these pollutants can cause a reduction in macroinvertebrate diversity.\textsuperscript{14} Due to the wide distribution of this contamination, nonpoint source pollution poses a unique set of challenges for efforts to limit contamination of urban waterways.

\textbf{EPA Stormwater Regulations}

Due to the impacts of worsening water quality in urban areas, the federal government passed the Clean Water Act (CWA) in 1972 (amended in 1987). The CWA “prohibits the discharge of pollutants into waters of the United States unless the discharge is in compliance with a National Pollutant Discharge Elimination System (NPDES) permit.”\textsuperscript{15} The NPDES element of the Clean Water Act was included in the 1987 amendment to the act, shifting the regulatory focus from only point source pollution to include nonpoint source discharges as well. Based on these new requirements, large cities were required to attain permits for discharges from their municipal separate storm sewer systems (MS4), which regulate the amount of pollution that can be discharged. Such permits, issued by the states, must ultimately be implemented on a local level by the city.\textsuperscript{16}

\textsuperscript{12} From Pitt et al., 1994 as cited in Gobel et al., 2007
\textsuperscript{13} United States Environmental Protection Agency, 1983
\textsuperscript{14} R. A. Rolle (1988), The effects of heavy metals pollution of the upper Arkansas River on the distribution of aquatic macroinvertebrates, \textit{Hydrobiologia}.
\textsuperscript{15} Portland Environmental Services (2008), \textit{Stormwater management manual: Chapter 1–requirements and policies} (ARB-ENB-4.01), p.2.
\textsuperscript{16} United States Environmental Protection Agency (2010), \textit{Green infrastructure case studies: Municipal policies for managing stormwater with green infrastructure} (EPA-841-F-10-004).
Managing Stormwater: Gray vs. Green Infrastructure

Stormwater management has been handled in a variety of ways. In most U.S. cities, storm drains and gutters funnel stormwater into a system of underground pipes that empty usually untreated water into the rivers. In some cities there are combined sewer systems, in which sewer lines collect industrial waste, stormwater runoff, and domestic sewage into one pipe that leads to a treatment plant. However, in large storms that exceed the capacity of these systems, the pipes overflow and spill not only polluted stormwater but also raw sewage into the rivers and streams. These spills are called combined sewer overflows (CSOs) and are a fundamental source of water pollution of high concern. Over 770 cities in the U.S, including Portland, Oregon, have combined sewer systems.

Expansive systems of pipes comprise the traditional method of managing stormwater. Cities have traditionally tried to prevent CSOs by increasing the capacity of their storm drainage systems and separating combined sewers. This approach, generally known as ‘gray infrastructure,’ follows the conventional strategy of transporting waste elsewhere for treatment, upsetting the hydrologic balance by removing this water from it. Additionally, this practice is often extremely expensive. In recent years, ‘green infrastructure’ has emerged as a novel strategy for managing stormwater, utilizing the ability of natural systems to capture and filter stormwater and providing benefits even beyond stormwater management.

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17 “What is Green Infrastructure”
19 “What is Green Infrastructure”
22 “Green Infrastructure”
water quality protection defined by a range of natural and built systems that can occur at the regional, community, and site scales. At the site level, it is called Low Impact Development (LID). LID aims to “restore the natural hydrologic character of a development site” by allowing infiltration of the runoff on site, preventing it from entering the storm-drainage system prior to filtration and thus reducing pollution levels in streams and creeks.

As an approach, the advantage of LID construction is that it takes into account the ability of natural ecosystems to manage pollution, and keeps rainfall on location rather than transporting it elsewhere for treatment. This management tool has environmental, economic, and social benefits. Rather than removing water from the system, LID construction recharges groundwater resources (for infiltration facilities), and adds green space (valuable for social benefit and neighborhood livability) to the city. LID is also often less costly than conventional treatment. Case studies have shown that green infrastructure can reduce peak flows by 80-85%, and retain 60% of storm volume.

Green Streets and Bioswales

One particularly prominent form of green infrastructure is a “green street.” The definition of green streets varies between cities, but generally refers to streets with

23 United States Environmental Protection Agency, 2010
24 Ibid.
26 Los Angeles, 2011, p.2
28 “Green Infrastructure”
29 Portland City Council (2007), Exhibit A: Green streets policy.
vegetated facilities (and sometimes other forms of green infrastructure, such as infiltration basins, porous pavement, etc.). For example, Portland’s Green Street Resolution defines them as “streets designed with landscape areas that capture, filter and allow for infiltration of stormwater runoff.”32 A green street additionally enhances the neighborhood by creating an aesthetically pleasing streetscape, provides water quality/recharge benefits, connects neighborhoods, parks, schools, etc., and enhances pedestrian and bicycle access.33

Bioswales (alternately named vegetated swales, or planter boxes)34 are one of the main features of green streets, although they can be constructed independently (not on a full green street) as well. They are defined by the EPA as a “broad, shallow channel with

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33 Portland City Council, 2007
34 Names of different types of planters vary by region and by organization. Infiltration planters, bioswales, and planter boxes all refer to some form of infiltration device with vegetation, although the specific structure and form of inputs varies.
a dense stand of vegetation covering the side slopes and bottom (Figure 1). They are located on a natural grade so water runs down the street and into the swale. Bioswales are intended primarily for stormwater capture, infiltration, recharge of groundwater, and improvement of water quality by trapping particulate pollutants. Vegetation in the bioswale is specifically selected to be drought resistant and flood tolerant. It is crucial that vegetation be well adapted to avoid the need for permanent irrigation. Soil is specially designed to maximize infiltration while slowing water down enough to filter out pollutants (generally a somewhat sandy loamy soil with a mulch/compost layer). Alkaline soils and subsoils increase the ability of the swale to remove pollutants.

Bioswales are designed mainly with stormwater capture in mind. However, pollutant retention and water quality improvement are also crucial functions. As water passes through soil, suspended solids carried by the water are captured and remain in the soil. Since heavy metals are found in stormwater runoff and can have severe water quality effects on waterways or groundwater, their filtration is of great importance. Heavy metals appear primarily in the particulate (suspended solids) fraction, with the exception of zinc (which is largely dissolved), and can therefore mostly be removed through sediment filtration. Dissolved metal ions and particulate metals are filtered

36 Ibid.
37 USEPA, 1999, *Stormwater technology fact sheet: Vegetated swales*
38 Portland Environmental Services, 2006
40 USEPA, 1999, *Stormwater technology fact sheet: Vegetated swales*
41 USEPA, 1999, *Stormwater technology fact sheet: Bioretention*
42 From Pitt et al., 1994 as cited in Gobel et al., 2007
out differently; dissolved metals are largely removed by adsorption onto the near-surface particles in the vadose zone, while particulate metals are removed by sediment filtration at the surface.\textsuperscript{46} Chemical interactions between metals and soil can also allow for filtration. Metals can enter into general cation (positive ion) exchange reactions with clay and organic matter in the soil.\textsuperscript{47} The composition of the soil therefore affects filtration capacity, with higher clay and organic content allowing for more cation exchange reactions.

Some plants can contribute to pollutant removal, but efficiency depends greatly on the species used.\textsuperscript{48} Plants can take up nutrients in the water (thus also benefiting the plants).\textsuperscript{49} Some plants have been shown to have additional pollutant removal capabilities (such as heavy metals) in constructed wetlands,\textsuperscript{50} but these have not yet been studied in bioswales so it is unclear which species are best for this purpose.

Research so far has shown bioswales to be successful in infiltrating stormwater.\textsuperscript{51} Designs have been optimized to create ideal conditions for capture and infiltration. However, water filtration effectiveness of bioswales is not yet entirely understood, especially in terms of design factors that optimize filtration.\textsuperscript{52} Several studies have been done on similar systems (such as constructed wetlands) that show that soil is in fact

\textsuperscript{45} Metals can additionally be removed from soil by one of the following processes: soil surface association, precipitation, occlusion with other precipitates, solid-state diffusion into soil minerals, and biologic system or residue incorporation (From Crites, 1985 as cited by Pitt et al., 1999).
\textsuperscript{47} Pitt et al., 1999
\textsuperscript{48} USEPA, 1999, \textit{Stormwater technology fact sheet: Vegetated swales}
\textsuperscript{49} USEPA, 1999, \textit{Stormwater technology fact sheet: Bioretention}
\textsuperscript{50} P. A. Mays & G. S. Edwards (2001), Comparison of heavy metal accumulation in a natural wetland and constructed wetlands receiving acid mine drainage, \textit{Ecological Engineering}.
\textsuperscript{51} USEPA, 1999, \textit{Stormwater technology fact sheet: Vegetated swales}
\textsuperscript{52} USEPA, 1999, \textit{Stormwater technology fact sheet: Vegetated swales}
effective in trapping many of these pollutants, but bioswales themselves are not yet extensively studied. This thesis aims to investigate the filtration and pollutant retention capacity of bioswales.

Case Studies

Two cities will be examined in this thesis with very different stormwater histories and policies. The purpose of this comparison is to provide a framework for understanding the use of bioswales, their integration into city policy, and the monitoring data that may still be necessary to verify their utility as sustainable stormwater-management strategies. The utility of bioswales will be compared between Portland, a leader in bioswale implementation and Los Angeles, which has implemented significantly fewer bioswales and only started building them recently, but is steadily expanding green infrastructure to deal with stormwater. Los Angeles thus provides an example of the up-and-coming uses of bioswales, as well as their functionality in a very different climate than that of Portland.

Portland, Oregon

Portland, Oregon is situated at the confluence of the Willamette and Columbia Rivers in the fertile Willamette River Valley. This area of the Pacific Northwest is generally considered a temperate rainforest region due to its moderate temperatures and

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54 United States National Oceanic and Atmospheric Administration (n.d.), *Climate of Portland*. 
heavy rainfall. Portland averages 37 inches of rainfall a year and 152.4 days of rainfall.\textsuperscript{55}

Storms in Portland are generally low intensity and destructive rains are rare,\textsuperscript{56} with small storms making up the majority of the precipitation in the area.\textsuperscript{57}

Several older neighborhoods of Portland have a combined sewer system.\textsuperscript{58} With a climate heavy in rainfall and outdated infrastructure, combined sewer overflows (CSOs) from these neighborhoods were frequent. Due to the pollution caused by CSOs, a non-profit organization, Northwest Environmental Advocates, brought a lawsuit against Portland in 1993 for violating the Clean Water Act for the Willamette River,\textsuperscript{59} and forced the city to develop a management plan.

Portland took a two-pronged approach to curb pollution of the Willamette River, gray infrastructure and green infrastructure. They instituted the CSO abatement plan (gray infrastructure), a massive construction project in which the city built three large pipes underground to hold excess stormwater from large storms until treatment facilities were available to handle the load.\textsuperscript{60} In conjunction with this gray infrastructure program, Portland developed a green infrastructure program to reduce the overall stormwater load. This program implements solutions that mimic natural systems and treat “stormwater as a resource rather than a waste.”\textsuperscript{61} One of the elements of the sustainable stormwater

\textsuperscript{55} United States National Oceanic and Atmospheric Administration (n.d.), \textit{Portland climate normals (1981-2010), means and extremes}.

\textsuperscript{56} US NOAA Climate of Portland


\textsuperscript{60} “Combined Sewer Overflows (CSOs)”

program is the Green Street Program. This program has led to the development of over
1200 publicly owned bioswales, with even more developed privately, primarily on the
east side of Portland where the majority of the impervious surface area is.

*Los Angeles, California*

Los Angeles, by contrast, has a warm and comparatively dry Mediterranean
climate. Rainfall in the Los Angeles Basin is highly concentrated in the winter months,
with 85% of rainfall occurring between November and March, and peak rainfall
occurring in January with an average of 3.7 inches. Due to this highly concentrated
rainfall, and a series of rivers and streams channeling water from the mountains into the
basin, flooding is a concern in the Los Angeles Basin. Average annual rainfall is highly
variable, currently approximately 15 inches in the Los Angeles Basin, which is mostly
accounted for by a few large storms. In the surrounding San Gabriel Mountains,
meanwhile, average annual rainfall is around 22 inches, and these steep, high elevation
mountains generate approximately 75% of the runoff in the Los Angeles Basin. Large
floods have occurred several times over the history of the city of Los Angeles, most
recently in 1938. Minor flooding, however, affects residents regularly.

Flood prevention and groundwater recharge are two of Los Angeles’ major

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62 “Portland Green Street Program,” Portland Bureau of Environmental Services, retrieved October 12,
64 Green, 2007
65 Los Angeles Unified School District PCR Services Corporation (2004), 3D: Hydrology/ water quality, in
Central L.A. area new high school no. 11 & Vista Hermosa Park (95-106).
66 Southern California Edison (2009), 4.0 Environmental impact analysis and mitigation measures:
Tehachapi renewable transmission project, in Proponent’s Environmental Assessment, retrieved November
67 Green, 2007
68 Ibid.
concerns with regard to stormwater management. Los Angeles has only recently begun to implement sustainable stormwater solutions, and passed a stormwater ordinance that went into effect in May of 2012. The ordinance calls for stormwater to be managed on-site for new development and redevelopment. However, it does not account for the large majority of land in the Los Angeles area that is already developed or lay out a plan for managing that stormwater. The plan does prioritize low impact development solutions over conventional stormwater management, due to their environmental benefits. “LID is widely recognized as a sensible approach to managing the quantity and quality of stormwater runoff by setting standards and practices to maintain or restore the natural hydrologic character of a development site, reduce off-site runoff, improve water quality, and provide groundwater recharge.”

**Purpose of study**

This study will examine the history and policies with regard to sustainable stormwater management of Portland and Los Angeles, as well as the pollutant removal effectiveness of bioswales in each city. Effectiveness will be discussed in the context of a water quality study that I conducted in Portland in collaboration with the City of Portland and Portland State University, and analysis of data from a soil quality study conducted by the Council of Watershed Health in Los Angeles. These studies will provide perspective on the current state of bioswales and their projected future success.

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71 Los Angeles, 2011
Chapter 2

PORTLAND, OREGON

Stormwater Management History

After its incorporation in 1851, Portland dealt with its sewage, as did other river or seaport cities, by directing combined sewer and stormwater straight to local waterways or oceans; in Portland’s case this meant the Willamette River and Columbia Slough (the two major waterways in the city). The first treatment facility was not constructed for another century when in 1952 the city constructed the Columbia Boulevard Wastewater Treatment Plant. Until its construction pollution built up in the river, and by the 1920s it was already apparent that this system had flaws, as heavy storms caused the sewers to back up into businesses along the waterfront. Historian William Lang cites a 1924 writer for the city’s primary newspaper, The Oregonian, saying, “If this evil [sewer discharge] is not checked early in its growth our ‘Beautiful Willamette,’ will become as repulsive to the eye and nose as some rivers flowing through industrial cities of the old world and will be deserted by its abundant fish.” In response, Olaf Laurgaard, the City Engineer, designed an expansive plan known as the Front Street Intercepting Sewer and Drainage System Project, which included a massive 5,400-foot seawall to prevent flooding from affecting downtown streets. The project was completed in 1929 and was the first major demonstration of Portland’s efforts to reduce pollution in the Willamette River.

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74 Ibid.
The Front Street Intercepting Sewer and Drainage System Project, while diverting some sewage, was not sufficient to clean up the Willamette. The effect of the sewage flowing into the river without treatment became evident in 1938, when dangerous levels of *E. coli* were found in the Willamette River. Mayor Joseph Carson initiated a public campaign supporting bond measures to pay for sewage treatment plants, and voters approved the creation of the Oregon State Sanitary Authority (OSSA). OSSA initially had limited enforcement authority, and the river’s condition continued to worsen.\(^{75}\)

The first sewage treatment plant, the Columbia Boulevard Wastewater Treatment Plant, significantly improved water quality in the river, but the combined sewers still spilled raw sewage into the river during overflow events caused by heavy rainstorms (known as Combined Sewer Overflows, or CSOs). A secondary treatment plant and expansion of the sewer system was completed in the 1970s, and further sewer improvements lowering overall CSOs were made throughout the 1980s.\(^{76}\) However, Portland was still not meeting federal water quality standards, so in 1990 Portland signed an agreement to begin investigating CSO control options after local environmental organizations filed a lawsuit against the city for violation of the federal Clean Water Act.\(^{77}\)

To fund and manage stormwater infrastructure, Portland instituted a stormwater utility fee in 1977. Property owners pay a fee based on the amount of impervious surface (in square feet) on their property.\(^{78}\) Credits and discounts are given for use of Best

\(^{75}\) Lang, 2011  
\(^{76}\) Portland Environmental Services, 2012  
\(^{77}\) Lang, 2011  
Management Practices (BMPs) and management of water on-site as of 2006. A Best Management Practice is a stormwater pollution control method that prevents pollution and/or is a treatment facility (such as a grassy swale) that removes pollutants from water.

In 1991 the City signed an agreement with the state Department of Environmental Quality (DEQ) to begin the CSO abatement plan, which was a Stipulation and Final Order (SFO) to control CSOs. The main project undertaken for this plan was the Big Pipe project. Prior to starting construction on this expensive and expansive project, four smaller, low-cost projects, known as Cornerstone Projects, were implemented to reduce the load of stormwater from the combined sewer system. The projects were: downspout disconnection (incentivizing homeowners to disconnect roof drains), sump installation (constructing manholes to trap sediment and sumps to allow stormwater to infiltrate), stream diversion (diverting creeks away from the combined sewer system), and sewer separation (eliminating combined sewers in several neighborhoods). Completion of these four projects has led to the removal of over two billion gallons of stormwater runoff from the combined sewer system every year.

Although all of the projects were effective in reducing the stormwater load, the downspout disconnection program is most often cited for its success, removing 1.2 billion gallons of stormwater from the combined sewer system every year. This program began

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80 City of Portland, Oregon (2011), *Stormwater Management Plan: National pollutant discharge elimination system (NPDES) municipal separate storm sewer system (MS4) discharge permit* (Permit number: 101314).
82 Portland Environmental Services, 2012
in 1993 and continued until 2011, and gave incentives and technical help to homeowners on the East Side to disconnect their roof drains from the combined sewer system, instead directing the flow to their yards or gardens. A total of 56,000 homes were disconnected through the program.83

The Cornerstone Projects demonstrate Portland’s commitment to lower-cost, best management practice solutions in the initial stages of its stormwater management plan. These projects, especially downspout disconnection, can be considered forerunners for the green infrastructure that has since emerged to manage stormwater in the combined sewer and separate sewer systems.

The Big Pipe project was the main avenue for reducing combined sewer overflows. The project was the largest capital construction project in Portland’s history at a total of $1.4 billion dollars, with the East Pipe alone costing $450 million. Three pipes were built, the smallest for the Columbia Slough, which was 12 feet in diameter, next the West Side Big pipe, which captures water from the west side of Portland and is 3.5 miles long and 14 feet in diameter. Finally, the East Side Big Pipe, managing water from the east side of Portland (which is significantly larger than the west side), is almost six miles long and 22 feet in diameter.84

The Big Pipe project has been remarkably effective in reducing the number of CSO events every year from around 50 to only four, and thus the amount of pollution in the Willamette River and Columbia Slough is expected to decrease dramatically.85 This project is representative of Portland’s gray infrastructure approach. Meanwhile, Portland

83 Portland Environmental Services, 2012
84 Ibid.
was also starting to investigate green infrastructure solutions. Some green infrastructure was used to lower the stormwater load and cost of construction on the Big Pipe project, with a $9 million dollar investment that is expected to save ratepayers (of the stormwater utility) $224 million in CSO maintenance costs. The majority, though, was in response to the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit issued by the state, for which Portland was required to develop a stormwater management program and plan that met regulatory standards. This program was directed toward reducing pollution in stormwater rather than controlling CSOs, and therefore had a strong emphasis on green infrastructure and BMPs.

A team at the Portland Bureau of Environmental Services (BES) investigated the City’s current procedures and practices to determine where regulations were already being met and where new practices needed to be implemented to meet regulations.

Meanwhile, several new BMPs were implemented to test feasibility. The City created a Stormwater Policy Advisory Committee (SPAC) in 1996 to compile the information gathered and decide on the best approach for requiring BMPs. The SPAC spent three years on the project and wrote the Stormwater Management Manual, which outlines the City’s requirements for stormwater management, specifies design guidelines for different approaches, and drives much of the regulation today. A citywide regulatory program was

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87 After the amendment of the Clean Water Act in 1987, the National Pollutant Discharge Elimination System (NPDES) was created to control illicit discharges into waterways. Large cities were required to obtain NPDES permits for their Municipal Separate Storm Sewer System (MS4) since it is a nonpoint source pollutant into the rivers (Portland Environmental Services, 2008, SWMM Ch. 1).
88 “Portland, Oregon: Building a Nationally Recognized Program Through Innovation and Research”
in place by 1999, and the manual is updated every two years to accommodate information from monitoring stormwater facilities.

Investigation of sustainable stormwater management options began more intensely in 2001 with the creation of the Sustainable Infrastructure Committee to coordinate efforts between bureaus. The establishment of this committee was soon followed by the development of the Sustainable Stormwater Management Program with the Bureau of Environmental Services.

**Current Policies**

To comply with the NPDES MS4 permit, cities to which it is issued are required to develop a stormwater management program to meet design standards for water quality and flow control of onsite stormwater management facilities. The program is concentrated on Low Impact Development (LID) practices, structural source control devices, and operation and management BMPs.

Portland’s stormwater management program required the development of a Stormwater Management Plan (SWMP), which outlines the strategies taken to mitigate stormwater pollution. The SWMP is comprised of eight BMP categories:

1. Public involvement
2. Operations and Maintenance
3. Industrial/ Commercial Controls
4. Illicit Discharge Controls

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89 Portland Environmental Services (2008), *Stormwater management manual: Chapter 1–requirements and policies* (ARB-ENB-4.01).
90 “Portland, Oregon: Building a Nationally Recognized Program Through Innovation and Research”
91 Ibid.
92 Portland Environmental Services, 2008, SWMM Ch.1
5. New Development Standards
6. Structural Controls
7. Natural Systems
8. Program Management

The plan highlights how each of these categories of BMPs addresses different requirements of the permit. The SWMP also lays out measurable goals for each BMP, intended to serve as targets for their implementation. To show progress being made as well as set more specific year-to-year goals, the City of Portland submits an annual compliance report every year to the Oregon Department of Environmental Quality.93

A few of these BMPs are particularly important to note in their impact on stormwater management practices. The public involvement BMP highlights Portland’s emphasis on education and outreach as a means of preventing pollution and reducing stormwater runoff.94 The downspout disconnection program is an example of this value in the CSO abatement plan, and similar programs have been undertaken under the SWMP.

Under New Development Standards, Portland requires projects developing or redeveloping over 500 square feet of impervious surface to meet pollution reduction and flow control requirements.95 This is an important component of the SWMP because it sets the stage for a future in which more stormwater runoff is managed on-site, by directing developers to the Stormwater Management Manual that describes techniques and principles of Low Impact Development.96

93 City of Portland Oregon, 2011
94 Ibid.
95 United States Environmental Protection Agency, 2010
96 City of Portland Oregon, 2011
The Structural Controls BMP category demonstrates that regulation of new development is not sufficient to address the majority of the stormwater management needs of the city. This has been most instrumental in setting Portland apart from other cities in its progress on green infrastructure. The Green Street Program, passed in 2007, falls under this BMP category. This is one form of green infrastructure that Portland is constructing on existing streets, renovating them to manage stormwater. Through Structural Control, Portland has also been reducing impervious surface area, through Green Streets as well as the Portland Watershed Management Plan (a plan focused on improving the condition of urban watersheds).\(^97\) For example, 340 linear feet of roadside ditches have been converted to swales as of 2007, which has likely increased dramatically since the adoption of the Green Street policy.\(^98\) These swales manage runoff from far more impervious area than their actual size (i.e. a 200 square foot bioswale may manage runoff from 4,000 square feet), thus reducing the effective impervious area in the city significantly.\(^99\)

The most current SWMP was written in 2011, and covers 2011-2016. The plan includes a mandatory hierarchy for developers of on-site infiltration.\(^100\) These BMPs are intended to be utilized to the “maximum extent practicable,” meaning implementation takes into account soil conditions, space limitations, and other priorities.\(^101\) This clause implies subjectivity in enforcement and brings into question how priorities are determined. Existing enforcement policies are therefore unclear.

\(^{97}\) City of Portland Oregon, 2011
\(^{98}\) Center for Neighborhood Technology (2007), *Green infrastructure community profile: Portland, Oregon*.
\(^{99}\) Tim Kurtz, personal communication, November 19, 2012
\(^{100}\) United States Environmental Protection Agency, 2010
\(^{101}\) City of Portland Oregon, 2011
The Green Street Program, which the City passed by resolution in 2007, has been crucial to the establishment of green infrastructure in Portland. The development of this program was instigated by a request from Commissioner Sam Adams in 2005 for City bureaus to develop an approach to include green street elements in street projects when feasible, and identify planning and implementation challenges to increase feasibility.\textsuperscript{102} According to this resolution, a green street incorporates several LID elements using an integrated approach to capture and infiltrate stormwater prior to it entering the drainage system. These include bioswales, permeable pavement, green roofs, and rain gardens.\textsuperscript{103} Several considerations and policies led to the adoption of the Green Street policy, as outlined in the resolution presented by the City Council. These include:

- The Watershed Management Plan, which involves a stormwater management strategy
- Requirements for stormwater pollution reduction by the Municipal Separate Storm Sewer System (MS4) Permit
- Metro’s adoption of onsite infiltration for transportation facilities
- The Stormwater Management Plan, which ranks on-site infiltration by surface infiltration as the best method of stormwater disposal
- The City Green Streets Cross-Bureau Team’s Phase 1 work that set out a policy laying out responsibilities for maintaining green street facilities
- The Office of Transportation and Cross-Bureau Task Force’s priority for design standards that allow stormwater treatment and infiltration

\textsuperscript{102} Portland Bureau of Environmental Services (2007), \textit{Green streets: Cross-bureau team report – phase 2.}
\textsuperscript{103} United States Department of Agriculture Natural Resources Conservation Service
Portland’s Development Commission, which partners with bureaus to incorporate Green Street design into new streetscape projects

- The City Policy ENN-3.01 of Sustainable City Principles, which requires the city to seek sustainable, cost-effective approaches to protect natural resources (such as water)

- The City’s Comprehensive Plan including several references to protection of resources and development of efficient and environmentally responsible land-use planning.\(^{104}\)

This program was designed as a cross-bureau policy, making green streets a citywide priority. The cross-bureau approach assures “thorough integration of the policy into each respective bureau’s operations and development programs.”\(^ {105}\) In addition to enhancing water quality and handling stormwater, they also “create attractive streetscapes that enhance neighborhood livability by enhancing the pedestrian environment and introducing park-like elements into neighborhoods.”\(^ {106}\) In adoption of the policy, the city agrees to make Green Streets an “integral part of the City’s maintenance, installation, and improvement programs for its infrastructure located in the public right of way, and to integrate the Green Street Policy into the City’s Comprehensive Plan, Transportation System Plan, and Citywide Systems Plan,”\(^ {107}\) ensuring their widespread implementation throughout the city. By emphasizing the multiple utilities of green streets, the City of Portland has implemented these projects more widely, which has been instrumental in

\(^{104}\) Portland Environmental Services (2007), *Green streets resolution* by S. Adams and L. Dobson.

\(^{105}\) Portland BES, 2007, *Green streets: Cross-bureau team report*, p.4

\(^{106}\) United States Environmental Protection Agency, 2010, p. 54

\(^{107}\) Portland Environmental Services, 2007, *Green streets resolution*, p.3
making it one of the leaders in green infrastructure and stormwater management in the United States.

**Design Criteria for Vegetated Facilities**

Several requirements have to be met for management of stormwater onsite, including infiltration and discharge, flow control, and pollution reduction. In developing green infrastructure, a large emphasis has been placed on building vegetated facilities. This can be explained in part by the Portland Stormwater Management Manual, which states, “the City’s current stormwater management approach relies on the use of vegetated surface infiltration facilities to comprehensively meet multiple requirements.”

The Stormwater Management Manual outlines specific design criteria for vegetated facilities to ensure proper capture and infiltration of stormwater. Stormwater management facilities can be surface infiltration, subsurface infiltration, or hybrid facilities. This paper will concentrate on surface facilities, which include swales, planters, and basins.

Vegetated surface facilities can be divided into total infiltration, partial infiltration, or flow-through, which depends on the degree to which water is diverted from the facility after filtration. Deciding which type of facility to build is based primarily on the native soil in a given site; total infiltration facilities require soils that drain well (infiltrate 2 inches per hour or more), while partial infiltration only needs soils

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108 Portland Environmental Services, 2008, SWMM Ch.1, p.8
that drain decently well (between 0.5 and 2 inches per hour), and flow-through facilities are used for soils that do not infiltrate well (less than 0.5 inches per hour).  

For the facility itself, the growing medium (or imported soil to the facility upon construction) must be at least 18 inches deep. The growing medium should be a sandy loam with about one-third compost by volume. Vegetation is chosen to minimize external care; that is, the plants should not need herbicides, pesticides, fertilizers, irrigation, mowing, or pruning. Mostly native species, such as *Juncus tenius* (slender rush) or *Scriptus americanus* (American bulrush) are recommended by BES for planting in facilities, and exclusively native species are required in certain sensitive environmental zones. Swales must be at least 5 feet (on private property) and at least 8 feet (in the public right-of-way) in width and must be fully vegetated.

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110 Portland Environmental Services, 2008, SWMM Ch.2
112 Portland Environmental Services, 2008, SWMM Ch.2
**Chapter 3**

**CASE STUDY: Water Quality Study in Portland, Oregon**

**Introduction**

Many Low Impact Development (LID) facilities have been built in Portland over the last 10-15 years. Bioswales in particular have been widely built around the city, as parts of green streets and also independently. The city has conducted some monitoring of these facilities and determined the ideal soil for infiltration, a biomix that is a sandy loam with compost.113 Fewer studies, however, have looked at the effectiveness of bioswales in improving water quality, despite the fact that this is one of their intended purposes. Heavy metals have been especially neglected in prior research, and are hazardous for the health of rivers and streams. Potential negative effects of high concentrations of heavy metals in waterways are numerous, such as reducing the diversity of macroinvertebrates in contaminated streams.114 The possible ability of bioswales to retain heavy metals from stormwater has implications for the longevity of the bioswale and for the safety of the groundwater beneath it. With effective filtration metals may accumulate in the soil over time up to hazardous concentrations, but a lack of effective filtration could contaminate the groundwater being recharged by water passing through the bioswale. To address this gap in knowledge, I conducted a research project under the supervision of Dr. Alan Yeakley at Portland State University and in collaboration with the Portland Bureau of Environmental Services during the summer of 2012. The project aimed to test water

quality effects of bioswales in Portland, specifically measuring heavy metal concentrations of water entering and leaving the bioswales. Samples were collected from the inlet and outlet of the bioswale and tested for heavy metals expected in stormwater, and these results were analyzed to determine filtration effectiveness.

Bioswales are designed to filter out both suspended and dissolved metals, but the filtration ability varies with particle size. We therefore set out to test both total and dissolved metal concentrations in stormwater that passed through bioswales. “Total metals” includes metals in suspended solids and those dissolved in water. For the purpose of this study we defined dissolved metals as particles smaller than 0.45 microns. Dissolved metals are often present in rainwater due to the low pH. The dissolved metal fraction tends to be smaller than the suspended metals, since much of the dry weather accumulation becomes suspended solids in rainwater, but the ratio depends on the particular storm conditions. Since bioswales (and soils in general) are known to capture suspended solids effectively by sediment filtration, suspended metals were expected to be filtered out more efficiently, while it was unclear how well dissolved metals would be filtered.

118 Ibid.
Methods

Since this was a short-term summer project, to investigate the effectiveness of bioswales in filtering heavy metals from stormwater we needed to simulate stormwater. We collected samples from the inlet of the bioswales and from an outlet spot after water had passed through the bioswale. Although samples taken from the outlet were necessarily not the same sample as was collected for the inlet, there was no other source of water to the outlet pipe so there was a degree of consistency with the water being sampled. Five simulated storms were sampled in all on three different bioswales, with two facilities tested twice. Total and dissolved concentrations of six heavy metals were analyzed for the samples from each bioswale to evaluate and compare bioswales for effectiveness in filtration of heavy metals.

Site Selection

Three bioswales were selected based on criteria that facilitated testing and allowed us to compare effects of vegetation, traffic and bioswale size. We chose lined facilities to allow us to take samples from the outlet of the facilities after water had passed through the soil. Lined facilities have a perforated pipe that runs through the bottom of the bioswale (buried 18” beneath the surface). Water passing through the soil collects in this pipe and flows out, either back into the storm drainage system or elsewhere away from the site of the bioswale. Lined bioswales are primarily built in locations where the water table is high and there is flooding concern, or where the native soil is not suited to infiltrate water (due mainly to high clay content).120 These facilities

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were ideal for this study since we were able to choose sites that had access to the outlet pipe, enabling sampling before the water reentered the storm drainage system but after it had passed through the facility.

Out of the seven lined facilities presented as options,\textsuperscript{121} consideration was given to the proximity and accessibility of a hydrant (for storm simulation purposes) and the manhole/pipe outlet, amount of traffic on the street, and the size, level of maintenance, and vegetation of the bioswale. Sites with relatively high traffic were given priority with the hope that these sites would have greater deposition of pollution,\textsuperscript{122} and we preferred to sample facilities with variable sizes and levels of maintenance.

\textit{Description of Sites}

The sites chosen were SW Barbur and Sheridan, NE Glisan & 28\textsuperscript{th}, NW 16\textsuperscript{th} & Everett. Exact size and vegetation composition for NW 16\textsuperscript{th} & Everett was measured in a survey conducted by Ted Hart in 2010, but is unknown for SW Barbur & Sheridan and NE 28\textsuperscript{th} & Glisan because they were constructed after 2010.

1. SW Barbur & Sheridan (Figure 2) is the largest of the sites, with stormwater flow coming from Barbur Boulevard, a fairly heavily trafficked street. It is decently vegetated, primarily with rushes and sedges (likely \textit{Juncus patens}, which is non-native), and had minimal

\textsuperscript{121} Many lined facilities exist in Portland, but they are not easily identified from the City’s GIS map, so only seven were presented to us as potential sites that were guaranteed to be lined facilities.

\textsuperscript{122} Gobel et al., 2007
trash build up in the facility. The bioswale was completed in 2011.\textsuperscript{123}

2. NE 28\textsuperscript{th} & Glisan (Figure 3) is fairly small and divided into two separate parts (each about 5’ x 10’), but flow from the uphill section enters directly into the downhill section. It is heavily vegetated with a variety of plants (exact species unknown), right in front of the outdoor seating area of a restaurant, with stormwater flow primarily from Glisan Street, which has heavy traffic. It was completed in 2011.\textsuperscript{124}

3. NW 16\textsuperscript{th} & Everett (Figure 4) is the smallest facility, about 7’ x 23’ with an area of 161 square feet, highly vegetated primarily with rushes and sedges (primary species \textit{Juncus patens} covering 64 square feet), and there was a fair amount of trash buildup in the facility. It is located on a busy intersection by the onramp to a freeway, but most of the stormwater flow comes down Everett Street, a relatively busy road. It is the oldest of the facilities tested and was installed in 2008.\textsuperscript{125}

\textsuperscript{123} Tim Kurtz, personal communication, November 19, 2012

\textsuperscript{124} Tim Kurtz, personal communication, November 19, 2012

\textsuperscript{125} Ted Hart, personal communication, November 16, 2012
Simulated Storms

Sampling during a real storm was impractical since the summer months are relatively dry in Portland, and we were interested in first flush samples that best represent the level of contamination in the region and to maintain consistency between sampling. We therefore decided to perform measurements during simulated storms. Storm simulations followed protocols established by the city for monitoring. We used water from a fire hydrant that was run through a Sensus© hydrant flow meter W-1250 to control flow rates. We planned storms so that there was at least a one-week antecedent dry period before the storm, in order for pollutants to have time to accumulate on the street. Additionally, all hoses were set up so water was flowing down approximately one city block (200 ft), allowing it to collect pollutants from the street before entering the bioswale. Higher flow rates for which a fire hose was used (greater than 20 gpm) flowed through a dechlorinator (Pollard Water.com LPD-250 dechlorinating diffuser) to comply with city regulations.

Storms were designed based approximately on water quality storms (a standard storm in which water quality would be a concern) typical for Portland, as established by the Bureau of Environmental Services. Peak flow rates were five times greater than minimum flow rates, the peak was held for eighteen minutes, and there was a gradual rise to and decline from the peak. Each test was two hours in duration.

One site was an exception for storm design (NE 28th & Glisan). This test was done during an ordinary flow test that the Field Operations team of the Bureau of Environmental Services was conducting, and thus flow rates were set based on their

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needs. The test still included a steady climb to a peak flow rate (significantly higher than our average peak rate), and we only tested during the first two hours of the five-hour simulated storm, so we did not observe the decline from the peak rate.

Since the project was done with simulated storms with flow rates crudely calculated to represent real storms, the data collected is not perfectly representative of a typical storm. The water flowed only down the curb and not down the main street, since we were unable to block traffic for such an extended period of time, and we were also missing runoff from non-street sources (i.e. roofs) that would have contributed to pollution in an ordinary rain event. Due to these considerations the observed metal concentrations are likely not representative of the levels during a storm, so the most valuable information from the data collected is the comparison of inlet samples to outlet samples to evaluate filtration efficacy of the bioswales.

**Sampling**

Before beginning each test, water was flushed from the hydrant out of the drainage basin of the swale for approximately one minute, to remove all initial iron and rust built up in the hydrant. Over the course of the two-hour test, samples were taken approximately every nine minutes from both the inlet and the outlet, for a total of 15 samples in each location. Since outlet sampling started later in the two-hour period (once there was actually flow from the outlet pipe), fewer samples were usually taken from the outlet. Three control samples were also taken: one at the beginning of the test (first water exiting the hose onto the street), and two at the end of the test, one from the fire hose and one from the garden hose (a fire hose was used for higher flow rates). Special care was
given to collecting the first flush (first water entering the bioswale) of each test since we predicted it would contain the highest levels of pollution as it effectively cleans the street.

Samples were collected using a stainless steel beaker kept well mixed by swirling, which was divided into two 250 mL plastic bottles (one for dissolved metal analysis, and the other for total metals analysis). The bottles were cleaned before sampling with 5% nitric acid solution and Nanopure water. The bottles were kept filled with Nanopure water that was dumped right before sample collection. Extra water was collected after each sample to test for conductivity and temperature with an Orion 4-star Conductivity Portable Meter. Conductivity was intended to be used as a proxy for metal concentration, to approximate the concentration in samples as they were being collected. Conductivity was generally higher in the outlet samples than in the inlet samples, but that was not found to be the case with metal concentrations in the samples. Therefore the conductivity change is likely due to other factors, such as ions from salts present in the soil, and was omitted from the results since it was not relevant to the study.

Five tests were conducted in all on three different sites, with two sites tested twice (SW Barbur & Sheridan and NW 16th & Everett). Two weeks passed between the two tests to act as the antecedent dry period (Table 1).
Table 1. Summary of sampling sites, number of samples, and antecedent dry period

<table>
<thead>
<tr>
<th>Sample site</th>
<th>Test date</th>
<th>Number of inlet samples</th>
<th>Number of outlet samples</th>
<th>Antecedent dry period¹ (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Barbur &amp; Sheridan</td>
<td>7/11/12</td>
<td>15</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>SW Barbur &amp; Sheridan²</td>
<td>7/27/12</td>
<td>15</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>NW 16ᵗʰ &amp; Everett</td>
<td>7/13/12</td>
<td>15</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>NW 16ᵗʰ &amp; Everett²</td>
<td>7/27/12</td>
<td>15</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>NE 28ᵗʰ &amp; Glisan</td>
<td>7/25/12</td>
<td>11</td>
<td>14</td>
<td>9</td>
</tr>
</tbody>
</table>

¹ A dry day is considered anything with <0.05 inches of precipitation. Data obtained from National Weather Service Climate Data.
² Analysis has not yet been completed on these samples, so data is still unavailable.

During the sampling, outlet flow rates were recorded for SW Barbur & Sheridan using a 5-gallon bucket and stopwatch to measure flow rates immediately after each sample collection. At NE 28ᵗʰ & Glisan, outlet rates were measured electronically with a flow monitor (Sigma 950 flow meter) with data collected every minute. Outlet flow rates could not be measured at NW 16ᵗʰ & Everett due to the location and shape of the outlet pipe.

Digestion and Analysis

Acid digestion to prepare samples for total metals analysis was done in the Water Pollution Control Laboratory in Portland. The method largely followed EPA Method 3015A for microwave acid digestions of aqueous samples.¹²⁷ One milliliter concentrated HCl and 1.5 mL concentrated ultra-pure HNO₃ were added using bottle-top dispensers to

¹²⁷ United States Environmental Protection Agency (2007), Method 3015A: Microwave assisted acid digestion of aqueous samples and extracts.
25 mL of sample (well mixed before pouring 25 mL of sample) and microwaved at 170°C for 20 minutes. For every set of 10 samples, a blank, a control, a duplicate, and a spike were also run. After microwave digestion, samples were transferred to 50 mL Falcon tubes and filled up to the 50 mL mark with Nanopure water.

Filtration for dissolved metal analysis involved using a vacuum filter with a 0.45 μm filter to filter out any particles in the water. Forty-five milliliters of sample were filtered into 50 mL Falcon tubes, 1 mL concentrated HCl and 1.5 mL concentrated ultra-pure HNO₃ were added using bottle-top dispensers, and samples were filled to the 50 mL mark on the Falcon tubes with Nanopure water. A blank and control sample were made every 20 samples, and the same (numbered) samples that were duplicated and spiked for microwave digestion were duplicated and spiked for the dissolved metals preparation.

Analysis for heavy metals was done by Inductively Coupled Plasma Optical Emission Spectroscopy (Agilent 720 series ICP-OES) in the Trace Element Analytical Laboratory at Portland State University. Samples were analyzed for cadmium, chromium, copper, lead, nickel, and zinc.

**Data Analysis**

Data was initially analyzed by plotting concentration of a given pollutant versus time of sampling. Concentrations that read below detection limits of the ICP-OES were listed as 0 ppb. Plots were also made for flow rate versus concentration and flow rate versus time. Each metal was graphed individually since contaminant concentrations were very different for different metals. Percent change from initial inlet sample to initial
outlet sample was calculated for each metal in each bioswale, and averaged across each facility and across each metal.

**Results**

The goal of the study was to compare the concentration of metals in samples from the inlet of the bioswale to the concentration of metals in samples from the outlet, and thereby determine whether the bioswale was effectively filtering out heavy metals. Concentration data obtained from the water quality study were therefore plotted against time.\(^{128}\)

Controls were taken at the beginning and end of each test. Control concentrations were higher at the beginning of the test than at the end, indicating that some contamination came through the fire hose and was not fully flushed out before the test began. However, as indicated above (simulated storms section), a premise of the experiment was that overall metal concentrations were not representative of concentrations in a real storm (due to a lower drainage area and lack of inputs). The importance of the data is in the ability to compare between inlet and outlet concentrations and not in the absolute values of the concentrations themselves. Since the origin of the metals in the water was inconsequential for this comparison, control samples were not factored into the analysis.

Figure 5 shows a sample graph for metal concentrations throughout the experiment. The first trend to note is the quick decline of metal concentrations after the

\(^{128}\) Data were only analyzed from the three earlier tests. Samples from the two tests conducted on 7/27 (repeats of Barbur & Sheridan and 16\(^{th}\) & Everett) have not yet been analyzed for heavy metal concentrations.
first sample for the inlet samples. This drop demonstrates a first flush effect, defined as “the initial period of stormwater runoff during which the concentration of pollutants is substantially higher than during later stages.”\textsuperscript{129} The presence of a first flush effect during storms can be particularly damaging to receiving water bodies due to high concentrations of pollutants,\textsuperscript{130} so the capacity of a management facility to mitigate first flush effects is crucial.

As seen by the slight concentration fluctuations in Figure 5, flow rate also had some impact on the metal concentrations found in the samples. Flow rate patterns over time are shown in Figure 6. NE 28\textsuperscript{th} & Glisan flow rates have a different pattern since they were set by the City’s flow test needs.

\begin{figure}[h]
\centering
\includegraphics[width=0.6\textwidth]{Cr_Consentration_vs_Time.png}
\caption{Sample graph for concentration vs. time (this shows the inlet sample chromium concentrations for total metals from the 16\textsuperscript{th} & Everett test on 7/13). The concentration drops off quickly after the first sample, demonstrating the first flush effect.}
\end{figure}


\textsuperscript{130} Ibid.
Flow rates were also compared to metal concentrations directly. Since flow rates increased to the peak and then declined, each test had to be split into two parts, flow rate from start to peak and flow rate from peak to end of the storm. Sample graphs using total zinc at each site are shown in Figure 7. Since the overall dynamics for metal retention in
the swale was similar for all metals, graphs for other metals and for dissolved metals can be found in Appendix A.

**Figure 7.** Sample flow rate vs. concentration graphs. Concentrations are initially high at all sites (despite low flow rates) due to the first flush effect. Fluctuations in concentration can be seen in the Barbur & Sheridan whenever flow rate is increased, but then concentrations stay low after the peak. 28th & Glisan is represented without connecting lines because flow rate was more variable. Overall, increases in flow rate don’t seem to have as important of a role in determining flow rate as the time of sampling (i.e. the first flush effect).
In comparing inlet concentrations to outlet concentrations, a large difference was observed between initial inlet samples and initial outlet samples. Due to this observed first flush effect, it is most relevant to compare these initial concentrations. Examples using zinc are shown for total metals in Figure 8, and dissolved metals in Figure 9. Graphs for the rest of the metals can be found in Appendix A.

Comparing initial inlet to initial outlet samples across all the metals, average percent change ranged from 85-97.2% for total metals, and 88-88.5% for dissolved metals (note: one dissolved metal site, Barbur & Sheridan, was not included because of insufficient data) (Table 2). This shows a very high retention capacity of the bioswale, even for dissolved metals. Of the total metals, lead had the highest percent difference (97%) on average (although this is partially due to samples below detection limits), and chromium had the lowest retention in the bioswales (82%). For dissolved metals, chromium had the highest (97%), again influenced by samples below detection limits, and copper had the lowest (34%), largely due to one significant outlier.

Table 2. Average percent change from initial inlet to initial outlet sample of each site.

<table>
<thead>
<tr>
<th></th>
<th>Barbur &amp; Sheridan</th>
<th>16th &amp; Everett</th>
<th>28th &amp; Glisan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average % Change total metals</td>
<td>-85.06% ± 15.72</td>
<td>-89.60 ± 5.18</td>
<td>-97.19 ± 2.19</td>
</tr>
<tr>
<td>Average % change dissolved metals</td>
<td>Omitted due to lack of data</td>
<td>-88.43 ± 7.37</td>
<td>-88.06 ± 15.59</td>
</tr>
</tbody>
</table>
Figure 8. Sample time vs. concentration graphs for total metals, comparing inlet and outlet samples. Zn concentrations are shown for all three sites. The large gap between the initial inlet and initial outlet concentration is evident in these graphs. There is a time lag between the first inlet and first outlet sample (particularly pronounced in Barbur & Sheridan) due to the time it took water to reach the outlet pipe filtering through the facility. The different effect of flow rates can also be seen well in these three examples. The 16th & Everett site demonstrates a fairly smooth curve, with a small bump at the peak flow rate (around 54 minutes). The 28th & Glisan has dramatic bumps for the times where flow rate was significantly increased (different than the other two due to a different storm pattern). The Barbur & Sheridan site also has a dramatic bump at the peak flow rate (around 54 minutes), but has an additional one at the first flow rate change, around 18 minutes.
Figure 9. Sample time vs. concentration graphs for dissolved metals, comparing inlet and outlet samples. Zn concentrations are shown for all three sites. There is a significant gap between initial inlet and initial outlet concentrations. The time lag between initial inlet and initial outlet samples is due to the time it took for water to travel to the outlet site. Effect of flow rate is not as dramatic in these graphs as it is for total metals, but the effect is still noticeable for Barbur & Sheridan and 28th & Glisan.
Discussion and Conclusions

Results from the water quality study show that concentrations drastically decrease from the inlet of bioswales to the outlet. This implies that the bioswales are effective in filtering out heavy metals, especially in the total metals category, although more data is necessary to confirm this conclusion. Surprisingly, although not quite as strong as the results from the total metals, dissolved metals also appear to be effectively filtered out by the bioswales.

As far as effectiveness of bioswales in improving water quality, these results are very positive. More data should be collected to ensure the accuracy of the study since the sample size was limited, and a future study with samples collected during a real storm would be ideal. However, these results demonstrate a clear trend of reduction of metal concentrations after infiltration through the soil. There was too much deviation in results and too few samples to provide a clear conclusion about which facility best retained heavy metals, so no specific bioswale design implications can be drawn. As far as impacts on groundwater, since water quality is so dramatically being improved through only 18 inches of soil, it can be assumed that levels of metals are very low by the time they reach groundwater (in unlined facilities). Studies in other cities have shown that stormwater infiltration does not have negative consequences on groundwater quality.\textsuperscript{131}

A few questions remain after the conclusion of this study. Since heavy metal loads were low, it is unclear how the bioswales would respond to higher metal concentrations, and whether there is a saturation point at which metals would no longer be filtered out as effectively. In addition, this study leaves open the question of

accumulation of these heavy metals in the soil. It is clear that at this point in time, there is not significant enough heavy metal accumulation in the soils of these facilities to leach back into the water filtering through them. However, there may be potential for such leaching or toxic levels of contamination accumulating in the soil (the oldest of these swales was built only four years ago), which is an important point of further study if bioswale construction continues at the current rate. The City operates on the assumption that the soil and plants will last 25 years, although since no long-term studies have been completed yet, it is unclear whether replacements will actually be necessary.\textsuperscript{132} Studies have shown that some metals are more mobile than others in soil. In some basins in Fresno, California, lead, zinc, cadmium and copper accumulated for over five years without significant downward movement through the soil. Other studies have shown that copper exhibits downward movement in sandy and loamy soils (as the soils are in Portland bioswales).\textsuperscript{133} Due to this mobility, another possibility is that metals are retained in the bioswale but are gradually released into the groundwater over time, in a manner that avoids accumulation in the bioswale but may not significantly contaminate groundwater (if the leaching is gradual and therefore diluted). The potential for accumulation or lack of accumulation could have implications for maintenance needs and longevity of bioswales.

\textsuperscript{132} Tim Kurtz, personal communication, November 19, 2012.
\textsuperscript{133} Pitt et al., 1999
Chapter 4

LOS ANGELES, CALIFORNIA

Stormwater Management History

In contrast to Portland’s rainforest climate, Los Angeles, California, has a Mediterranean climate characterized by warm and dry summers with rainfall concentrated in the winter months. Concentrated periods of rainfall along with a significant amount of runoff from the mountains leads to flooding concerns in the city, which have increased as Los Angeles has grown in size. According to Dorothy Green, founder of Heal the Bay,

In the 1920s roughly 95% of the rain falling on Los Angeles either infiltrated into the ground or evaporated. Today, with the extensive development and the paving over of our urban environment (as much as 80% of the land is now covered with roofs, roads, parking lots, patios, etc.) and the construction of the massive storm channel system, about 50% of stormwater runs off in the Los Angeles River drainage area, while 50% either infiltrates or evaporates.134

Such a dramatic change in the amount of runoff during a storm requires a significant change in infrastructure.

With unpredictable rainfall and a growing population, Los Angeles has had to dramatically increase its water supply over the course of the 20th century. It is currently the second largest city in the country, with over 3,500,000 people and 500 square miles.135 The city initially relied on the Los Angeles River and groundwater aquifers, but supplies quickly ran low and Los Angeles extended its search for water outside of the region. After exhausting all options for damming the local rivers to create reservoirs and

134 D. Green (2007), Managing water: Avoiding crisis in California, p. 16
extracting groundwater, William Mulholland, superintendent of the City’s water
department, lead the search for a source of water to import. The 233-mile-long Los
Angeles aqueduct was built in 1913 to bring water from the Owens River (north of Los
Angeles), initially, and then extended to near Mono Lake in 1940.\textsuperscript{136}

When this water supply also became limited, the Los Angeles Department of
Water and Power, responsible for providing water for the City of Los Angeles, began to
purchase water from the Metropolitan Water District (MWD) of Southern California. The
MWD sources its water from Northern California and the Colorado River, via the State
Water Project that transports water from the Feather River and the San Francisco Bay/
Sacramento-San Joaquin River Delta through the 444-mile long California aqueduct,\textsuperscript{137}
and the Colorado River Aqueduct that transports water approximately 242 miles from the
Colorado River to Riverside County. Combined, these imported water sources make up
88% of the City of Los Angeles’ water supply.\textsuperscript{138} Importing water is energy intensive and
expensive, and these once bountiful sources of water are now also being depleted. These
water supply concerns and associated costs are pushing Los Angeles to focus on ways to
augment its groundwater supply and import less water.\textsuperscript{139}

In addition to potable water supplies, Los Angeles has also developed and
managed an expanding sewer system. Incorporated in 1850 as a small pueblo with about
1600 people, Los Angeles had no sewer system or stormwater drainage.\textsuperscript{140} Expansion of
the city and population growth over the years created both sewage and flooding

\begin{thebibliography}{99}
\bibitem{gumprecht} B. Gumprecht (1999), \textit{The Los Angeles River: Its life, death, and possible rebirth.}
\bibitem{ladwp} “Metropolitan Water District of Southern California,” LADWP, retrieved November 20, 2012, from
\url{https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-water/a-w-sourcesofsupply/a-w-sos-
metropolitanwaterdistrictofsoutherncalifornia?_adf.ctrl-state=3n5v9z49d_4&_afrLoop=780241014500000.}
\bibitem{villaraigosa} City of Los Angeles Department of Water and Power (2008), \textit{Securing L.A.’s water supply: City of Los
Angeles water supply action plan} by Mayor A.R. Villaraigosa.
\bibitem{villegas} Rafael Villegas, personal communication, November 4, 2012
\bibitem{sklar} A. Sklar (2008), \textit{Brown acres: An intimate history of the Los Angeles sewers.}
\end{thebibliography}
problems. Early city engineers such as Robert Lecouvreur and Fred Eaton had the foresight not to create a combined sewer and storm system (like Portland’s), due to the unpredictability of rainfall in the area, which would easily and frequently overwhelm such a system.141

By 1887, Los Angeles had its first comprehensive sewer system to collect and divert sewage out of the city. However, debates continued about creating a sewer outfall (where the collected sewage discharges) and treatment of the sewage. Sewage initially flowed into the Los Angeles River, but pollution concerns led engineers (Fred Eaton in particular) to advocate for an outfall into the ocean. In 1892, a new sewer outfall was approved and constructed to discharge the city’s sewage into the Pacific Ocean. After several episodes of deterioration, rebuilding, overflows, and expansion of the sewer system, the California State Board of Health visited a sewer outfall at Hyperion in 1913 and announced that conditions needed to be improved. Plans began to build a treatment plant, which began with a screening plant built in 1924. Since then the plant has expanded capacity and increased treatment significantly, but pollution of the beaches and ocean continues to plague the city as demand for sewage treatment grows, overwhelming treatment capacity, and occasional leaks or spills are not always rapidly fixed.142

Flooding became more of a concern as the city expanded and impervious area increased. Impervious surfaces cause stormwater to accumulate and run-off into nearby surface waters, as opposed to native soils, which are adapted to infiltrate rainwater.143 Hardening the surface could intensify floods, too: the great flood in 1914 left 177 people

141 Ibid.
142 Ibid.
dead,\textsuperscript{144} and caused immense property damage, making flood control a high priority in the City and leading to a plan to control the rivers in Los Angeles. The Los Angeles County Flood Control District (LACFCD) was established to implement these plans. As plans to manage flooding began to unfold, the problem was often viewed as an engineering project only, rather than acknowledging the human and political aspects. New engineering solutions could not keep up with the pace of development, which continued augmenting the stormwater flow into the rivers, exacerbating the flooding problem.\textsuperscript{145}

As floods became more costly, the Army Corps of Engineers became heavily involved in flood control in Los Angeles. The Army Corps of Engineers is a federal agency responsible for maintaining infrastructure around the country, and became involved in flood control in the beginning of the 20\textsuperscript{th} century.\textsuperscript{146} In the 1930s, they commenced the channelization of the Los Angeles River, containing the rivers banks and bottom in concrete.\textsuperscript{147} In addition to the channelization project, they developed a 1,500-mile underground drainage system with over 30,000 catch basins and 100 miles of open channels.\textsuperscript{148} This system dramatically lowered the frequency and intensity of flooding; however, the city still experienced a disastrous flood in 1938, and smaller ones in 1952, 1954, and 1956, along with unexpected flooding from a moderate storm in 1980. These

\textsuperscript{144} Green, 2007
\textsuperscript{148} “History”
floods demonstrated that dangerous stormwaters continued to be an unresolved problem for the City of Los Angeles.\footnote{Orsi, 2005}

While the city struggled with sewage and flood control, the water quality of the Los Angeles River deteriorated from stormwater inputs. The EPA started regulating water quality in 1972 with the Clean Water Act. As an offshoot of that act, the National Pollution Discharge Elimination System (NPDES) permit program was established in 1987 to regulate pollutant discharges into waterways and address nonpoint source pollution. The County of Los Angeles, which includes the City of Los Angeles and 83 other incorporated cities, was issued its first NPDES municipal stormwater permit in 1990 by the California Regional Water Quality Control Board, which imposed a set of standards on the stormwater management in the region. The Department of Public Works became involved in the establishment of the City of Los Angeles’ stormwater program, while the Watershed Protection Division was responsible for stormwater pollution abatement projects and programs. In 1996, California passed the Porter-Cologne Water Quality Act mandating water quality standards for both surface and groundwater. The state therefore had to develop and implement Total Maximum Daily Loads (TMDLs) for bodies of water.\footnote{“History”} A TMDL is “the amount of a specific pollutant—such as trash, bacteria or pesticides—that is allowed in specific water bodies like rivers, creeks, lakes or the ocean.”\footnote{“Total Maximum Daily Loads (TMDLs),” City of Los Angeles Stormwater Program, retrieved November 4, 2012, from http://www.lastormwater.org/about-us/npdes-municipal-permit/total-maximum-daily-loads-tmdls/}

These permits and laws governing pollution led to the creation of a stormwater ordinance in 1998 by the City of Los Angeles prohibiting illicit discharges (disposals into
the drainage system without a permit) into the storm drainage system; it also gave the city legal authority to enforce the standards required for the NPDES permit. Thus businesses or anyone cited for discharging wastewater into the storm drainage system would face legal penalties. In 2001, the Los Angeles Regional Water Quality Control Board adopted a municipal stormwater permit, which included requirements for enforcing TMDLs, making the issue more enforceable. To fund the necessary infrastructure changes, voters passed a bond measure in 2004 that provides $500 million toward improvements addressing the regulatory requirements of the Clean Water Act.\textsuperscript{152}

Throughout this period stormwater was viewed as a hazard rather than a resource. However, water supply concerns eventually brought stormwater to the forefront as a potential resource for recharging groundwater supply in the region’s aquifers. Even with spreading basins already constructed at the foothills of the mountains to capture stormwater and recharge groundwater, an estimated 180,000 acre-feet per year still flowed to the ocean, so the city began to consider ways of capturing this water onsite within city limits.\textsuperscript{153} In 2011, the City of Los Angeles passed a Low Impact Development (LID) ordinance that serves as an amendment to the 1998 stormwater ordinance and requires new and re-development projects to capture water at the source using best management practices (BMPs) and thus mitigate runoff on site.\textsuperscript{154} Similar to the way it was defined in Portland, Low Impact Development (on a wider scale known as green infrastructure) for Los Angeles is an approach to stormwater management for capturing

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{152} “History”
\item \textsuperscript{153} Council for Watershed Health (2012), \textit{Stormwater recharge feasibility and pilot project development study: Final report.}
\item \textsuperscript{154} “History”
\end{itemize}
\end{footnotesize}
rain at the site it falls and infiltrating it into the groundwater. The ordinance became effective in May 2012. As a result, pilot green street projects (streets retrofitted with vegetated facilities as well as other green infrastructure) are now being constructed to incorporate a Green Street program into Los Angeles urban infrastructure design. A Green Street program, already initiated by the City Board of Public Works, would institutionalize low impact development for Los Angeles streets.

**Current Policies**

This brief history of Los Angeles’ stormwater management reveals that the city faces three main concerns in managing water: mitigating pollution, preventing floods, and increasing local water supply. Low Impact Development (LID) addresses all three of these concerns to varying degrees and specific departments and bureaus in the city address each of these concerns as well. Therefore the attempt to integrate green infrastructure into the city has required the development of interdepartmental or cross-bureau agencies, as well as communication and cooperation between bureaus. For example, the Los Angeles Department of Water and Power (LADWP) is primarily focused on water supply, enacting various water conservation measures. Part of their recent work has been in developing stormwater capture measures, such as maximizing efficiency of spreading basins in the washes flowing out of the foothills of the mountains. These spreading basins allow infiltration of stormwater from the mountains back into the

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155 Council for Watershed Health, 2012
158 United States Environmental Protection Agency, 2011
groundwater basins. In addition to this work, which yields the greatest stormwater capture per cost, they are also working with other departments and non-profit organizations on smaller LID projects in the city that are multi-benefit, although they are less effective in stormwater capture than the larger spreading basins.159

To address the pollution impact of stormwater, the 1998 stormwater ordinance (L.A.M.C. 64.70) focuses primarily on the entry of illicit discharges into the municipal storm drainage system, and therefore targets serious offenders,160 not city infrastructure in general. As part of this ordinance, inspectors regularly conduct stormwater inspections at local businesses to ensure compliance with regulations.

In 2000, the State Water Resources Control Board adopted the Standard Urban Stormwater Mitigation Plan (SUSMP) as part of the municipal stormwater program. It addresses stormwater pollution from new developments and redevelopment projects by requiring stormwater mitigation as part of the design of development projects.161 This moves away from targeting only point-source pollution and particular polluting businesses to address the city infrastructure as a whole and the impact of nonpoint source pollution on river water quality.

LID became prominent enough to be introduced into regulations in Los Angeles in 2011, with the adoption of the LID ordinance as an amendment to the stormwater ordinance. By adopting this ordinance, Los Angeles became a leader in promoting low impact development.162 The LID ordinance essentially expands on the SUSMP,

159 Rafael Villegas, personal communication, November 4, 2012
162 United States Environmental Protection Agency, 2011
introducing an on-site mitigation requirement for new developments and redevelopments. The ordinance lays out a priority order for managing stormwater onsite as “infiltration, evapotranspiration, capture and use, treated through high removal efficiency biofiltration/biotreatment system of all of the runoff on site”. It also states that onsite stormwater management has to account for all stormwater from a typical storm. Runoff that is filtered onsite is not required to also be infiltrated onsite.

For actual guidelines of how to achieve onsite mitigation, the LID ordinance directs developers to follow guidelines in the Development Best Management Practices (BMP) Handbook. Developers of less than one acre are expected to comply with the BMP Handbook, while developers of more than one acre or greater than 50% impervious surface alteration on larger projects are expected to comply with the LID ordinance (develop an LID plan and capture stormwater to the maximize extent feasible) as well as with the BMP Handbook. The BMP handbook defines LID as “a stormwater management strategy that seeks to mitigate the impacts of increases in runoff and stormwater pollution as close to its source as possible”. The BMP handbook stresses the importance of maintenance to ensure proper operation, effectiveness, and efficiency of BMPs, and requires developers to sign a maintenance form.

Not all sites are suitable for LID facilities, so the ordinance contains a clause for sites and/or projects in which it is not feasible to implement LIDs (for reasons of soil

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164 Ibid.
165 Ibid.
infiltration capacities, space, budget, etc.). For such projects, stormwater management must instead comply with the SUSMP.

It is important to note that the LID ordinance contains no mention of incorporating green infrastructure into current infrastructure, unlike Portland’s Stormwater Management Plan. While new construction is an important target, the majority of stormwater runoff is in fact coming from already existing buildings and streets, and thus this LID ordinance will take a long time to affect the majority of Los Angeles.

As part of expanding the LID ordinance, Los Angeles is now taking steps toward developing a Green Street Program with similarities to Portland’s program. The program was developed by the Board of Public Works and utilizes the streets of Los Angeles for capturing, filtering, and infiltrating runoff to prevent pollution and recharge groundwater. The program is in its pilot phase and as of 2012 has not yet been integrated into the City’s infrastructure programs and construction standards; however, that is the eventual goal.167 A pilot project was recently completed on Riverdale Avenue in August 2010, following up on pilot projects that had previously been built on Oros Street and Elmer Avenue.168

Rafael Villegas of the Los Angeles Department of Water and Power (LADWP) stated that creating regulations for existing streets is cost prohibitive, and therefore the city usually only incorporates new policies for new and redevelopment. Over time, existing streets and infrastructure will have to be redeveloped in some way (street widening, etc), and during these renovations, once there is regulation for new

167 Chau, 2009
development, green infrastructure would be put in. In that way, the entire city could gradually be converted to green infrastructure\textsuperscript{169} but the time frame will be longer than that adopted in Portland.

**Design Criteria for Infiltration BMPs**

The BMP handbook outlines design criteria for infiltration BMPs, the highest priority of the possible LID facilities. Infiltration BMPs are expected to:

- Be designed and constructed to promote uniform ponding and infiltration
- Have a sediment forebay or separate pretreatment unit located between the inlet and infiltration BMP when necessary
- Have the bottom of the bed be native soil and over-excavated (excavated beyond the level of construction) at least one foot
- Have maximum drawdown time be 48 hours determined by the hydraulic conductivity of the subsurface layers
- Ensure overflow is safely conveyed to an acceptable discharge point
- Provide an observation well for underground facilities
- Be vegetated with drought and flood resistant plants native to California, when possible
- Utilize soils with higher hydraulic conductivity than the underlying soil that do not restrict performance requirements.
- Be inspected frequently to ensure ponding infiltrates within time intended by the design.

\textsuperscript{169} Rafael Villegas, personal communication, November 4, 2012
• Include inspections of the pretreatment sediment removal BMP or forebay, and remove sediments exceeding 50% of forebay storage capacity.
• Be maintained to prevent clogging by removing accumulation of debris/sediment
• Maintain vegetation when necessary for aesthetic and filtration capabilities of site.\textsuperscript{170}

Prior to the development of the BMP handbook, the Council for Watershed Health, an organization dedicated to the protection of the Los Angeles and San Gabriel Rivers Watershed, partnered with the City to develop a Stormwater Recharge Feasibility study, which outlined several catchment areas appropriate for stormwater recharge. Choosing an effective location for implementing Best Management Practices is important in the overall benefit derived from the facility. For this study, catchments identified as candidates for projects had to be able to infiltrate stormwater to recharge potable aquifers, and needed sufficient recharge potential to make the project worthwhile. They additionally highlight that technical and field investigations are necessary prior to BMP implementation at a particular site to verify suitability. Suitability of a site involves “large, relatively flat areas that can be hindered by obstructions both above and below ground.”\textsuperscript{171}

\textsuperscript{170} City of Los Angeles, 2011, \textit{Development BMP handbook}
\textsuperscript{171} Council for Watershed Health, 2012
Chapter 5

CASE STUDY: Elmer Avenue Green Street

LID work in Los Angeles has been largely motivated by the efforts of non-profit organizations aiming to improve the quality of rivers and streams. These organizations then go on to collaborate with the city on larger infrastructure projects, such as green streets. One such example is the Elmer Avenue Green Street in Sun Valley, a project that was spearheaded by the Council for Watershed Health in collaboration with several other organizations, including the city.172

Council for Watershed Health

The Council for Watershed Health (the Council) was formed in 1996 (as the Los Angeles & San Gabriel Rivers Watershed Council) to serve as an organized cooperative effort for protecting the Los Angeles and San Gabriel Rivers Watershed.173 The mission statement of the Council is “to facilitate an inclusive consensus process to enhance the economic, social, and ecological health of the region's watersheds through education, research, and planning.”174 They work toward an ideal vision of the future that they

172 Funding for Elmer Avenue was provided by grants and agreements from the U.S. Department of Interior Bureau of Reclamation and California Department of Water Resources (Prop 50). Additional funding and match support was provided by Los Angeles City Bureau of Sanitation, Los Angeles City Bureau of Street Services, Los Angeles City Bureau of Street Lighting, Los Angeles Department of Water and Power, Los Angeles County Department of Public Works, Metropolitan Water District of Southern California, Pomona College, Santa Monica Environmental Programs Division, TreePeople, University of California Riverside, Water Replenishment District of Southern California (personal communication, Mike Antos, December 5, 2012).
outline on their website in which flood protection and water conservation are integrated, and Southern California provides the majority of its own water. Water quality, native landscaping and habitat restorations, and healthy rivers are also parts of this vision for the future.\footnote{175}{“A Vision for the Future: Circa 2025,” Council for Watershed Health, retrieved November 10, 2012, from http://www.watershedhealth.org/thecouncil/visionstatement.aspx.}

Research is prioritized at the Council, as is evident by the mission statement, as a mechanism for promoting watershed health with innovative techniques. They conduct a large portion of the important watershed research and analysis in the region. LID projects fall under this category. To encourage development of LIDs, the Council conducted the Water Augmentation Study, which demonstrated that there was “no significant degradation of groundwater quality from the infiltration of stormwater pollutants.”\footnote{176}{Council for Watershed Health (2012), \textit{Stormwater recharge feasibility and pilot project development study: Final report}.} The Council has collaborated with various organizations and city bureaus to construct LID projects around the city, including the Elmer Avenue Green Street, a demonstration project in Sun Valley.\footnote{177}{“Water Augmentation Study: Elmer Avenue Retrofit,” Council for Watershed Health, retrieved November 15, 2012, from http://www.watershedhealth.org/programsandprojects/was.aspx?search=elmer.}
Elmer Avenue Green Street

Elmer Avenue in Sun Valley (Figure 10) was retrofitted in 2009-2010 as a demonstration Green Street by the Council in partnership with several other organizations. It was the first pilot facility and demonstration green street implemented toward developing a Green Street Program in Los Angeles. It includes 21 bioswales, as well as an infiltration gallery, catch basins, drought resistant landscaping, permeable pavers, and solar powered streetlights (Figure 11).^{178}

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Figure 11. Plan for the Elmer Avenue Green Street Project. Blue arrows indicate the location of swales from which soil was sampled for this study (Image courtesy of the Council for Watershed Health, used with permission).
The Elmer Avenue Green Street was constructed to mitigate flooding problems as the street received runoff stormwater from 40 acres of residential land use.\textsuperscript{179} It was also intended to mitigate water quality impacts of stormwater, which includes pollutants such as heavy metals, pathogens, pesticides, nutrients, organics, suspended solids, and oxygen-demanding substances.\textsuperscript{180} The retrofit combined individual homeowners re-landscaping along with the street renovation.

The Council regularly monitors the Elmer Avenue Green Street, which is especially important in a pilot project to demonstrate effectiveness and areas of improvement for future streets. Monitoring areas include (but are not limited to) water quality sampling for the infiltration gallery, water capture ability of the permeable pavement and rain barrels, groundwater recharge of the infiltration gallery and bioswales, and soil and plant tissue sampling for the bioswales.\textsuperscript{181} For the purpose of this study I chose to focus on results from soil monitoring in the bioswales. Soil samples were taken from five of the bioswales in 2010 after construction, prior to the onset of the first storm season, and again in 2011, following a storm season. A comparison of the data from these two years can provide a baseline from which to begin identifying pollutants that are present in urban stormwater and that are accumulating in the swale soil. As the Portland study and other previous studies show,\textsuperscript{182} it appears that bioswales are successful in removing pollutants from stormwater. As discussed in the Portland case study, this pollutant removal suggests a potential for accumulation of these pollutants in the soil,

\textsuperscript{179} The Los Angeles and San Gabriel Rivers Watershed Council (2010), Elmer avenue neighborhood retrofit project, \textit{Water augmentation study}.

\textsuperscript{180} United States Environmental Protection Agency (1983), \textit{Results of the nationwide urban runoff program: Volume I – Final report} (WH-554).

\textsuperscript{181} Los Angeles and San Gabriel Rivers Watershed Council (2010), \textit{Elmer Avenue 2010-2011 Monitoring Plan}.

which could have implications for long-term use of the bioswales; thus, an understanding of this potential accumulation is crucial for continued bioswale use.

**Methods**

*Soil sampling methods at Elmer Avenue*

Soil sampling was done by a team at the Council for Watershed Health. Five swales were sampled in Elmer Avenue in 2010 and 2011. Swales were selected from both sides of the street at random locations along the street. Five sub-samples from each swale were taken from the inlet to the outlet at each of the following points: inlet, halfway from inlet to middle, middle, halfway from middle to outlet, and outlet. Before sampling, rocks were cleared until the geotextile (a permeable fabric used in bioswale construction) was located, and samples were taken 10-12 cm below the geotextile. Samples were collected using a 1” diameter LaMotte soil sampling tube. The five sub-samples were composited and homogenized and shipped on ice to Weck Laboratories, City of Industry, CA for analysis. A list of constituents analyzed can be found in Appendix B.

*Data analysis methods*

To analyze the changes in pollutant concentration in bioswale soils, I obtained the data from the Council for Watershed Health for the Elmer Avenue Green Street bioswales. Data from soil in 2010 (prior to any storm events) were compared to data from 2011 (after a storm season). Particular attention was paid to constituents of concern in urban stormwater such as the metals antimony, arsenic, cadmium, chromium, cobalt,
copper, lead, mercury, molybdenum, nickel, silver, vanadium, and zinc. The difference in concentration of these metals prior to and following storm events was calculated, as well as percent change for every aforementioned contaminant. Data were compared for each bioswale to compare differences due to the location of the swale and other factors.

Results

The raw data for all measured contaminants of concern can be found in Appendix B, and data for metals expected in stormwater (cadmium, chromium, copper, lead, nickel and zinc) are shown in Table 3. The concentrations of these select metals in the swale soils were compared between 2010 and 2011.

The data show a significant difference between concentration of metals in the swale soils on the east side of the street (even-numbered) and the west side of the street (odd-numbered) (p=0.00138 < 0.05). Odd-numbered swales showed a decrease in contaminant concentrations from 2010 to 2011, while even numbered swales showed an increase. Note that of the even numbered swales, 7732 had the smallest positive percent change (as well as a negative change for chromium), suggesting smaller loadings.

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### Table 3. Summary of results for the 5 bioswales samples

<table>
<thead>
<tr>
<th>Metal</th>
<th>7711</th>
<th>7747</th>
<th>7712</th>
<th>7732</th>
<th>7752</th>
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<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2011</td>
<td>%Δ</td>
<td>2010</td>
<td>2011</td>
</tr>
<tr>
<td>Cadmium</td>
<td>ppm¹</td>
<td>ppm</td>
<td>%Δ²</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td>0.62</td>
<td>0</td>
<td>-100</td>
<td>0.6</td>
<td>0</td>
</tr>
<tr>
<td>Chromium</td>
<td>14</td>
<td>8.7</td>
<td>-38</td>
<td>12</td>
<td>8.1</td>
</tr>
<tr>
<td>Copper</td>
<td>19</td>
<td>12</td>
<td>-37</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Lead</td>
<td>17</td>
<td>9.6</td>
<td>-44</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td>Nickel</td>
<td>7.3</td>
<td>4.7</td>
<td>-36</td>
<td>7.5</td>
<td>6.9</td>
</tr>
<tr>
<td>Zinc</td>
<td>62</td>
<td>45</td>
<td>-27</td>
<td>57</td>
<td>54</td>
</tr>
</tbody>
</table>

¹ Measured in mg/kg
² 2010 value was subtracted from the 2011 value
ND=no data available
*A concentration of 0 indicates the concentration was below detection limits.
**Water Quality Data**

Water samples were taken in 2010 and 2011 during storm events to determine the level of pollutants in stormwater flows on the street (Table 4). These data represent two single storm events for each storm season, and were collected at different times in the season. Typically, early season storms carry more pollutants that are accumulated over the dry summer months in Southern California than late season storms.\(^{184}\) The value in the data shown is the concentration and types of metals present in run-off from the 40-acre watershed upstream.

**Table 4. Water quality data**

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>2010 Value (ug/L)(^1)</th>
<th>2011 Value (ug/L)(^2)</th>
<th>Δ</th>
<th>%Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony, Total</td>
<td>5.15</td>
<td>2.7</td>
<td>-2.45</td>
<td>-90.7</td>
</tr>
<tr>
<td>Arsenic, Total</td>
<td>4.88</td>
<td>1.48</td>
<td>-3.4</td>
<td>-230</td>
</tr>
<tr>
<td>Barium, Total</td>
<td>183</td>
<td>83.5</td>
<td>-99.5</td>
<td>-119</td>
</tr>
<tr>
<td>Cadmium, Total</td>
<td>2.08</td>
<td>1.07</td>
<td>-1.01</td>
<td>-94.4</td>
</tr>
<tr>
<td>Chromium, Total</td>
<td>22.1</td>
<td>14.1</td>
<td>-8.0</td>
<td>-56.7</td>
</tr>
<tr>
<td>Cobalt, Total</td>
<td>5.28</td>
<td>1.77</td>
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<tr>
<td>Zinc, Total</td>
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<td>146</td>
<td>-208</td>
<td>-142</td>
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</tbody>
</table>

\(^1\)Samples collected on 12/18/10 from curbside prior to water entering catch basin
\(^2\)Samples collected on 2/16/11 from curbside

Discussion

Performance

Due to the grade of the street, the stormwater flow is generally restricted to the east side of the street, so western swales may not have received any water during the storm events. This observation helps to explain the difference between the eastern and western swales (Figure 12).

![Figure 12. Comparison of west side (left) and east side (right) bioswales during a storm. The pictures clearly show that significantly more water is entering the east side swale than the west side (Photo credit: Kristy Morris, Council for Watershed Health).](image)

Since the flow of water is only on one side of the street during a typical storm event, the results imply that the swales are in fact performing their function. In bioswales that are receiving water, pollutant concentrations are increasing, confirming that the soil is absorbing pollutants and implying that these pollutants are not entering the groundwater. The swales receiving little or no water provide an interesting comparison as they show that pollutant concentrations can even decrease without the addition of stormwater. This suggests that the plants and other biological processes in the swale soils
are functioning to remove the metals, which is an important area of study for future projects.

The presence of swales on the side of the street not receiving as much stormwater is an important point in regard to effectiveness of the Green Street and the importance of design. Pilot projects are helpful to acquire this kind of information and encourage significant forethought for future projects.

_Danger of accumulation?_

The results indicate that accumulation could be taking place. Accumulation of pollutants in the swales could eventually rise above toxicity limits and become a danger to plants, animals, or any person in contact with the soil. Continued monitoring is important to determine whether pollutants could reach dangerous levels. Another concern is leaching of pollutants into the groundwater at higher concentrations. Leaching can happen when the soil is oversaturated and can no longer absorb the contaminants it is receiving. Studies have shown that high heavy metal loading in soil can lead to leaching and therefore increased concentrations of metals in groundwater.\(^{185}\) Depending on conditions, the concentration of metals in the soil that may lead to leaching is very variable, and while there is no indication yet that this is a concern at Elmer, it remains a potential threat.

It may also be valuable to examine the effect of vegetation in removing pollutants from the soil. Some vegetation can remediate heavy metals and nutrients in the soil to prevent them from accumulating, however rates for this remediation are not known.

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Further studies on this topic would provide an important basis for continuing to analyze long-term sustainability of bioswales.

**Conclusion**

Bioswales provide an efficient and natural solution to stormwater management issues. As this new technology is being further developed and implemented around Los Angeles County, it is important to continue monitoring efforts to understand performance and long-term sustainability. Maintenance and monitoring are both necessary for bioswales to continue performing at their full capacity, and for the community to understand what that capacity is.
Chapter 6

CONCLUSIONS

Policy Development

The history and development of current stormwater policies of Portland, OR and Los Angeles, CA are considerably different, but have resulted in the adoption of Low Impact Development (LID) policies and the implementation of a sizable amount of green infrastructure. However, Portland has emerged as a leader in managing stormwater, often cited as the best example,\(^\text{186}\) while the public still holds a fairly negative perception of Los Angeles in its ability to manage stormwater. The question, then, is why has Portland been so effective? What has held Los Angeles back? What is the future of stormwater management in these two cities?

To begin exploring the ways these cities have arrived at their respective current stormwater policies, it is important to consider motivations for stormwater management in each city. Portland is primarily interested in preventing river pollution and CSOs, as well as somewhat in flood control.\(^\text{187}\) Los Angeles, meanwhile, is focused on flood prevention, stormwater capture (to replenish groundwater), and pollution prevention.\(^\text{188}\) Both are largely pushed to action by the federal requirements, primarily the NPDES permit requirements for nonpoint source pollution.

By examining these motivations, one would think that Los Angeles would be more invested in developing green infrastructure since it has more to gain from it.

\(^{186}\) United States Environmental Protection Agency (2010), *Green infrastructure case studies: Municipal policies for managing stormwater with green infrastructure* (EPA-841-F-10-004).


\(^{188}\) United States Environmental Protection Agency (2011), Region 9: Los Angeles, California, in *Green infrastructure program community partner profiles: 2011 partners* (EPA 832N12009).
However, the pollution problem in Portland was more extreme and time sensitive because of the CSO problem and the lawsuit surrounding it, leading to earlier action than in Los Angeles, with the CSO abatement plan underway by 1991\textsuperscript{189} and investigation into sustainable alternatives by 2001.\textsuperscript{190} In addition, because Portland is not as interested in groundwater recharge and most of the drinking water comes from large reservoirs outside the city, the potential for pollution of the groundwater by infiltration of stormwater has not been as central of a concern. The lack of importance of groundwater and urgency of the pollution problem in the Willamette River probably allowed Portland to be able to begin constructing bioswales and other infiltration devices before conclusive research about the impacts on groundwater supplies was completed. Los Angeles, by contrast, relies heavily on its groundwater supply, and could not risk potential contamination to this resource. Therefore, research likely needed to be at a more advanced stage and have demonstrated that infiltration facilities do not contaminate groundwater before they could be constructed.

For the rate of adoption of LID facilities throughout the city, one of the crucial distinctions between the two cities is their treatment of current infrastructure. Los Angeles is heavily focused on implementing green infrastructure standards for new development and redevelopment.\textsuperscript{191} There appear to be no requirements for retrofitting existing infrastructure. Portland, while much of the work is on standards for new and redevelopment, additionally emphasizes controlling stormwater from existing

infrastructure through retrofits, found primarily in their Structural Controls BMP of the Stormwater Management Plan.\footnote{City of Portland, Oregon (2011), \textit{Stormwater Management Plan: National pollutant discharge elimination system (NPDES) municipal separate storm sewer system (MS4) discharge permit} (Permit number: 101314).} The effect of this policy is evident in the extensive number of bioswales and other green infrastructure currently in Portland, while Los Angeles is still primarily limited to pilot studies and minimal facilities.

Funding is essential to implement all of these stormwater management projects. Portland’s stormwater utility fee has been fundamental in allowing Portland to be so progressive and effective in implementing LID infrastructure. The adoption of this fee in 1977\footnote{“Portland, Oregon: Building a Nationally Recognized Program Through Innovation and Research”} likely created the mechanism for the city to build up funds for larger infrastructure changes and to adjust the fee as needed based on new standards and pollution prevention measures. Los Angeles does not have the same kind of stormwater fee (although one is now being proposed)\footnote{C. Jao (2012, November 29), Property Owners To Pay for Urban Runoff Clean-up? \textit{KCET}, retrieved December 3, 2012, from http://www.kcet.org/socal/departures/lariver/confluence/river-notes/property-owners-to-pay-for-urban-runoff-clean-up.html.}, and the city had to issue bonds to pay for any large construction projects. While Portland may have also needed bonds (detailed funding sources for the project are unknown), the established fee likely made the need to issue bonds smaller, whereas Los Angeles had to pay for the majority of the construction costs with bonds, which always have to be voted on and approved by the public. The need for bonds limits effectiveness of construction and strains the budget in Los Angeles for implementing stormwater projects, and has been a serious concern for planning construction of new green infrastructure projects.

The establishment and commitment of an institution to develop and further stormwater infrastructure is crucial to the success of a program. The commitment of
Portland’s Bureau of Environmental Services to stormwater management has allowed for the development and enforcement of policies and programs.\textsuperscript{195} Los Angeles has also established several committees and departments to specifically handle stormwater regulation. For example, the Department of Public Works as well as the Watershed Protection Division contributed significantly to stormwater regulation and enforcement.\textsuperscript{196}

Another difference between Portland and Los Angeles is the involvement of the county in stormwater management decisions. In Portland’s case, the state seems to have issued the NPDES permits and set some standards but the majority of the work has been done on the city level. The city internalized these standards, developed some of its own, and established a stormwater management plan and set of regulations. The story of Los Angeles appears to be more complicated, as the County of Los Angeles actually obtained a NPDES permit before the city did,\textsuperscript{197} beginning to implement standards and a plan that affected the city but was not as locally relevant as the plan established once the city was directly involved. The involvement of the county could perhaps be a reason for Los Angeles obtaining a NPDES permit later than Portland, since some of the standards were already being upheld by the county’s permit so the need was not as pressing.

Despite dramatic differences in climate, hydrology, city government and policies, Portland and Los Angeles have clearly settled on green infrastructure as the future of stormwater management. Los Angeles is now also starting to be seen as national

\textsuperscript{195} City of Portland, Oregon, 2011
\textsuperscript{197} Ibid.
leader, although it is still has considerably less green infrastructure than Portland.

Progress is not limited just to these cities; all around the country, cities are developing LID ordinances, building bioswales and other LID facilities, and treating their stormwater as a resource. What has caused this shift to a watershed management approach over the old “out of sight, out of mind” mentality?

One explanation is the EPA’s endorsement of green infrastructure in 2007. Many cities are working to comply with EPA regulations for the Clean Water Act, and green infrastructure is becoming a more acceptable way of doing so. Cities adopting LID have likely caused the EPA to begin to accept it as an approach, while the EPA’s adoption is also spurring growth in other cities. The pattern is difficult to track down in any particular location, but it seems clear that this has had a significant impact. As of 2010, the EPA was developing a Green Infrastructure Action Strategy to make inclusion of green infrastructure fit into the regulatory framework of the CWA and NPDES permit program, incentivizing cities to adopt these policies. The increased amount of research demonstrating effectiveness of these facilities is also encouraging their implementation and validating their use around the country in a variety of climates.

**Bioswale Effectiveness**

The case studies presented in this thesis imply an overall effectiveness of bioswales. The water quality study and the soil analysis show that bioswales are effectively filtering out heavy metals, which has positive implications for the quality of the groundwater that these bioswales are frequently recharging. Other studies support this

198 United States Environmental Protection Agency, 2011
199 United States Environmental Protection Agency, 2010
conclusion,\textsuperscript{200} and there appears to be no significant evidence showing any water quality harm caused by bioswales.

Future studies to confirm pollutant removal effectiveness could be more robust in sample size and consistency of sampling procedure to eliminate sources of error. Environmental monitoring inherently contains a multitude of variables, so it is especially important to have sufficient samples to control for whichever of these variables possible. Controlled laboratory experiments testing soil filtration capacities would also benefit this research.

Another important area of future research is the effect of vegetation on pollutant retention and removal. There is a need to understand which plant species best filter out pollutants from stormwater, which pollutants plants can mitigate, the effect of these pollutants on the health of the vegetation, and any potential accumulation of pollutants in the plants. Developing this knowledge could facilitate an introduction of bioswale designs that are more effective at pollutant retention and are a sustainable model for the long-term.

**Implications for the Future and Next Steps**

In terms of long-term sustainability of bioswales, the main concern is an accumulation of pollutants in the soil. So far, there has been no evidence indicating that this is occurring at toxic levels; however, no long-term studies have been conducted. A study I conducted in collaboration with Portland State University and the City of Portland in the summer of 2011 in Portland measured concentrations of heavy metals in soils of

bioswales of various ages, but no significant trends were found, likely due to variation in other variables. When compared to toxicity standards, none of these soils were toxic.

However, the Los Angeles case study demonstrates that flow of polluted stormwater through the bioswale causes soil heavy metal concentrations to increase. Since it was only a one-year study, no significant conclusions can be drawn for long-term accumulation, but this result provides grounds for continued research.

Due to the measured effectiveness of bioswales, as well as other LID facilities, continued expansion of these technologies and methodologies is encouraged. LID is the design tool of the future; by considering stormwater a resource rather than a disposable waste, we can begin to restore the natural ecosystem balances and use a watershed management approach to address the various water issues arising in cities. LID is a multi-benefit system addressing several of a city’s concerns by improving water quality, reducing flooding risks, enhancing green space and creating jobs. By critically evaluating the design of these facilities, we can maximize efficiency and perhaps find a design strategy that can be sustainable in the long-term. With increased understanding of effects of design components, cities can further specialize to maximize benefits for particular locations.

As more cities adopt LID as a design approach, case-study evidence can be accumulated to determine the ideal design for any given climate. For example, the EPA has already published a Green Infrastructure Case Studies report, comparing policies of 12 cities implementing green infrastructure and how their policies are designed to

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accommodate and encourage it. An expansion of such a work into the design elements and effectiveness of specific facilities used can be useful for furthering the program.

Cities are rapidly adopting policy requiring on-site stormwater mitigation for new development and redevelopment projects, generally encouraging green infrastructure as an approach to accomplish such mitigation. Projects can be found around the U.S., primarily in big cities but also in some smaller suburbs. The health of our waterways, the beauty of our cities, and the replenishment of our groundwaters have much to gain from this widespread adoption.
Glossary and Abbreviations used

**Best Management Practice (BMP):** stormwater pollution control method that prevents pollution and/or is a treatment facility (such as a grassy swale) that removes pollutants from water.

**Bioswale:** A vegetated facility located on a natural grade intended for stormwater infiltration.

**Clean Water Act (CWA):** Federal water quality regulation passed in 1972 and amended in 1987 that regulates discharges to waterways with the goal of providing swimmable, fishable waterways.

**Combined Sewer Overflow (CSO):** Overflow of the combined sewer system (sewage and stormwater collected together) during heavy rains, resulting in raw sewage spilling into the river.

**Council for Watershed Health (the Council):** A non-profit organization established to coordinate efforts for protection of the Los Angeles and San Gabriel Rivers Watershed.

**Department of Environmental Quality (DEQ):** A state regulatory department established to protect the quality of the environment, in charge of issuing NPDES permits to municipalities.

**Gray infrastructure:** Conventional stormwater management via pipes and drains, primarily concrete.

**Green infrastructure:** An alternative to the conventional method, a “comprehensive approach to water quality protection defined by a range of natural and built systems that can occur at the regional, community, and site scales”\(^{202}\)

**Low Impact Development (LID):** Site-level green infrastructure that “restores the natural hydrologic character of a development site”\(^{203}\) and infiltrates runoff on site.

**Metropolitan Water District of Southern California (MWD):** Consortium of 26 cities that provides “a supplemental supply of water for domestic and municipal uses to its member agencies.”\(^{204}\)

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\(^{204}\) “Metropolitan Water District of Southern California” LADWP, retrieved November 20, 2012, from https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-water/a-w-sourcesofsupply/a-w-sos-metropolitanwaterdistrictofsoutherncalifornia?_adf.ctrl-state=3n5v9z49d_4&_afrLoop=780241014500000.
**Municipal Separate Storm Sewer System (MS4):** Conventional storm drainage system, separate from sewer, that collects urban stormwater and funnels it toward waterways.

**National Pollution Discharge Elimination System (NPDES):** Permitting program developed as part of the Clean Water Act that regulates illicit discharges from waterways. Cities must obtain an NPDES permit for the nonpoint source pollution from their municipal stormwater systems.

**Nonpoint source pollution:** Pollution not discharged from a particular source but rather occurring from a variety of diffuse sources, such as stormwater runoff.205

**Northwest Environmental Advocates (NWEA):** Non-profit environmental advocacy group that brought charges against Portland for violating the Clean Water Act.

**Portland Bureau of Environmental Services (BES):** Portland Bureau primarily responsible for developing and implementing the stormwater management program.

**Stormwater:** Rainwater that accumulates on impervious surfaces.

**Stormwater Management Plan (SWMP):** Portland’s stormwater management strategy developed to comply with the NPDES permit.

**Stormwater Policy Advisory Committee (SPAC):** Committee created by Portland to decide on the best approach for requiring BMPs and responsible for writing the Stormwater Management Manual.

**Standard Urban Stormwater Management Plan (SUSMP):** Management plan adopted by Los Angeles that addresses stormwater pollution from new developments and redevelopment projects by requiring stormwater mitigation as part of the design of development projects.

**Total Maximum Daily Load (TMDL):** A limit set for “the amount of a specific pollutant—such as trash, bacteria or pesticides—that is allowed in specific water bodies like rivers, creeks, lakes or the ocean.”206

REFERENCES


http://www.usace.army.mil/About/History/BriefHistoryoftheCorps/Introduction.aspx


Appendix A: Graphs from Portland Water Quality Study

Time vs. Concentration: Total Metals

SW Barbur & Sheridan

Barbur & Sheridan Cd total concentration vs. time

Barbur and Sheridan Cu concentration vs. time

Barbur & Sheridan Cr total concentration vs. time

Barbur and Sheridan Ni total concentration vs. time

Barbur and Sheridan Pb total concentration vs. time

Barbur and Sheridan Zn total concentration vs. time
NW 16th & Everett

**16th & Everett Cd total concentration vs. time**

**16th & Everett Cu total concentration vs. time**

**16th & Everett Cr total concentration vs. time**

**16th & Everett Ni total concentration vs. time**

**16th & Everett Pb total concentration vs. time**

**16th & Everett Zn total concentration vs. time**
NE 28th & Glisan

**28th & Glisan Cd total concentration vs. time**

**28th & Glisan Cu total concentration vs. time**

**28th & Glisan Cr total concentration vs. time**

**28th & Glisan Ni total concentration vs. time**

**28th & Glisan Pb total concentration vs. time**

**28th & Glisan Zn total concentration vs. time**
Time vs. Concentration: Dissolved metals

SW Barbur & Sheridan
Other metals omitted because of insufficient data (concentrations below detection limits).
NW 16th & Everett

16th & Everett Cd dissolved concentration vs. time

16th & Everett Cu dissolved concentration vs. time

16th & Everett Cr dissolved concentration vs. time

16th & Everett dissolved Ni concentration vs. time

16th & Everett Pb dissolved concentration vs. time

16th & Everett Zn dissolved concentration vs. time
NE 28th & Glisan

28th & Glisan Cd dissolved concentration vs. time

28th & Glisan Cu dissolved concentration vs. time

28th & Glisan Cr dissolved concentration vs. time

28th & Glisan Ni dissolved concentration vs. time

28th & Glisan Pb dissolved concentration vs. time

28th & Glisan Zn dissolved concentration vs. time
Flow rate vs. Concentration: Total metals

SW Barbur & Sheridan

Barbur & Sheridan Cd concentration vs. flow rate start to peak

Barbur & Sheridan Cr concentration vs. flow rate start to peak

Barbur & Sheridan Cu concentration vs. flow rate start to peak

Barbur & Sheridan Cd concentration vs. flow rate peak to end

Barbur & Sheridan Cr concentration vs. flow rate peak to end

Barbur & Sheridan Cu concentration vs. flow rate peak to end

Barbur & Sheridan Ni concentration vs. flow rate start to peak

Barbur & Sheridan Pb concentration vs. flow rate start to peak

Barbur & Sheridan Zn concentration vs. flow rate start to peak

Barbur & Sheridan Ni concentration vs. flow rate peak to end

Barbur & Sheridan Pb concentration vs. flow rate peak to end

Barbur & Sheridan Zn concentration vs. flow rate peak to end
NW 16th & Everett
(Only inlet samples shown because no flow rate could be measured for the outlet)
NE 28<sup>th</sup> & Glisan
(Start to peak and peak to end not split because of pattern of storm, not straight to a peak flow)
Flow rate vs. Concentration: Dissolved metals

SW Barbur & Sheridan
Other metals omitted because of insufficient data (concentrations below detection limits).
NW 16th & Everett
(Only inlet samples shown because no flow rate could be measured for the outlet)
NE 28th & Glisan
(Start to peak and peak to end not split because of pattern of storm, not straight to a peak)
### Appendix B: Data from Elmer Avenue Case Study

Constituents analyzed in soil samples

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<th>Component</th>
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</thead>
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<td>N-Nitrosodi-n-propylamine</td>
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<td>N-Nitrosodimethylamine</td>
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<td>Chloride, Water Leachable</td>
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<td>Chemical Structure</td>
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<td>Dibenzofuran</td>
<td>Simazine</td>
</tr>
<tr>
<td>4-Bromophenyl phenyl ether</td>
<td>Dibromochloromethane</td>
<td>Sodium, Total</td>
</tr>
<tr>
<td>4-Chloro-3-methylphenol</td>
<td>Dibromofluoromethane</td>
<td>Specific Conductance (EC)</td>
</tr>
<tr>
<td>4-Chloroaniline</td>
<td>Dibromomethane</td>
<td>Strontium, Total</td>
</tr>
<tr>
<td>4-Chlorophenyl phenyl ether</td>
<td>Dichlorodifluoromethane (Freon 12)</td>
<td>Styrene</td>
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<tr>
<td>4-Chlorotoluene</td>
<td>Diethyl phthalate</td>
<td>Sulfate as S, Water Leachable</td>
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<tr>
<td>4-Methyl-2-pentanone</td>
<td>Dimethoate</td>
<td>Terbacil</td>
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<tr>
<td>4-Nitroaniline</td>
<td>Dimethyl phthalate</td>
<td>Terphenyl-dl4</td>
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<tr>
<td>4-Nitrophenol</td>
<td>Diphenamid</td>
<td>tert-Butylbenzene</td>
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<tr>
<td>4,6-Dinitro-2-methylphenol</td>
<td>Disulfoton</td>
<td>Tetrachloroethene</td>
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<tr>
<td>Acenaphthene</td>
<td>E. coli</td>
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<td>Thiobencarb</td>
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<tr>
<td>Acetone</td>
<td>Ethylbenzene</td>
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<td>Acrolein</td>
<td>Fecal Coliform</td>
<td>Titanium, Total</td>
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<td>Fluoranthene</td>
<td>Toluene</td>
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<tr>
<td>Alachlor</td>
<td>Fluorene</td>
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<tr>
<td>Alkalinity as CaCO3</td>
<td>Fluoride, Water Leachable</td>
<td>Total Coliform</td>
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<tr>
<td>Aluminum, Total</td>
<td>Hexachlorobenzene</td>
<td>trans-1,2-Dichloroethene</td>
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<tr>
<td>Aniline</td>
<td>Hexachlorobutadiene</td>
<td>trans-1,3-Dichloropropene</td>
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<td>Anthracene</td>
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<td>Hexachlorocyclopentadiene</td>
<td>Trichlorofluoromethane</td>
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<tr>
<td>Arsenic, Total</td>
<td>Hexachloroethane</td>
<td>Triphenyl phosphate</td>
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<td>Atrazine</td>
<td>Hydroxide Alkalinity as CaCO3</td>
<td>Vanadium, Total</td>
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<td>Indeno (1,2,3-cd) pyrene</td>
<td>Vinyl chloride</td>
</tr>
<tr>
<td>Barium, Total</td>
<td>Iron, Total</td>
<td>Zinc, Total</td>
</tr>
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<tr>
<td>Zinc</td>
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<td>45</td>
</tr>
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</table>

1 Measured in mg/kg
2 2010 value was subtracted from the 2011 value
*A concentration of 0 indicates the concentration was below detection limits.