ECONOMIC APPROACHES TO MANAGING STORMWATER RUNOFF IN THE SEATTLE AREA

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Abstract

Economic Approaches to Managing Stormwater Runoff in the Seattle Area

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This thesis evaluates the use of best management practices (BMPs) as cost effective tools for reducing the incidence of combined sewer overflows (CSOs) in the Ballard CSO basin. I estimated the cost of detaining stormwater runoff in the Ballard CSO basin through BMPs. This study also evaluated three separate stormwater management programs that incentivized the adoption of BMPs. A full stormwater capture program, a tradable allowance program, and a BMP credit program were simulated to estimate total cost. The full stormwater capture program used a quantity instrument to require all parcels to detain stormwater on-site. The tradable allowance program also used a quantity instrument, but gave parcel owners the option to detain runoff on-site or to purchase stormwater allowances. The BMP credit program utilized a price instrument to charge parcel owners for runoff. Parcel owners were given the option to waive the fee if they allowed the city to build BMPs on their property. The findings indicate BMPs have a lower average cost of managing stormwater runoff than traditional centralized infrastructure. All three scenarios also generated lower total costs than a centralized infrastructure approach. The simulation determined a tradable allowance program generated the lowest total costs, however

difficulties in implementation of the program limited the viability of the program. The analysis determined the BMP credit program to be a more viable option. This program provided relatively low total costs and promoted BMP adoption in the Ballard CSO basin. The thesis also identified how Seattle's current drainage fee may be unfairly charging parcels for runoff. I recommend a stormwater management program that offers a BMP credit to parcels utilizing stormwater runoff technologies and increased drainage fee transparency.

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1 Introduction

The city of Seattle is located in the Pacific Northwest of the United States, the largest city in the state of Washington. The Seattle area experiences roughly 152 days of rain, occurring predominately in the months between October and May.[1] The city of Seattle through Seattle Public Utilities (SPU) manages rainfall by collecting stormwater and diverting the runoff into a network of drainage pipes. The city's sewer system network utilizes a separated and combined sewer network. The separated system collects stormwater and directly channels runoff into the surrounding water bodies, while the combined system collects stormwater runoff and wastewater from surrounding buildings into the same sewer pipes and conveys it to water treatment facilities. The combined sewer system treats stormwater and sewage before releasing it into the surrounding water bodies. The combined sewer system encounters problems during large storm events when large amounts of stormwater runoff enter the combined sewer system. This causes the conveyance capacity of the sewer system is overrun, causing a combined sewer overflow (CSO) event that releases untreated sewage and stormwater into neighboring water bodies.[2]

The city of Seattle can approach the CSO issue through two primary methods: Stormwater overflows can be avoided by either increasing the capacity of stormwater infrastructure (non-source point pollution control) or by decreasing stormwater runoff entering the system (source point pollution control). The first method of increasing capacity of the current system involves either increasing the physical size of the conveyance system or increasing the

[1] National Oceanic and Atmospheric Administrtion. "1981-2010 Data." *NOAA Online Weather Data.* http://nowdata.rcc-acis.org/ (accessed February 20, 2013).
[2] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

treatment capacity of the combined system. Increasing conveyance capacity could involve additional storage tanks to temporarily store additional stormwater or increasing the physical size of the sewer pipes. Increasing treatment capacity would involve upgrades to current processing facilities or the construction of additional facilities. These solutions require large investments in infrastructure and are very capital intensive.[3] The second method is to reduce the amount of water entering the combined sewer system by diverting runoff, slowing runoff, or altering the landscape to reduce runoff. Stormwater runoff can be diverted prior to entering the combined system and sent into the separated system. Stormwater runoff can also be slowed down and reduced through the use of best management practices (BMPs), allowing runoff to either be naturally absorbed into the ground or delayed from entering the combined sewer system. Diagram 1 outlines the processes involved in stormwater management through infrastructure and BMPs. Delaying the flow of stormwater runoff reduces peak flows and allows for a more gradual flow of runoff into system, while reducing runoff reduces the amount of water entering the system. This prevents the system from over flowing, reducing the occurrence of CSOs. BMPs include the use of rain gardens, infiltration strips, porous surfaces, retention ponds, and other practices that promote the containment and absorption of stormwater runoff.[4]

The city of Seattle pays for stormwater infrastructure through a stormwater drainage fee and wastewater sewer charge. The drainage fee is linked to property taxes as a user fee and is typically based on the size of the parcel. The fee charge considers impervious surface coverage rates for large residential, commercial, and industrial parcels. Large residential, commercial, and industrial parcels can lower rates through the implementation of low impact development

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[3] Thurston, Hale W., Goddard, Haynes C., Szlag, David, Lemberg, Beth. "Controlling Storm-Water Runoff with Tradable Allowances for Impervious Surfaces." *Journal of Water Resources Planning and Management*, September/October 2003: 409-418.
[4] Hinman, Curtis, Wulkan, Bruce. *Low Impact Development: Technical Guidance Manual for Puget Sound.* Manual, Washington State University Extension, Puget Sound Partnership, Puget Sound Partnership, 2012, 1-365.

techniques.[5] The wastewater fee is charged as part of the utility bills to customers. Each customer is charge a fee based on the amount of potable water used. These two sources of funding are used to pay for stormwater infrastructure in the city of Seattle.

1.1 Research Question

This study attempts to find alternative management programs for stormwater runoff in the Seattle area. CSO events are common in many areas of the city where combined sewer systems exist. The goal of this research is to answer two questions:

1. Are source point stormwater control methods such as BMPs more cost effective than centralized infrastructure?
2. If so, how can management programs create incentives for the widespread adoption of source point control such as BMPs?

This thesis quantifies the cost of implementing source-point control of stormwater in the Seattle area. My research examines the use of dispersed small-scale source point stormwater runoff control methods, known as BMPs, to manage stormwater runoff. I also explore the potential effects of altering the method used to assign responsibility for stormwater runoff to parcels. SPU currently uses a user fee system to charge parcel owners to pay for large-scale infrastructure projects to manage stormwater.

My research quantified the costs of BMPs and compared the overall costs to centralized infrastructure. My research also explored how the structure of responsibility for stormwater runoff may affect the adoption of stormwater BMPs. I proposed three alternative scenarios; full stormwater capture, a tradable allowance, and a stormwater BMP credit program and assigned responsibility to parcel owners through quantity and price instruments. Each scenario resulted in

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[5] Seattle Public Utilities. "Sewer Rates." *Sewer (Wastewater) Rates.* City of Seattle. 2013. http://www.seattle.gov/util/MyServices/DrainageSewer/SewerRates/index.htm (accessed April 24, 2014).

cost allocations that suggest various possible levels of adoption of BMPs with varying total costs to both parcel owners and SPU. Each of the scenarios demonstrates how reductions in stormwater runoff could be achieved at lower total costs.

1.2 Research Design

The research is broken down into six chapters, the introduction, literature review, methodology, results, discussion, and conclusion. The literature review examines the theories, empirical research, and literature of practice used in stormwater management. My methodology outlines how the research was conducted. The results outline my calculations and findings of the research. The discussion reviews assumptions and limitations of my research and discusses the results in the context of the Ballard CSO basin. The conclusion reviews work conducted and offers suggestions for applying the findings to the Ballard CSO basin.

1.2.1 Research Breakdown

My research examined the Ballard CSO basin where a large number of CSO events occurred. I began by evaluating the basin to simulate runoff totals and appropriate BMPs to manage the runoff. I then calculated the costs of the BMPs and implemented three scenarios for managing stormwater runoff. Total reduction in stormwater and costs were calculated in each scenario.

The first portion of my research gathered runoff and BMP information for the CSO basin. I used Geographic Information System (GIS) mapping data and BMP cost estimating tools. The mapping data allowed me to gather detailed parcel information for the entire area. I began by determining the overall number and types of parcels in the CSO basin. Average parcels for each type were used to simulate runoff and BMP adoption for the entire area. The average parcels were examined in detail to determine impervious surface coverage. With the impervious surface coverage, I calculated runoff and assigned BMPs to manage the runoff. To estimate how much water each parcel would manage was estimated using a one-year storm event. BMPs were based on the building footprint and the types of impervious surfaces on each parcel, I assigned the total costs for implementing BMPs on each parcel type. These calculations for each parcel type were used to extrapolate totals for the entire Ballard CSO basin.

The second part of my study simulated three separate stormwater management program scenarios in the Ballard CSO basin. The first scenario involved a full capture of stormwater runoff on parcels. Each parcel was assigned a runoff figure and estimated to fully detain this amount of runoff through the use of BMPs. The second scenario involved a tradable allowance program. Each parcel was again assigned a runoff figure and BMPs to either manage all runoff or purchase allowances equivalent to their runoff. The third scenario simulated a BMP credit program. Each parcel was assigned a runoff fee based on the current schedule. A parcel could then implement a BMP to detain runoff and have their runoff fee waived. The paper estimated the reduction in stormwater runoff and the total costs of the program.

1.3 Seattle Background

Since 1968 the city of Seattle has been working towards reducing CSO events. Initial investments were made into separating combined sewer systems, by rerouting right of way drainage. Later efforts have focused on creating facilities to store stormwater during large events. The city invested $524 million from 1968 to 2009, with $385 on separating the combined sewer system, $134 million on storage, and $5 million on retrofits. In total, the city has reduced the incidence of CSO events from an average of 2,000 events per year to 200 events in 2008. This is a reduction from 400 million gallons per year to less than 100 million gallons of overflow a year.

In 2007, the city replaced monitoring devices at outfalls to dramatically improve data on CSO events.[6]

Between the years 2006 and 2010, the Ballard CSO basin outfalls 150,151, and 152 averaged 44 overflow events a year. The same outfalls deposited roughly 17 million gallons of combined stormwater and wastewater into Salmon Bay. Table 1 details the occurrences of overflow events at the 3 outfalls located in the Ballard CSO basin, while table 2 details the volume of the overflow events.

Table 1 Number of Overflow Events[7]

Outfall Number	2006	2007	2008	2009	2010	Total	Avg
150/151	29	10	2	22	29	92	18.4
152	13	11	11	29	63	127	25.4
Totals	42	21	13	51	92	219	43.8

Table 2 Overflow Volume in Gallons[8]

Outfall Number	2006	2007	2008	2009	2010	Total	Avg
150/151	4,285,061	2,704,949	62,108	3,168,871	2,848,612	13,069,601	2,613,920
152	1,387,719	8,319,136	364,243	20,546,673	40,356,610	70,974,381	14,194,876
Totals	5,672,780	11,024,085	426,351	23,715,544	43,205,222	84,043,982	16,808,796

The city of Seattle created the CSO reduction plan in 2010 to reduce CSO events over the next five years. The city's CSO plan is focused on optimizing current infrastructure through the implementation of low cost retrofits, construction of large scale infrastructure projects, construction of green infrastructure, and the creation of a long term plan to control CSO events in the future. The plan calls for the reduction of CSO incidents in Seattle neighborhoods through a combination of these approaches.[9]

[6] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.
[7] Ibid
[8] Ibid
[9] Ibid

The city has created two separate alternative programs to help reduce CSO events, the CSO Retrofit and Residential Rainwise programs. The CSO retrofit program invests up to $2 million annually to reduce CSO volume by optimizing the performance of existing infrastructure. This includes maximizing the collection system's storage and flow to wastewater treatment facilities. The Rainwise program focuses on encouraging residents reduce runoff coming off their property. This program promotes the adoption of small scale solutions such as rain gardens, cisterns, rooftop drain disconnects, and other green stormwater techniques. The Rainwise program also created a website providing residents with information and tips on reducing stormwater runoff.[10]

To manage long-term reductions of CSO events the city has identified a combination of green stormwater infrastructure projects and storage facilities in the Ballard CSO basin. Green stormwater infrastructure projects for the area comprise mostly of rain gardens, cisterns, permeable pavements, and rooftop disconnects. The storage tanks are either on-line or off-line from the combined sewer system. The long-term plan calls for roughly 2 million gallons to be divided amongst the green stormwater infrastructure and storage facilities at an estimated cost of $32 million over the next 10 years. $20.6 million of that is estimated to be required for the storage facilities.[11]

The city collects revenue to fund capital expenditures through SPU's wastewater and drainage bills. To fund the $162 million in CSO related investments in the capital improvement projects (CIP), the city will be forced to increase rates paid by customers. On average, household bills will face a monthly increase of $4.75 from 2010 to 2015. As of 2010, the average monthly bill is roughly $63.87. Total spending for the city's CSO improvements in 2010 were expected to

[10] Ibid
[11] Ibid

be $19 million, with roughly 82% coming from wastewater bill and 18% coming from the drainage bill. By 2015, expenditures are expected to rise to $31 million, with roughly 45% coming from wastewater bills and 55% coming from the drainage fee.[12]

Revenue for stormwater management is collected through the wastewater bill and stormwater runoff fee. Wastewater is tied directly tied to the amount of potable water used, while drainage rates are collected as part of the property tax. As of 2014, the wastewater fee is $11.75 per hundred cubic feet (CCF) of water, with the average household using 4.3 CCF per month.[13] Drainage rates for single-family residential customers are divided into 4 sizing groups, with rates ranging from $180.96 a year to $403.70 based on parcel size. Large residential, commercial, and industrial parcels are charged rates based on impervious surface coverage and low impact development practices. Each parcel is charged anywhere from $25.71 per 1,000 square feet for undeveloped land to $91.65 per 1,000 square feet for heavily developed areas. Heavy development refers to properties with large impervious surface coverage, roughly 86% to 100% impervious coverage. Appendix 1 outlines the stormwater drainage charges for the various zones.[14]

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[12] Ibid

[13] Seattle Public Utilities. "Sewer Rates." *Sewer (Wastewater) Rates.* City of Seattle. 2013. http://www.seattle.gov/util/MyServices/DrainageSewer/SewerRates/index.htm (accessed April 24, 2014).

[14] Seattle Public Utilities. "Drainage Rates Schedule." *Drainage Rates.* City of Seattle. http://www.seattle.gov/util/MyServices/Rates/DrainageRates/RateSchedule/index.htm (accessed April 24, 2014).

2 Literature Review

The literature review is in three sections. The first reviews the economic theories used to address environmental issues such as stormwater runoff and resulting combined sewer overflow (CSO) events. The second discusses empirical research in the connection between impervious surface coverage and runoff, the use of best management practices (BMPs) to reduce runoff, and policy tools used to manage urban stormwater runoff. The final discusses the literature of practice, or existing programs and reports in stormwater runoff management. The literature review is used as the foundation for the research in the following sections of my thesis.

2.1 Theory

The economic theories explored in my thesis deal with how pollution is an externality; a social cost incurred by the public. Pollution of stormwater runoff often becomes a tragedy of commons and the production of pollution is evidence of a market failure.

Adam Smith's *Wealth of Nations* asserts individual gains would lead to the betterment of society.[15] However, these ideas fail to account for the inevitable costs of those actions. The use of resources to produce a good inevitably leads to a depletion of resources. This poses a social cost that is often not internalized in the decision making process.[16] The pollution causes an externality that poses a social cost. The externality of stormwater runoff is not internalized by the private costs of development. The total social cost is the sum of the private costs and

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[15] Smith, Adam. *An Inquiry Into the Nature and Causes of the Wealth of Nations* . Edited by ed. Edwin Cannan. London: Methuen & Co., Ltd., 1904.
[16] Hardin, Garrett. "The Tragedy of the Commons." *Science* 162, no. 3859 (December 1968): 1243-1248.

externalities.[17] With increased population and development, costs of the individual actions become collective problems to society as a whole. To preserve public goods such as air and water, mechanisms to limit the discharge the pollutants must be used. Private property rights inherently promote the overuse of resources, and favor pollution. Pollution can be controlled though the use of mechanisms that prohibit or limit the actions creating these problems.[18] In the Ballard CSO basin, the development of the urban environment has lead to the overproduction of the externality of stormwater runoff. The excess runoff causes CSO events, leading to overflow events that dump raw sewage into Salmon Bay. The emission of untreated raw sewage creates a tragedy of the commons that poses an environmental and public health cost to the public.

Pigou's *Economic of Welfare* asserts that if producers of pollution do not internalize cost of the negative externalities, it will be over produced.[19] If parties responsible compensate the affected parties, an efficient level of output can be produced, thus internalizing the cost of the externality. Pollution is often used as an example of this phenomenon. Mechanisms that internalizes cost, assigning them to polluters and compensating those affected by the pollution, are seen as ways to limit the effect of the externality.[20]

Coase's "The Problem of Social Cost" contends that internalizing the cost to producers may not lead to the most efficient outcome. With no transaction costs, negotiation between two parties will reach to a mutually beneficial level of output. In the real world transaction costs often prevent parties from efficiently negotiating this optimal level of output. Government intervention can reduce social costs by reassigning property rights or by placing financial responsibility to parties responsible. Limiting or taxing producers of externalities may be

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[17] Thompson, Stephen. "Reduction of Urban Runoff Through Economic Incentives: Boulder, Colorado." *Water Rersources Bulletin* (American Water Resources Association) 18, no. 1 (February 1982).
[18] Hardin, Garrett. "The Tragedy of the Commons." *Science* 162, no. 3859 (December 1968): 1243-1248.
[19] Pigou, Arthur C. *The Economics of Welfare.* London: Macmillan and Co., 1932.
[20] Coase, R.H. "The Problem of Social Cost." *Journal of Law and Economics* 3 (Oct. 1960): 1-44.

desirable if the social product is maximized under this arrangement. However, placing the burden of an externality on those responsible may not necessarily maximize social product. The action of limiting parties from producing an externality may impose a greater social cost than the externality itself. When considering alternative polices, the total cost of preventing the harm must be compared to the total benefits of preventing the harm. This should be conducted by comparing the total social product of alternative social arrangements. The premise is to create a practical system that corrects externalities without causing harm in other areas. When instituting a policy change, policy makers should attempt to determine if the change would in total be better or worse than the original.[21]

These economic theories explain that legal rules and regulations are justified in reducing the effects of stormwater runoff. The social costs of pollution are increasingly evident with the occurrences of CSO events. Assigning responsibility of pollution to the emitters are attempts to internalize those costs to production. These changes alter behavior and create incentives to behave in a more socially desirable manner. Seattle currently imposes a tax in the form of a drainage fee to parcel owners. Alternative forms of management that internalize the costs of stormwater runoff can lead to a beneficial outcome for the entire city of Seattle.

Regulatory approaches such as command and control techniques are often used to limit pollutants. Command and control mechanisms require either the prohibition of pollutants, or the use of specific technologies or behaviors to reduce pollutants. Economic incentive approaches provide more flexible options to manage pollutants.[22]

The uses of taxes are commonly used to achieve environmental goals. The pigouvian tax acts as a price signal to the firm to internalize some of the cost of the externality and reduce the

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[21] Ibid
[22] Tietenberg, Tom H. "Economic Instruments for Environmental Regulation." In *Economics of the Environment*, edited by Robert Stavins, 279-301. New York, NY: W. W. Norton & Company, 2005.

output to account for the externality. A price for the tax is established on the pollutants and may lead to a reduction in the output of the pollutant. This leads to a more desirable output, as more efficient levels of development and pollution are produced. Also, compensation from the tax revenue can be used to offset the negative effects of pollution. Regulating agencies must have complete information on the market and establish an accurate price on the externality.[23]

Emission trading programs can reduce overall costs by allowing those with high costs to pay those with low costs to reduce pollution to an acceptable level. The emission trading theory sets a cap on overall levels of pollution and assigns credits for these emissions. The credits are then released into the market, where firms are then given the option to either purchase credits or eliminate the externality.[24] Different firms on the market typically have varying costs in managing an externality. These differences in costs make certain firms more efficient in reducing the externality. If firms are cost minimizers and experience low transaction costs, an emission-trading program can lower the overall level of pollution. Firms with lower marginal costs for reducing pollution are able to reduce pollution at lower costs than firms with higher marginal costs are able to pay others to reduce pollution.[25] In effect, the high marginal cost firms are paying low marginal cost firms to reduce pollution for them. Firms become price setters instead of price takers, removing the burden on the governing entity to determine accurate price information.[26]

The use of taxes and emission trading programs to manage an externality such as stormwater runoff can reduce overall cost to society. In establishing a program, the decision

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[23] Ibid
[24] Ibid
[25] Thurston, Hale W., Goddard, Haynes C., Szlag, David, Lemberg, Beth. "Controlling Storm-Water Runoff with Tradable Allowances for Impervious Surfaces." *Journal of Water Resources Planning and Management*, September/October 2003: 409-418.
[26] Tietenberg, Tom H. "Economic Instruments for Environmental Regulation." In *Economics of the Environment*, edited by Robert Stavins, 279-301. New York, NY: W. W. Norton & Company, 2005.

making process must regard the technical, economic, financial, legal, and political feasibility of the program. The program must consider if the technology is available to meet the stated goals. The economic feasibility balances the benefits and costs to determine if the program is viable. Financial constraints can ruin a program, as capital must be available to implement and run the program. The legal authority to implement the program must also exist. Finally, the program must have the political backing to be sustainable.[27] These considerations must be taken into account as they can create high transaction costs and prevent a program from being successful.

2.2 Empirical Research

The empirical research reviews the existing research on managing stormwater runoff. I examine the link between impervious surfaces and runoff, runoff management strategies through the use of best management practices (BMPs), and runoff reducing incentive programs.

2.2.1 Runoff

Stormwater runoff is a product of increased impervious surface coverage associated with urban development. Extensive research has been conducted linking the increased impervious surface coverage and population growth.[28] This impervious surface coverage is further linked to increased runoff from smaller storm events. Problems associated stormwater runoff include degraded stream banks, reduced stream base flows, increased pollution, and where sewer networks are combined with waste water, combined sewer overflows.[29]

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[27] Ostrom, Vincent, Ostrom, Elinor. "Legal and Political Conditions of Water Resource Development." *Land Economics* 48, no. 1 (Feb. 1972): 1-14.
[28] Shuster, W. D., Bonta, J., Thurston, H., Warnemuende, E., Smith, D. R. "Impacts of Impervious Surface on Watershed Hydrology: A Review." *Urban Water Journal* 2, no. 4 (December 2005): 263-275.
[29] Roy, Allison H., Shuster, William D. "Assessing Impervious Surface Connectivity and Applications for Watershed Managment." *Journal of the American Water Resources Association* (American Water Resources Association), February 2009: 198-209.

In Shuster's 2005 article "Impacts of Impervious Surface on Watershed Hydrology" evaluated the relationship between development, the resulting imperviousness, and stormwater runoff.[30] The paper reviewed literature and studies examining the link between growth and runoff. Many previous papers have found a positive correlation between population growth and impervious surface coverage. Population growth leads to increased development that increases impervious surface coverage. There is a strong link between impervious surface coverage and runoff. The measure of total impervious area (TIA), or the impervious surface coverage ratio, is used to determine the imperviousness of a region. Higher TIAs hydraulically connected to drainage systems have a significant impact on stormwater runoff. Connected impervious areas reduce hydrologic recharge and natural stream flows, requiring additional need for stormwater infrastructure to manage runoff. [31]

The increased impervious surface coverage associated with the built environment has lead to increased runoff and peak flows during storm events. The lack of natural infiltration and drainage in urban areas increases the volume and velocity of runoff. Mitigating the effects of runoff is achieved by large centralized infrastructure, dispersed small-scale BMPs, or a combination of the two.[32] Large scale centralized infrastructure includes treatment plants, sewer piping and networks, as well as large sewage tunnels and storage tanks. BMPs include drainage basins, culverts, detention ponds, cisterns, rain barrels, porous pavement and other natural processes that allow dispersed infiltration of stormwater into the ground.

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[30] Shuster, W. D., Bonta, J., Thurston, H., Warnemuende, E., Smith, D. R. "Impacts of Impervious Surface on Watershed Hydrology: A Review." *Urban Water Journal* 2, no. 4 (December 2005): 263-275.
[31] Ibid
[32] Thurston, Hale W., Goddard, Haynes C., Szlag, David, Lemberg, Beth. "Controlling Storm-Water Runoff with Tradable Allowances for Impervious Surfaces." *Journal of Water Resources Planning and Management*, September/October 2003: 409-418.

2.2.2 Runoff Management

The most common method to control stormwater in municipalities is through non-point source control. Sewer drains are used to collect runoff from the built environment and channeled through a network of sewage pipes. In many cities the collected stormwater runoff is combined with wastewater from surrounding buildings and sent to a treatment facility. The stormwater and wastewater is then treated before being released into surrounding water bodies. However, many of the municipalities with combined sewer systems often encounter CSO events during periods of heavy rainfall. The stormwater combined with sewage overruns the sewer's capacity and releases the untreated mixture at outfalls. Municipalities often lack alternative methods to control stormwater runoff and are often left with options that are very costly and capital-intensive.

Stormwater BMPs have been established over the course of many years. The Environmental Protection Agency (EPA) has created a list of practices and techniques used to manage and control the amount and quality of stormwater runoff.[33] Stormwater BMPs can refer to a variety of structural controls for stormwater runoff. Federal standards for managing stormwater runoff have evaluated and researched appropriate techniques and measures to manage pollution from stormwater runoff. The EPA created a list of structural BMPs considered effective in managing stormwater runoff. These structural BMPs have been research and evaluated as effective forms of managing stormwater runoff. The list of BMPs has evolved over the years as new research and techniques are added to the list of what is considered a BMP.[34]

BMPs are an alternative to the centralized management of stormwater. BMPs are used to control source point runoff through natural infiltration and detention processes. BMPs are

[33] Environmental Protection Agency. *Stormwater BMP List.* http://www.epa.gov/nrmrl/wswrd/wq/stormwater/bmp.html (accessed May 23, 2014).
[34] Environmental Protection Agency. *Stormwater Best Managment Practices.* http://www.epa.gov/oaintrnt/stormwater/best_practices.htm#best_practices (accessed May 22, 2014).

incremental investments to alter the urban environment to improve natural hydrological processes to reduce runoff from properties, thus reducing runoff entering the sewer systems. BMPs also provide ecological benefits by increasing groundwater recharge, filtering out pollutants, leading to healthier base stream flows.[35] Incremental investments such as BMPs are lower in total cost and can be a cost effective way to manage stormwater runoff. Property owners have a variety of BMP options to choose from that fit unique characteristics of each site. Each of these BMPs has a unique set of design features with varying capital costs and maintenance requirements.[36]

The use of BMPs can effectively reduce stormwater runoff in post development. Research has shown implementing BMPs such as retention ponds, infiltration trenches, rain gardens, green roofs, and permeable pavements can effectively reduce stormwater runoff. BMPs have been shown to significantly impact runoff during peak flow events. Detaining and withholding stormwater runoff can reduce overall peak flows to the entire watershed. However, the performance of BMPs can be significantly impacted by site characteristics and require site designs.[37]

To assist land owners and municipalities estimate costs for implementing BMPs, the Water Environment Research Foundation (WERF) and the EPA released a cost estimating spreadsheet tool. The spreadsheet tool provides whole lifecycle cost estimates for stormwater BMPs, including retention ponds, swales, detention basins, permeable pavements, green roofs,

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[35] Battiata, Joseph, Collins, Kelly, Hirschman, David, Hoffman, Greg. "The Runoff Reduction Model." *Journal of Contemporary Water Reseach & Education* (Universities Council on Water Resrouces), no. 146 (December 2010): 11-21.

[36] Thurston, Hale W., Goddard, Haynes C., Szlag, David, Lemberg, Beth. "Controlling Storm-Water Runoff with Tradable Allowances for Impervious Surfaces." *Journal of Water Resources Planning and Management*, September/October 2003: 409-418.

[37] Battiata, Joseph, Collins, Kelly, Hirschman, David, Hoffman, Greg. "The Runoff Reduction Model." *Journal of Contemporary Water Reseach & Education* (Universities Council on Water Resrouces), no. 146 (December 2010): 11-21.

curb-contained bioretention, residential rain gardens, cisterns, and in-curb planter vaults. The spreadsheet offers capital costs for planning and implementing the BMP, along with long term operation and maintenance costs. Each BMP tool allows users to either enter site-specific information or to use predetermined defaults for each BMP. These include the size and drainage area of the site, the level of maintenance, the use of professional installation and engineering, or the use of certain materials. The tool also provides an extensive list of anticipated capital cost items, expected maintenance, and other expenses. The spreadsheet also allows for users to input appropriate discount rates when evaluating the lifecycle cost of the project.[38] The tool's intent is to allow users to share information on cost estimates and provide a reliable planning cost estimates. There is currently little information available on the costs of BMPs as they are often new technologies. Many private firms withhold cost estimations, while some municipalities have shared cost information with other agencies.[39]

The cost estimating spreadsheet uses previously published information on cost estimates as well as information from engineering firms. Cost estimates are based on these public and professional cost information. The number of sources of information is dependent on the BMPs. The WERF estimating tool has undergone some improvements from the first iteration and have incorporated more BMPs into their toolbox. Although the cost information may be limited by the lack of sources, it is a tool planners can use to help estimate the costs of implementing stormwater control BMPs. The tools provided by the cost estimator can be useful in helping

[38] Water Environment Research Foundation. "User's Guide to the BMP and LID Whole Life Cost Models Version 2.0." Manual, Water Environment Research Foundation, 2009, 1-32.
[39] Houdeshel, C. Dasch, Pomeroy, Christine A., Hair, Lisa, Moeller, Jeff. "Cost-Estimating Tools for Low-Impact Development Best Management Practices: Challenges, Limitations, and Implications." *Journal of Irrigation and Drainage Engineering*, March 2011: 183-189.

whether or not BMPs are cost effective tools in lowering the costs of managing stormwater runoff.[40]

2.2.3 Runoff Incentives

There have been numerous papers examining policies employed by municipalities to manage stormwater runoff. In the past, stormwater runoff has typically been ignored. However in recent years pollution from runoff has become a popular topic. Research on the management of stormwater has grown from the inclusion of a simple stormwater fees to a more complex stormwater retention credit programs.

Thompson's "Reduction of Urban Runoff Through Economic Incentives" evaluated stormwater runoff charge as an incentive to reduce stormwater runoff.[41] Stormwater runoff is an externality that has a social cost and in the past has typically been ignored. Development occurs with property owners occupying and "using" land previously uninhabited, leading to runoff. The use of the land often has no cost associated with the externality. A property owner thus only has the costs of development and basic utilities. The paper addresses if the government or a private entity could promote runoff-reducing technologies, and if so should the parties responsible for stormwater runoff pay the full cost to the community.

The study examined a flood control fee issued to property owners in Colorado. The fee is based on average stormwater runoff attributed to development. This is the difference in runoff with and without development. The city calculated the average residential property runoff as roughly 43% of all water falling on the property. The monthly fee was then tied to this calculation for runoff and impervious surface coverage. Property owners received reductions in

[40] Ibid
[41] Thompson, Stephen. "Reduction of Urban Runoff Through Economic Incentives: Boulder, Colorado." *Water Rersources Bulletin* (American Water Resources Association) 18, no. 1 (February 1982).

the runoff fee with the installation of retention technologies. The result of the fee has shown that little post construction installation of retention technologies occurred. The majority of runoff reducing technologies was implemented during planning stages for new construction, with savings going to future property owners.[42]

Parikh's "At the Intersection of Hydrology, Economics and Law" paper evaluated the hydrologic, economic, and legal application of managing stormwater runoff.[43] The paper evaluated the suitability of alternative forms of managing stormwater runoff by examining these three criteria. The hydrologic aspect addresses the effectiveness of the runoff mitigation. The economic aspect evaluates the cost effectiveness of the approach and how runoff is reduced at the lowest cost. Finally, the legal aspect examines the authority of implementing the approach, including constitutional issues, existing laws, jurisdictional issues, and any other legal objections. The paper breaks down runoff reducing policies into price and quantity instruments. Price instruments include stormwater user fee and a runoff charge, while the quantity instruments include a runoff allowance market and voluntary offset programs. Price instruments use a fee or tax to charge property owners runoff coming off their property. Quantity instruments calculate runoff attributed to each property and assign responsibility for runoff to the property. [44]

The stormwater user fee is the traditional method used to manage runoff in many municipalities. The user fee is a universal charge for services that must be fair, equitable, and related to costs associated with a service. User fees often do not produce the desired reduction in runoff and are set too low to induce runoff reducing technologies and practices. The majority of

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[42] Ibid
[43] Parikh, Punam, Taylor, Michael A., Hoagland, Theresa. "At the Intersection fo Hydrology, Economics, and Law: Application of Market Mechanisms and Incentives to Reduce Stromwater Runoff." In *Economic Incentives for Stormwater Control*, edited by Hale W. Thurston, 167-192. Boca Raton, FL: CRC Press Taylor & Francis Group, 2012.
[44] Ibid

time the user fee is directly related to runoff and impervious surface coverage, with credits for reduction in impervious surface coverage. User fees often over generalize runoff calculations, and fail to take into account how the impervious surfaces are connected to the drainage systems.[45]

A stormwater runoff charge is an incentive based charge related to the marginal cost of reducing stormwater runoff. The charge would act as price signal to property owners to alter behavior. The charge would incorporate impervious surface coverage, but also landscape, development, sewer infrastructure, and other drainage factors. From an economic standpoint, the runoff charge is more likely to alter behavior, however may be difficult to accurately price the runoff charge. Legally a user charge may be difficult to implement. Depending on the location, implementing a fee must be proven to reflect the cost of service. Justifying the charge or rate could face strong legal opposition.[46]

As an alternative to price instruments, the paper examined quantity instruments. Quantity instruments provide an alternative to price instruments by establishing an allowance for runoff coming of properties. A desired level of runoff is determined and allowances are allotted to all property owners. Typically the total allowances are set to predevelopment levels of runoff. The paper explores two forms of quantity instruments, a cap and trade allowance market and a voluntary offset program. [47]

The cap and trade allowance market allows property owners to sell off excess allowances to the open market if they are below their allotted runoff amount. The cap and trade program effectively reduces runoff by establishing a set cumulative amount of runoff. It also is economically desirable as it allows those that can cost effectively reduce stormwater to do so,

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[45] Ibid
[46] Ibid
[47] Ibid

while those with high costs are allowed to purchase credits. The market sets the prices of allowances, so the municipalities would not need to set the price for retention credits. Legally speaking however, this program may run into property rights issues by limiting the right of property owners to allow runoff. [48]

A voluntary offset program is a voluntary program where property owners adopting BMPs and other retention technologies are directly compensated. The voluntary program can effectively reduce runoff if incentives to reduce runoff are high enough. Economically speaking, by allowing those with low costs to reduce runoff, it will lower total costs for reducing runoff. Legally speaking, as a voluntary program would face few legal barriers.[49]

This paper discussed potential for runoff reducing programs, as well as the pitfalls of traditional and non-traditional stormwater management programs. In order for a policy program to be effective, it must weigh these three criteria before making a final decision.

Thurston's "Controlling Stormwater Runoff with Tradable Allowances" paper evaluated and quantified a simulated stormwater retention credit swap program in Cincinnati's Mill Creek area.[50] The simulation examined an area both semi-urban and urban areas along the Mill Creek tributary to the Ohio River. The EPA considers Mill Creek to be polluted from a combination of industrial point source pollution and CSOs. The upriver suburban portion of the municipality uses a separated system, while the urban center of Cincinnati uses a combined sewer system. During large storm events the combined sewer system becomes overwhelmed and releases 6.2 billion gallons of untreated water at 233 sewer outfalls located in the city. The city explored various solutions to the problem, including separation of the sewers, installation of large scale

[48] Ibid
[49] Ibid
[50] Thurston, Hale W., Goddard, Haynes C., Szlag, David, Lemberg, Beth. "Controlling Storm-Water Runoff with Tradable Allowances for Impervious Surfaces." *Journal of Water Resources Planning and Management*, September/October 2003: 409-418.

BMPs, and a detention tunnel. The paper hypothesized that small scale BMPs would be more cost effective than large-scale centralized treatment and capture of stormwater runoff. Thurston also hypothesized a tradable allowance market would effectively lower the total costs. This would work if the marginal costs of abatement for parcel owners were significantly lower and the transaction costs would be no greater than the cost savings achieved. [51]

The paper used GIS to evaluate the area parcel by parcel for total land size, percent impervious surface, and soil types. The use of GIS allowed the authors to predict the runoff from each parcel as a function of the physical attributes. To calculate the potential runoff the study used a 1.5-year storm event, the peak rainfall amount from a storm occurring every year and a half, producing 1.23 inches of rain. The runoff was then calculated for the developed and undeveloped sites. The excess runoff attributed to development was then identified as the difference between the two. Each parcel was then assigned this excessive runoff value. Each parcel was assigned a suitable BMP depending on land use and soil types. Construction costs were estimated for each BMP as a function of the abated amount of runoff. Each parcel then had an ID number, land use, soil type, excessive stormwater runoff, and the cost of BMP as a function of the excessive stormwater runoff.[52]

The paper's tradable allowance market promoted the adoption of technologies of least cost at the most efficient size and capacity. Thurston's paper calculated the total cost of implementing various BMP based on the land use and soil type. The total cost of the BMP is defined as the function of abated runoff, where the cost is determined for a set amount of runoff abated. To demonstrate the potential for trading, the paper determined the BMP costs for the same amount of water abated for two land uses with differing soil types. As an example, to abate

[51] Ibid
[52] Ibid

321ft^3 of water, a single family home had a BMP cost of $1,069, while a multifamily residential parcel has a BMP cost of $5,957. The cost to the single family home with a sandy soil type has a much lower abatement cost than the multi family housing unit with a more impermeable soil type. [53]

To determine the potential gains, the paper simulated a market scenario. Each parcel was identified and assigned an appropriate BMP. Residential land uses with sandy soil type were assigned sand filters, while residential parcels with soil more loamy and clay soil types were assumed to use grassy swales. Commercial and multifamily units with sandy soil type were assigned infiltration basins, while commercial and industrial parcels with loamy soil types were assigned infiltration trenches. Public right of ways and publicly owned or operated properties were ignored in the simulation. Each BMP technology was provided with a cost as a function stormwater runoff abated. Each parcel's cost calculations did not include opportunity costs of the land. The simulation also did not determine an equilibrium price. The simulation ran scenarios with differing allowance pricing. Under various allowance cost scenarios, the paper determined what if any trading would occur.[54]

To determine the total costs to each parcel, the study assigned appropriate BMP costs to detain a 1.23-inch storm event. Across all parcels, the average cost of appropriate BMPs came out to $5.40, with an average of 292 ft^3 of runoff detained. To establish the comparison price range, the paper used the proposed storage tunnel under Mill Creek. The proposed tunnel's total cost was determined to be around $600 and $800 million, with costs of $8.93 to $11.90 ft^3. This

[53] Ibid
[54] Ibid

cost did not contain full life cycle costs such as operation and maintenance. All suitable BMPs required costs to be less than the tunnel to be considered more efficient. [55]

To determine potential gains from trading, the paper used stormwater credit cost scenarios of $15, $8, $5, and $2.50. Each parcel identified whether they would purchase stormwater credit or implement BMPs under each scenario. At a cost $5 per ft^3 of stormwater, the amount of stormwater detained would be 99,954ft^3. The average cost of detained stormwater was $4.59 per $sqft^3$. The allowances sold would equate to $114,105. With allowances being $15 and $8, the total storage would yield 119,685 and 118,111 ft^3 respectively at average costs of $5.08 and 4.97 per ft^3. The allowances sold would generate $46,275 and $37,312 respectively. If the price of allowances were set to $2.50, no parcels would invest in BMPs. This would result in no water being detained, but would generate $306,937 for offsite alternative detention. This final scenario is more akin to what occurs with a fee for stormwater runoff. [56]

To demonstrate additional possible gains associated with trading, the paper discussed further investments in BMPs with the fees generated through allowance purchases. The paper determined with $5 allowances, the revenue generated would equate to $114,105. Using this additional income, the utility or city could invest in additional dispersed BMPs or infrastructure to handle the runoff at other locations throughout the city. The paper found an additional detention capacity of 20,432 ft^3 with investments from the sale of allowances. This increased the total detention capacity to 120,386 ft^3. The utility could hypothetically take on the roll of identifying areas suitable for additional detention, and paying those who can detain additional water on their property.

[55] Ibid
[56] Ibid

The Thurston's paper evaluated the possible savings associated with a tradable allowance program. The simulation compared the cost of an investment in large-scale infrastructure to dispersed BMPs. The simulation determined the average cost of detention would be lower under a $5.00, $8.00, and $15.00 allowance-pricing program than traditional command and control methods. Although many assumptions were made, the alternative form of management could potentially provide a cost-effective method of management.[57]

2.3 Literature of Practice

The literature of practice reviews how existing municipalities have addressed stormwater runoff. Many municipalities have addressed stormwater runoff by implementing various tools to mitigate harmful effects of runoff. The most common approach to manage runoff is the use of stormwater fees to pay for infrastructure. Many cities have also promoted the adoption of alternatives to stormwater infrastructure through the use of BMPs. These programs include a retention credit swap program in Washington D.C. and a drainage discount program in Portland.

Many municipalities offer stormwater fee credits with the implementation of stormwater reducing practices. Appendix 2 outlines many of these retention credits offered. The municipalities providing incentives to reduce runoff offer a wide range of credits. These range from 25% to 100% of the stormwater fee for the retention and implementation of runoff reducing technologies. The majority of credits are directed towards commercial and larger multifamily housing properties. These are typically for reducing impervious surface coverage and providing onsite detention in some capacity. [58]

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[57] Ibid

[58] Doll, Lindsey. *Credits Bring Economic Incentives for Onsite Stormwater Management.* Bulletin, Water Envrionment Federation, Watershed & Wet Weather Technical Bulletin, 1999. (L. Thompson 2014)

2.3.1 Washington DC Stormwater Retention Credit

The city of Washington D.C. has approached the stormwater runoff in an innovative fashion. In 2013, Washington D.C.'s District Department of the Environment (DDOE) implemented a new stormwater rule. The new stormwater rule introduces stormwater performance standards and a retention credit swap program. New development and redevelopment projects greater than 5,000 square feet are required to meet performance new standards for stormwater runoff. For new developments, the new standard states that the first 1.2 inches of stormwater be retained on-site or at an off-site location, while redevelopment projects must retain the first 0.8 inches of rain. The retention credit swap program helps to reduce the cost of compliance to the new standards by allowing those with higher costs to pay those with lower costs to retain some of the stormwater runoff.[59]

These new standards are seen as the key to addressing Washington D.C.'s stormwater runoff problems. 43% of the city has impervious surface coverage. A storm depositing 1.2 inches of rain on the impervious surfaces generates about 525 gallons of runoff. The runoff contributes to the increased number of pollutants entering the region's waterways and the degradation of the natural habitat from erosion and other hydrological processes.[60] The city has taken an alternative approach to reduce runoff by promoting flexible on-site detention. The program attempts to increase detention through the implementation of shared BMPs.

The program's stormwater retention credit (SRC) allows for flexibility in onsite retention. The SRC requires at least half of the detention requirements to be on-site, while the other half can be implemented off-site. The property owner is given two options for off-site detention, an in

[59] District Department of the Environment. "Overview of 2013 Stromwater Rule." *2013 Stormwater Management Rule and Guidebook.* District of Columbia. http://ddoe.dc.gov/swregs (accessed December 10, 2013).
[60] District Deparment of the Environment. "Why DC Needs Stormwater Retention." *2013 Stormwater Management Rule and Guidebook.* District of Columbia. 2013. http://ddoe.dc.gov/swregs (accessed December 10, 2013).

lieu fee or a privately traded SRC. The in lieu fee is paid directly to the DDOE at a cost of $3.50 per gallon of runoff per year.[61] The privately traded SRCs are issued by DDOE for a 3-year period to property owners exceeding retention requirements. Properties are eligible to sell SRCs on the market if they exceed the 1.2 or 0.8 inches of required retention. New developments are able to sell up to 0.5 inches of retention credits while redevelopments are able to sell up to 0.8 inches.[62] Each SRC must be sold for at least a year, and up to a total 3 years.[63]

The DDOE's SRC program offers an alternative method to manage stormwater runoff. The program promotes the efficient adoption of runoff reducing technologies for redevelopment and new development projects. Properties with low cost of retaining stormwater are given the option to sell credits if the property goes beyond the requirements. Properties with higher costs are then able to purchase the credits, lowering their compliance costs.

2.3.2 Portland Clean River Rewards Program

In 1977, the city of Portland created a stormwater utility fee to help pay for the cost of managing stormwater runoff. In October of 2006, the City of Portland created the Clean Rivers Rewards program offering a drainage fee discount to residential and commercial properties that managed stormwater on their property. The fee discounts up to 100% of the on-site stormwater charge. The stormwater on-site charge comprises 35% of the overall sewer and drainage bill.[64] The city's sewer and drainage bill covers the sanitary sewer, drainage/ stormwater management, and the Willamette River/ Portland Harbor Superfund charges. The drainage/ stormwater

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[61] District Department of the Environment. "Overview of 2013 Stromwater Rule." *2013 Stormwater Management Rule and Guidebook.* District of Columbia. http://ddoe.dc.gov/swregs (accessed December 10, 2013).
[62] District Department of the Environment. *Stormwater Management Guidebook.* Guidebook, Watershed Protection Division, District Department of the Environment, District of Columbia, 2013, pp 319-322.
[63] District Department of the Environment. "Overview of 2013 Stromwater Rule." *2013 Stormwater Management Rule and Guidebook.* District of Columbia. http://ddoe.dc.gov/swregs (accessed December 10, 2013).
[64] City of Portland Bureau of Environmental Services. *Clean River Rewards Program Overview.* https://www.portlandoregon.gov/bes/41976 (accessed June 8, 2014).

management portion of the bill is divided into on-site and off-site stormwater management fees.[65] The on-site portion of the stormwater management fee deals with runoff on properties, while the off-site portion of the bill deals with citywide stormwater management, including right of ways, sewers, and programs aimed at preventing pollutants from entering the Willamette River.[66]

The Clean River Rewards program is a discount on the on-site portion of the stormwater management fee. The program itemizes the bill for the purposes of informing ratepayers how fees are spent, creating opportunities for ratepayers to lower bills by taking actions to manage stormwater on-site, and reforming how street drainage is paid by not relying on charges based on impervious areas of developed property. For residential properties, full discounts apply to those capturing all stormwater runoff from rooftops, a 67% discount to those partially detaining runoff, a 25% discount if total developed areas cover less than 1,000 square feet, and an 8% discount if there are four or more trees exceeding a height of 15 feet.[67] A discount calculator on the program's webpage allows customers to estimate their discounts by entering information on their properties.[68] Commercial properties receive discounts based on site controls for pollution, flow rate, and the disposal of stormwater runoff from developed areas. Commercial parcels are required to provide complete information on the detention capacities of these controls. The program requires all participants to register for the program and outlining their runoff detaining

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[65] City of Portland Bureau of Environmental Services. "Complete 2013-2014 Sewer and Drainage Rates and Charges." *City of Portland Bureau of Environmental Services.* July 1, 2013. https://www.portlandoregon.gov/bes/article/453033 (accessed June 8, 2014).
[66] City of Portland Bureau of Environmental Services. *Q & A.* https://www.portlandoregon.gov/bes/article/336520 (accessed June 8, 2014)
[67] City of Portland Bureau of Environmental Services. "Clean River Rewards Stormwater Discount Program." Policy, Auditor's Office, City of Portland, Portland, OR, 2012.
[68] City of Portland Bureau of Environmental Services. *Techncal Assistance.* https://www.portlandoregon.gov/bes/article/390681 (accessed June 8, 2014).

strategies. Property owners must also allow the city to inspect each property, where they are subject to fines for major violations of the program.[69]

The Clean Rivers Rewards program website provides technical information on how to assess properties for discounts and build and maintain stormwater facilities. The website also provides online videos and tutorials and a list of referrals for professionals certified in the city's Clean Rivers Rewards program.[70] The city of Portland offers an innovative approach to charging for stormwater runoff by separating stormwater runoff fees into on-site and off-site charges. The city of Portland also allows property owners to control a portion of their stormwater drainage bill through the implementation of runoff-reducing techniques.

2.3.3 Seattle Rules and Regulators

The stormwater issue in Seattle is a complicated issue that is affected by the area's geography, history, economy and urban development. The urban environment is diverse, ranging from tall skyscrapers and large condominium complexes near the downtown core, to single-family residential and low-rise commercial and industrial properties in the outer neighborhoods. The city has developed significantly over the past 100 years, however in recent years the city has experienced a development boom.[71]

Properties typically manages stormwater by collecting rainwater from building rooftops, along with rainwater collected from impervious surfaces into the existing sewer system. The stormwater runoff enters either a separated system or the combined sewer system depending on the location. In areas under a combined stormwater system, the stormwater runoff is combined

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[69] City of Portland Bureau of Environmental Services. "Clean River Rewards Stormwater Discount Program." Policy, Auditor's Office, City of Portland, Portland, OR, 2012.
[70] City of Portland Bureau of Environmental Services. *Techncal Assistance.* https://www.portlandoregon.gov/bes/article/390681 (accessed June 8, 2014).
[71] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

with wastewater from the building. The combined runoff and sewage is then sent to a water treatment facility. The water is treated and then released back into the neighboring water bodies.[72]

Much of the city's older developments are located in the combined sewer system. CSO events often occur in the combined sewer system during storms with large amounts of rain falling on impervious surfaces. CSO events occur when the combined sewer system receives more water than it can handle and releases the excess stormwater and sewage at outfalls located along the water bodies throughout the city. The pipes and treatment facility are limited in the amount of water it can handle at any given time. To prevent the pipes and facility from shutting down, the system has strategically placed overflow valves that release excessive water into the surrounding water bodies. The water released is untreated water with a mixture of roughly 90% stormwater runoff and 10% wastewater from buildings. The untreated sewage poses great environmental and health risks to the region.[73]

The Environmental Protection Agency and Washington State Department of Ecology are responsible for regulating storm water management in Washington State. The Department of Ecology is responsible for issuing National Pollution Discharge Elimination System (NPDES) Phase I Municipal Separate Storm Sewer Systems (MS4) permits to municipalities with over 100,000 people releasing any water into water bodies. The NPDES permits are the primary regulating program for stormwater management under the Federal Clean Water Act of 1972. The federal NPDES permit program requires minimum federal emission standards to be met by the city of Seattle.[74]

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[72] Ibid
[73] Ibid
[74] Seattle Public Utilities. "2013 NPDES Phase I Municipal Stormwater Permit." Permit, Stormwater Management Program, Seattle Public Utilities, Seattle, 2013.

Each NPDES permit is issued by state government agencies. In the State of Washington, the Department of Ecology is responsible for reviewing and issuing the permits to municipalities, such as the city of Seattle. The NPDES permit system also requires self-reporting by the municipality. The municipality is required to collect and report stormwater information to the Environmental Protection Agency as well as the Washington Department of Ecology. Regular inspections are also conducted by the Environmental Protection Agency. If pollution standards are not met, the Federal Environmental Protection Agency along with the Department of Ecology is responsible for issuing sanctions on municipalities. Non-compliance of the standards established by the Clean Water Act result in penalties, primarily in the form of fines.[75]

The rules and standards regulate effluents entering water bodies. As part of the MS4 permitting process, the city is required to internally coordinate stormwater management. The permit requires the city of Seattle to establish an authority to monitor industrial wastewater, illicit discharges from spills, inter-jurisdictional agreements, developments and redevelopments, and construction. Standards required by the NPDES permits also include mapping the wastewater infrastructure and discharge locations within the city. Public participation in the planning and implementation of programs to reduce the stormwater discharge are also requirements of the NPDES permits. The NPDES permit program mandates an average of one CSO event per year per outfall. The permit program also requires the city to implement one or more alternative CSO reduction alternatives. [76]

In 1994, the city of Seattle began the Storm Water Management Program (SWMP) to manage the city's stormwater. Seattle Public Utilities (SPU) is the primary governing body in Seattle responsible for overseeing and managing the program. The SWMP works with other city

[75] Ibid
[76] Ibid

agencies including, Department of Planning and Development, Seattle Parks and Recreation, Seattle Department of Finance and Administrative Services, Seattle City Light, and Seattle Department of Transportation. Prior to the SWMP each city agency managed individual stormwater programs. The SWMP was first approved by the Department of Ecology in 1997, and issued a Phase I MS4 permit. The Department of Ecology re-issued the SWMP in 2007, with a 5-year expiration period.[77]

The city of Seattle continually monitors CSO events at all outfall locations. During 2006 and 2010 the Ballard CSO basin outfalls 150,151, and 152 had a total of 219 overflow events, roughly 44 overflow events a year. Over the same period of time, the outfalls released 84 million gallons of stormwater and raw sewage, averaging 17 million gallons of overflow a year.[78] To address these overflow events, the city of Seattle created the 2010 CSO amendment plan.[79]

The 2010 CSO amendment plan called for a 5-year planning period for reducing CSO events throughout the city of Seattle. The plan evaluated alternatives and strategies for reducing stormwater CSO events at the city's most problematic outfalls, including the Ballard CSO basin's outfall 150, 151, and 152. The plan calls for the retrofits to optimize existing CSO infrastructure, construction of new CSO infrastructure projects, an evaluation of green stormwater projects, the possible expansion of green stormwater infrastructure projects, and the completion of a 2015 CSO amendment plan.[80]

The city has proposed implementing programs in 2015 to reduce nearly 2 million gallons of stormwater entering the combined system in the Ballard CSO basin at a total cost of $32

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[77] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.
[78] Seattle Public Utilities. *Combined Sewer Overflow Reduction Program: 2010 - Annual Report.* Report, Restore Our Waters, Seattle Public Utilities, Seattle: City of Seattle, 2010, 1-71.
[79] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.
[80] Ibid

million. Of that $32 million, $20 million will be used on inline and offline storage facilities in the area. The centralized infrastructure is expected to manage roughly 1.1 million gallons at an average cost of $17.69 per gallon of runoff. The cost estimates reflect the lifetime costs of the planning, designing, constructing, operating, and maintaining the said infrastructure. The remainder of the 0.8 million gallons is to be managed through a variety of green stormwater infrastructure projects. These include roadside rain gardens, residential rain gardens, permeable pavements, cisterns, and fixing infiltration-inflow of current sewage piping. As part of the green stormwater infrastructure, SPU created the Rainwise program. The Rainwise program provides rebates for residential rain gardens and cisterns and provides information on how residents can reduce stormwater runoff. In total the plan calls for over half of the stormwater to be managed through centralized infrastructure. The majority of funds will be devoted to centralized infrastructure projects.[81]

To pay for the he city of Seattle currently collects revenues through a user fee system from the wastewater utility bill and stormwater drainage fee. The wastewater fee is based on potable water usage and is included in the monthly utility bills.[82] The stormwater drainage fee is a fee based on property characteristics and is part of the yearly property tax bill. The fee system for residential users is based on the lot size of the property, while larger residential, commercial, and industrial fees are based on impervious surface coverage and parcel size.[83] Appendix 1 provides a more detailed description of the runoff fees. The drainage fees are expected to rise dramatically in the next couple of years to help offset costs for many of the CSO projects.[84]

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[81] Ibid
[82] Seattle Public Utilities. "Sewer Rates." *Sewer (Wastewater) Rates.* City of Seattle. 2013. http://www.seattle.gov/util/MyServices/DrainageSewer/SewerRates/index.htm (accessed April 24, 2014).
[83] Seattle Public Utilities. "Drainage Rates Schedule." *Drainage Rates.* City of Seattle.
[84] Thompson, Lynn. "Seattle Public Utilites Seeking Increase in Rates." *The Seattle Times*, April 24, 2014.

Monthly bills are expected to rise from $1.75 per month to nearly $4.62 a month, with the majority of change resulting from increased drainage fees.[85]

[85] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

3 Methodology

This thesis proposes research that attempts to find alternative cost-effective stormwater management strategies. My research quantified the costs of small-scale best management practices (BMPs) and incentive based pricing programs. I used geographic information system (GIS) mapping information to simulate the implementation of BMPs for an area in Seattle with high incidences of combined sewer overflow (CSO) events. My analysis assigned runoff figures to each parcel and created 3 different scenarios using quantity and pricing instruments to manage the stormwater runoff.

I began by calculating vital statistics on the Ballard CSO basin and identified average parcels for single family residential, multi family residential, office, retail, parking, and parcels types. The average parcels were used as representative samples for each parcel type in the area. The sample parcels were used to extrapolate information for the entire Ballard CSO basin. Each parcel was examined for impervious surface coverage to calculate runoff. My research continued by calculating cost information for the basin. This involved calculating the current revenue and proposed centralized infrastructure in the Ballard CSO basin. I then assigned optimal BMPs for each parcel type. Once the assigned BMPs were chosen, I calculated the costs of each BMP. I also calculated the opportunity costs of the land occupied by each BMP.

My thesis explored three separate stormwater management programs. The 3 scenarios used in the analysis were a full stormwater capture, a tradable allowance, and a BMP credit program. The first scenario simulated a full capture requirement of detaining all stormwater runoff on-site. The second scenario simulated a tradable allowance market where parcel owners were given the option to detain stormwater or purchase runoff allowances. The final scenario simulated the current runoff fee program with a credit to parcel owners who allowed the city to implement BMPs on their properties. The analysis determined the total costs under each scenario as well as the total amount of runoff detained.

3.1 Area of interest

This thesis is interested in reducing the incidents of storm related CSO events in the city of Seattle. The city has mapped CSO basins and linked outfalls for the basins using GIS data. My evaluation evaluated the Ballard CSO basin and outfall numbers 150, 151, and 152. This CSO basin experience an average of 44 overflow events with roughly 16 million gallons of overflow a year during a five-year period between 2006 and 2010.[86] Figure 1 provides a context map for the location of the Ballard CSO basin relative to the city of Seattle. Figure 2 provides the location of the CSO basin and locations of the outfalls. The Ballard CSO basin area stretches from NW 85th St. in the north to the waterfront along Salmon Bay in the south. The eastern boundary borders Golden Gardens Park in the west to NW 15th Ave. in the east.

I chose to evaluate an area with a significant number of CSO events and a large number of residential properties such as the Ballard CSO basin. Residential properties typically have a lower impervious surface coverage compared to most industrial and commercial areas, allowing for greater BMP options. Furthermore, the current stormwater charges for residential properties provide no incentives to reduce stormwater runoff. Narrowing the area to a CSO basin allowed me to examine the parcels more closely. This allowed me to determine the level of development and calculate runoff figures for the area. This also allowed me to better determine appropriate

[86] Seattle Public Utilities. *Combined Sewer Overflow Reduction Program: 2010 - Annual Report.* Report, Restore Our Waters, Seattle Public Utilities, Seattle: City of Seattle, 2010, 1-71.

BMPs for parcels. The GIS information mapped all the all parcels within the CSO basin, with information on the property size and building footprint. GIS information also provided data on the area's sewer network, publicly owned areas, right of ways, zoning, and present uses.

My research analyzed the CSO basin for a variety of characteristics. To determine the typical parcels in the basin, I calculated the average parcel size and building footprint for various parcel types. The average parcel sizes and building footprint were then used to represent each parcel type. Creating average parcels for each parcel type allowed me to generalize the stormwater runoff and runoff detaining technologies appropriate to each of these parcels.

Each of the sample parcel types was examined in greater detail to determine the impervious surface coverage. I chose parcels for each type to closely match the average size and building footprint in the CSO basin. I used aerial photography to determine the types of impervious surfaces on the parcel. I then used GIS to manually map the impervious surface coverage for each of the parcel types. The analysis mapped out the building footprint, driveways, walkways, parking, or other impervious areas to calculate the total impervious surface coverage. I then used this information to estimate the total runoff and appropriate stormwater detention technologies for the parcels.

3.2 Determining Runoff

Stormwater runoff is highly correlated to the level of development or the impervious surface coverage of an area. My analysis assumed runoff as a product of amount of rainfall on the impervious surface coverage. I calculated stormwater runoff as the amount of rainfall falling during a 24-hour rainfall period for a particular storm event multiplied by the area of impervious surface coverage. It should be noted however that runoff is a function of the total area, runoff coefficients of the impervious and non-impervious surfaces, and amount of rain. The runoff coefficients are the rate at which rainfall flows off a certain type of surface, with soil, vegetation and other factors affecting the runoff coefficient. I assumed the non-impervious surfaces do not contribute to stormwater runoff, and impervious surfaces have a runoff coefficient of 1. Simplifying the runoff calculations allowed me to quickly generate runoff with the limited data I was able to acquire. The stormwater runoff was calculated to be the rain falling on impervious surfaces.

The CSO phenomenon occurs during heavy rainfall periods when excess runoff enters the combined sewer system and overs the sewer's capacity. CSO events occur only during large storm events when peak flows overrun the sewer system's capacity. To determine the appropriate peak rainfall, this analysis used a specified year storm event. I used the historic rainfall totals and storm events for the Ballard area. The year storm event is measured by the number of inches falling over a specified duration of time. The year storm represents the historical peak rainfall from a large storm event with the frequency of a given number of years. A one-year storm is a storm event that occurs every year, while a five-year storm event is a storm that occurs every five years. This analysis used the rainfall occurring during one-year storm event over a period of 24 hours. This rainfall causes the peak flow for a CSO event in an average year. It should be noted that a storm event could exceed a 24-hour period, leading to a CSO event occur with less rainfall.

The rainfall from a one-year storm falling on impervious surfaces was used as the simplified runoff calculation for the Ballard CSO basin. I used these runoff calculations throughout my analysis and assigned each parcel type this runoff total.

3.3 Cost Estimates

The various cost estimates were calculated prior to running the scenarios. My thesis first estimated the current revenue generated by the stormwater runoff fee. I continued by calculating the costs of the proposed centralized infrastructure from the 2010 CSO amendment plan. My research continued by determining the optimal BMPs for each parcel type. Once the optimal BMPs were selected, I estimated the total costs of each BMP option. The total cost included the capital costs, the full lifecycle operating and maintenance costs, and opportunity costs of the land occupied each BMP.

3.3.1 Current User Fee Revenue

The cost calculations began by estimating the revenue generated by the Ballard CSO basin. The revenue is based on the current stormwater drainage fee .The fee is dependent on the size of the parcel, as well as the zoning on the parcel. Appendix 1 outlines the stormwater drainage charge in more detail. Each of the sample parcel types was used to determine the appropriate fee. The calculation assumed none of the parcels qualified for the low-impact discount. The total revenue generated by each parcel type was also used to estimate the charge per gallon of stormwater runoff. Diagram 2 outlines the structure of the current drainage fee.

3.3.2 Proposed Centralized Infrastructure

The city has proposed centralized infrastructure in the Ballard CSO. The 2010 CSO Amendment Plan calls for in-line and off-line storage tanks to be placed in the basin to collect and store stormwater runoff. The proposal provides an expected detention capacity and a cost for the storage tanks. The costs include all planning, design, construction, and operational costs for the project. To calculate the costs of a centralized infrastructure, I used these cost estimates to determine the cost per gallon of stormwater of centralized infrastructure. The analysis uses this cost estimate to determine overall cost detaining stormwater runoff through centralized infrastructure.

3.3.3 Optimal BMP Selections

The scenarios required a choice of the optimal BMPs for each parcel. Each parcel type was assigned an optimal BMP from the WERF BMP cost estimators. The spreadsheets provided nine different BMP options to choose from. The WERF estimator tool provided cost information for, curb-contained bioretention, cisterns, extended detention basins, green roofs, in-curb planter vaults, permeable pavements, rain gardens, retention ponds, and swales. The selection of the optimal BMPs considered the existing features of the parcel and the overall cost of the BMP. As an example, a cistern was not considered a viable option for a parcel with no buildings. Also, a retention pond was determined to be impractical for a small parcel with little space. The BMP must be physically possible on the parcel to be considered as the optimal BMP choice. For cost considerations, I considered the overall costs of implementation when determining optimal BMPs. If a rain garden was estimated to be cheaper than a cistern, the optimal BMP choice was determined to be a rain garden. The analysis took these considerations into account to determine the optimal BMPs for each parcel. The same optimal BMP choices were used throughout the scenarios. Capital costs and the whole lifecycle costs were estimated for each parcel. The operating and maintenance costs were discounted at a rate of 5.5% for the 50 year estimated lifespan of the BMP.

Opportunity costs for each BMP selection were also determined for each parcel type. BMPs occupy an area on the parcel, and parcel owners forgo the use of this land. This cost was represented as the opportunity cost to parcel owners and added to the total cost of the BMP. To estimate the opportunity costs, I used the most current appraised land value from the King County Assessor's website.[87] I calculated the value of the land per square foot, and multiplied

[87] King County Department of Assessments. *eReal Properties.* http://info.kingcounty.gov/Assessor/eRealProperty/default.aspx (accessed June 5, 2014).

the amount of space occupied by the BMP. This estimate became the opportunity cost for each BMP.

3.4 Scenarios

This thesis explored three separate scenarios to determine the total costs of managing stormwater runoff. The three scenarios explored were a full stormwater capture program, a tradable allowance program, and a BMP credit program. Each scenario calculated the total costs of detaining an amount of stormwater runoff. All three scenarios assumed the parcels chose the optimal BMPs identified earlier. I also assumed each parcel owner had perfect information on BMPs, was a cost minimizer, experienced low transaction costs, and SPU has the ability to implement the programs in each scenario.

3.4.1 Scenario 1: Full Capture Program

The cost estimates for the first scenario involved a requirement that all parcel owners detain all stormwater on-site. This required each parcel to implement the optimal BMP choice on their property. The parcel owners were also responsible for paying all costs. The total costs included the full BMP costs and opportunity costs for the land occupied by the BMP. The cost total of the BMP included the capital and operating costs for the lifespan of the BMP. The analysis calculated the total costs for all parcel owners in the simplified Ballard CSO basin. Using the total runoff for each parcel, the cost per gallon of stormwater detained was also calculated. Diagram 3 outlines the structure of the full stormwater capture program.

3.3.4 Scenario 2: Tradable Allowance Program

Under the second scenario, parcel owners were given the option to either detain stormwater runoff on site or to purchase stormwater runoff allowances. The scenario simulated parcel owners making a choice between implementing a stormwater retention technology and purchasing a stormwater runoff allowances.

The decision made by each parcel owner was based on the cost per unit of stormwater detained for each parcel type. If a parcel owner had a lower BMP cost per unit of stormwater detained, the parcel owner implemented a BMP. If the cost of the allowance was lower than the BMP cost per unit of stormwater, the parcel owner purchased allowances. It was assumed SPU would manage the stormwater not detained through existing infrastructure, with the revenue generated by allowance credits paying for existing services.

The scenario took cost information for each parcel owner and outlined who would purchase allowances under the simulated allowance cost. The parcel owners who purchased credits generated revenue for SPU to manage the unaccounted stormwater runoff. I calculated the total costs to each parcel owner along with total amount of stormwater runoff detained. I also calculated the total revenue and the amount of runoff not detained for the area. Diagram 4 outlines the structure of the stormwater tradable allowance program.

3.3.5 Scenario 3: BMP Credit Program

The third scenario presented in my research is a BMP credit program. The scenario utilized the current runoff fee program with SPU waiving the runoff fee to owners who implemented BMPs on their properties. The runoff fee is waived by SPU to parcel owners for allowing the city to use their property for a BMP. Parcel owners not participating in the paid the normal runoff fee.

The scenario also made an assumption that SPU limited the availability of the credit to specific parcel owners. Parcels with optimal BMPs with high cost per gallon of stormwater retained were exempt from the credit. The threshold was set at the cost per gallon of the centralized infrastructure. If a parcel BMP had a higher cost per gallon of detaining stormwater runoff than the centralized infrastructure, they were exempt from the credit program. It is also assumed that SPU was responsible for the costs of implementing and maintaining the BMP.

The behavior of parcel owners in the scenario is based on the opportunity costs of the BMP. Parcel owners participated in the program only if their opportunity costs were lower than the expected savings from the avoided runoff fee. The only cost to parcel owners was the forgone use of the land occupied by the BMP. I calculated the expected cost of drainage fee over the course of 50 years, or the expected lifecycle cost of BMP. The drainage fee assumed to increase at an annual average of 3%, roughly the rate of inflation, and discounted at an annual rate of 5.5%.

My calculations estimated the total costs of the project. Estimates were calculated for both parcel owners and SPU. The costs and benefits to parcel owners included the opportunity costs of BMPs, the drainage fees paid, and the benefits of avoided fees for those implementing BMPs. For SPU, the costs and benefits included the BMP costs, the lost revenue from avoided fees, and the revenue from runoff fees paid. The expected reduction in stormwater runoff as well as the cost per gallon of detaining stormwater was also calculated in this scenario. Diagram 5 outlines the structure of the BMP credit program.

4 Results

4.1 Area Statistics

The Ballard CSO basin covers a little over 48 million square feet or over 1,100 acres in the city of Seattle. The area is comprised of 6,407 different parcels, covering nearly 30 million square feet. Figure 3 provides a map of the differing parcel types in the Ballard CSO basin. The parcels in the area occupy nearly 62% of the Ballard CSO basin area. Table 3 outlines detailed information on the parcel area coverage. With 5,007 parcels, single-family parcels cover nearly 50% of entire Ballard CSO basin area. The second and third most common parcel types are duplex and apartment parcels, each covering nearly 5% of the area. Office and parking parcels are the least common parcel type, with 19 and 17 parcels respectively and each covering less than 1% of the area. The area is dominated by single-family homes, and are scattered throughout the entire CSO basin. Multi-family, retail, office, and parking parcels are grouped around the southern and northeastern portions of the CSO basin. Figure 3 maps the dispersal of parcel types throughout the Ballard CSO Basin.

Table 3 Parcel Types

Parcel Type	Number of Parcels	Area (Sqft)	% of Area in CSO Basin
Single-Family	5,007	23,718,037	49.2%
Duplex	970	2,596,351	5.4%
Apartment	307	2,183,351	4.5%
Retail	87	941,943	2.0%
Office	19	139,962	0.3%
Parking	17	147,796	0.3%
Totals	6,407	29,727,440	61.6%

An analysis of the six types of parcels, single-family, duplex multifamily, apartment multi-family, retail, office, and parking resulted in varying impervious surface coverage. Table 4 outlines the impervious surface coverage for each parcel type. Figure 4 is the aerial view of each parcel type, highlighting the impervious surface coverage. My analysis determined an average single-family home's impervious surface coverage as roughly 52% of the parcel area. This consisted of the building, driveway, and walkway. The duplex parcels had 92% impervious surface coverage, with the building and walkways accounting for the impervious surfaces. An average apartment parcel had an impervious coverage of 70%, with the building and parking lot accounting for the impervious surfaces. Retail parcels also had high impervious surface coverage of 96%, the 66% of being occupied by parking spaces. Office parcels also had a relatively high impervious surface coverage of 92%, with building and parking accounting for the impervious surface coverage. The parking parcels had the highest impervious coverage with 100% of the area being impervious.

Table 4 Impervious Surface by Parcel Type

	Building	Non-Building	Total Impervious Area	Avg. Parcel Size (Sqft)
Single-Family	36%	16%	52%	4,737
Duplex	41%	51%	92%	2,677
Apartment	48%	22%	70%	7,159
Retail	30%	66%	96%	11,349
Office	61%	31%	92%	7,366
Parking	-	100%	100%	8,694

4.2 Runoff

My simulation estimated the runoff from each of the parcel types. The calculated runoff figures used a one-year storm event estimate of 1.71 inches of rain. Runoff was calculated by multiplying 1.71 inches of rain by the total impervious surface coverage. The calculated runoff for each parcel type is presented in table 5 and 6. I estimated the total runoff for the Ballard CSO basin to be roughly 19 million gallons. Single-family homes accounted for the majority of the runoff, as they occupied the largest amount of total area in the Ballard CSO basin.

Table 5 Runoff from 1-Year Storm Event[88]

	Avg. Impervious Area (Sqft)		Rainfall (inches)	Runoff (ft^3)	Runoff (Gal)
Single-Family	2,471	x	1.71	4,226	2,634
Duplex	2,572	x	1.71	4,398	2,741
Apartment	5,031	x	1.71	8,602	5,362
Retail	10,904	x	1.71	18,645	11,622
Office	6,758	x	1.71	11,556	7,203
Parking	8,694	x	1.71	14,867	9,267
Total	36,429			62,294	38,830

Table 6 Total Runoff

	Number of Parcels	Total Runoff (Gal)
Single-Family	5007	13,189,999
Duplex	970	2,658,942
Apartment	307	1,646,192
Retail	87	1,011,140
Office	19	136,857
Parking	17	157,536
Total		18,800,666

4.3 Cost Estimates

4.3.1 Current Revenues

In my analysis, the sample parcels of the Ballard CSO basin generated nearly $1.6 million a year in runoff fees. Each parcel is assumed to have regular development, and did not qualify for the low impact development discount. The single-family and duplex lots had set rates

[88]Rainfall calcluation estimated using historical storm event data for 1-year storms.
Seattle Public Utilities. *Stormwater Manual: Stormwater Flow Control & Water Quality Treatment Technical Requirements Manula.* Manual, Department of Planning & Development, Seattle Public Utilties, Seattle: City of Seattle, 2009, 1-589.

based on lot size. The rates for apartment, retail, office, and parking rates were based on impervious coverage and size of the parcel. Table 7 outlines the revenue generated by each parcel type. Not surprisingly, single-family parcels generated most of the revenue. I also calculated the runoff fee per estimated gallon of runoff for the area. Table 8 outlines the estimated fee per gallon of runoff. The runoff charge per gallon of runoff is lowest for the duplex parcels, while apartment and office parcels ended up paying more per gallon of runoff.

Table 7 Drainage Fees per Year[89]

	Runoff Fee	Number of Parcels	Total Fees
Single-Family	$ 234.87	5007	$ 1,175,994
Duplex	$ 164.05	970	$ 159,129
Apartment	$ 554.65	307	$ 170,277
Retail	$ 1,040.11	87	$ 90,490
Office	$ 675.13	19	$ 12,828
Parking	$ 796.79	17	$ 14,342
Total	$ 3,465.60		$ 1,623,059

Table 8 Drainage Fee per Gallon of Runoff

	Runoff (Gal)	Fee per Gal of Runoff
Single-Family	13,189,999	$ 0.0892
Duplex	2,658,942	$ 0.0598
Apartment	1,646,192	$ 0.1034
Retail	1,011,140	$ 0.0895
Office	136,857	$ 0.0937
Parking	157,536	$ 0.0910
Total	18,800,666	$ 0.0863

4.3.2 Centralized Infrastructure

In the city's proposed 2010 CSO amendment plan, the city outlines the cost estimates for centralized infrastructure projects in the Ballard CSO basin. The costs and storage capacity of the project are outlined in table 9. The city proposed 3 storage tanks, two in-line storage tanks and

[89]Runoff fee esimtated using 2014 drainage rates.
Seattle Public Utilities. "Drainage Rates Schedule." *Drainage Rates.* City of Seattle. http://www.seattle.gov/util/MyServices/Rates/DrainageRates/RateSchedule/index.htm (accessed April 24, 2014).

one off-line storage tank. The total estimated costs for detaining the stormwater is over $20 million. The tanks are estimated to hold a little over 1 million gallons of stormwater. The cost per gallon of stormwater detained equals roughly $17.69.

Table 9 Proposed Centralized Infrastructure[90]

	Gal Detained	Cost	Cost Per Gal
Inline Storage Tank	240,000	$ 4,560,000	$ 19.00
Offline Storage Tank	682,000	$ 13,650,000	$ 20.01
Inline Storage Tank	165,523	$ 2,324,000	$ 14.04
Total	1,087,523	$ 20,534,000	$ 17.69

4.3.3 Optimal BMPs

To manage the calculated runoff, each parcel used different combinations of BMPs. The optimal BMPs for each parcel type were determined to be small rain gardens, cisterns, and curb-contained bioretention. Table 10 outlines the optimal BMP choices for each parcel type. Small residential rain gardens were used for single-family residential parcels. Cisterns were used for duplex, apartment, retail, and office parcels. Curb-contained bioretention were used for duplex, apartment, retail, office and parking parcels. Parcels using cisterns captured rainwater from buildings, while curb-contained bioretention captured runoff from large walkways and parking areas. Each parcel explored alternative BMPs, however the optimal choice was made based on characteristics of the parcel and the total costs. Table 11 details the BMP costs to each parcel type, while table 12 details the expected stormwater detained and the cost per gallon of the detention. The duplex BMP had the highest total cost of per gallon of stormwater detained at $21.38. Retail and parking parcels had the lowest at $10.16 and $10.12 respectively.

[90] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

Table 10 Optimal BMP Choices

	BMPs
Single-Family	Rain Gardens
Duplex	Cisterns & Curb-Contained Bioretention
Apartment	Cisterns & Curb-Contained Bioretention
Retail	Cisterns & Curb-Contained Bioretention
Office	Cisterns & Curb-Contained Bioretention
Parking	Curb-Contained Bioretention

Table 11 BMP Costs[91]

	Capital Costs	Annualized O&M Costs	Opprotuntiy Costs	Total Cost
Single-Family	$ 8,885	$ 209	$ 22,435	$ 41,794
Duplex	$ 8,688	$ 924	$ 3,738	$ 58,603
Apartment	$ 16,755	$ 873	$ 6,004	$ 66,407
Retail	$ 27,806	$ 924	$ 44,052	$ 118,034
Office	$ 18,853	$ 907	$ 17,619	$ 81,819
Parking	$ 21,250	$ 573	$ 43,904	$ 93,793

Table 12 Runoff Detained and Cost per Gallon

	Total Cost	Runoff Detained (Gal)	Cost Per Gal
Single-Family	$ 41,794	2,634	$ 15.87
Duplex	$ 58,603	2,741	$ 21.38
Apartment	$ 66,407	5,362	$ 12.38
Retail	$ 118,034	11,622	$ 10.16
Office	$ 81,819	7,203	$ 11.36
Parking	$ 93,793	9,267	$ 10.12

4.4 Scenarios

4.4.1 Scenario 1: Full Runoff Capture

This scenario assumed each parcel was required to manage all stormwater from their property. Each parcel was required to manage the stormwater runoff using the previously assigned BMPs. The entire cost of managing stormwater was placed on the parcel owner, as they

[91] 2004 assessed land value from the King County Assessor's Office's database was used to determine cost per square foot of assessed land value.
King County Department of Assessments. *eReal Properties.* http://info.kingcounty.gov/Assessor/eRealProperty/default.aspx (accessed June 5, 2014).

were required to pay for managing their parcel's contribution to the overall runoff in the Ballard CSO basin.

In this scenario, I calculated that all parcels managed 19 million gallons of stormwater runoff at a cost of $300 million. This came out to be roughly $15.95 per gallon of stormwater runoff detained. The annualized cost is roughly $6 million for the entire area. The overall cost per gallon of detaining stormwater comes out to $15.95 per gallon. Table 13 outlines the costs to each parcel type, including the BMP and opportunity costs. Table 14 details the amount of runoff and cost per gallon detained.

Table 13 Total Costs to Parcel Owners[92]

	BMP Costs	Opprotunity Costs	Total Cost	Annualized Cost
Single-Family	$ 96,930,513	$ 112,329,959	$ 209,260,472	$ 2,246,599
Duplex	$ 53,219,050	$ 3,626,056	$ 56,845,106	$ 72,521
Apartment	$ 18,543,721	$ 1,843,178	$ 20,386,899	$ 36,864
Retail	$ 6,436,434	$ 3,832,564	$ 10,268,998	$ 76,651
Office	$ 1,219,800	$ 334,757	$ 1,554,557	$ 6,695
Parking	$ 848,113	$ 746,368	$ 1,594,481	$ 14,927
Totals	$ 177,197,631	$ 122,712,881	$ 299,910,512	$ 5,998,210

Table 14 Cost per Gallon of Detained Stormwater

	Total Cost	Gallons Detained	Cost/ Gal
Single-Family	$ 209,260,472	13,189,999	$ 15.87
Duplex	$ 56,845,106	2,658,942	$ 21.38
Apartment	$ 20,386,899	1,646,192	$ 12.38
Retail	$ 10,268,998	1,011,140	$ 10.16
Office	$ 1,554,557	136,857	$ 11.36
Parking	$ 1,594,481	157,536	$ 10.12
Totals	$ 299,910,512	18,800,666	$ 15.95

92 2004 assessed land value from the King County Assessor's Office's database was used to determine cost per square foot of assessed land value.
King County Department of Assessments. *eReal Properties.* http://info.kingcounty.gov/Assessor/eRealProperty/default.aspx (accessed June 5, 2014).

4.4.2 Scenario 2: Tradable Allowance

Scenario 2 gave parcel owners the option to manage all stormwater on their property or to purchase stormwater allowances from SPU. Each parcel owner was given the opportunity to weigh the cost of implementing runoff management techniques against the cost of purchasing allowances. Parcel owners with lower cost per gallon of detaining stormwater runoff would implemented BMPs, while parcel owners with high cost per gallon of detaining stormwater purchased allowance. Those parcel owners contributed revenue to SPU to manage stormwater elsewhere. The price points of $12 and $1.09 were evaluated in this scenario. Depending on the cost of the allowance, the investments in BMPs changed. Table 15 outlines the parcel owners purchasing allowances based on different price points for the allowances.

The price points chosen in this scenario reflected the proposed plans in Seattle's 2010 CSO amendment plan. The price point of $12 was estimated to detain roughly the equivalent amount of runoff in the Seattle's proposed 2010 CSO amendment plan. The plan called for detaining a little over 1 million gallons of stormwater in centralized storage tanks. The second price point of $1.09 was estimated to also generate enough income to pay for the proposal in the 2010 CSO amendment plan. The centralized infrastructure in the plan calls for a little over $2 million.

Table 15 Parcel Behavior Tradable Allowance

	Cost Per Gal	Allowance Purchase ($11/Gal Cost)	Allowance Purchase ($1.09/Gal Cost)
Single-Family	$ 15.87	Yes	Yes
Duplex	$ 21.38	Yes	Yes
Apartment	$ 12.38	Yes	Yes
Retail	$ 10.16	No	Yes
Office	$ 11.36	Yes	Yes
Parking	$ 10.12	No	Yes

If SPU set an allowance rate of $11 per gallon of stormwater runoff, retail and office parcels would implement BMPs on their property. Table 13 outlines the total costs to parcel owners, while table 14 outlines the revenue to SPU. Roughly 1.2 million gallons were detained using BMPs under an $11 allowance price. Tables 15 details the runoff detained by parcels and the cost per gallon of detaining the stormwater runoff. The overall cost of detaining stormwater drops to $10.15.

Table 13 Costs to Parcel Owners ($11 Allowance)[93]

	BMP Cost	Opprotuntiy Costs	Allowance Costs	Total Costs	Annualized Cost
Single-Family	$ -	$ -	$ 145,089,987	$ 145,089,987	$ 2,901,800
Duplex	$ -	$ -	$ 29,248,363	$ 29,248,363	$ 584,967
Apartment	$ -	$ -	$ 18,108,108	$ 18,108,108	$ 362,162
Retail	$ 6,436,434	$ 3,832,564	$ -	$ 10,268,998	$ 205,380
Office	$ -	$ -	$ 1,505,432	$ 1,505,432	$ 30,109
Parking	$ 848,113	$ 746,368	$ -	$ 1,594,481	$ 31,890
Totals	$ 7,284,547	$ 4,578,932	$ 193,951,889	$ 205,815,368	$ 4,116,307

Table 14 SPU Revenue ($11 Allowance)

	Allowance Revenue	Annualized Revenue
Single-Family	$ 145,089,987	$ 2,901,800
Duplex	$ 29,248,363	$ 584,967
Apartment	$ 18,108,108	$ 362,162
Retail	$ -	$ -
Office	$ 1,505,432	$ 30,109
Parking	$ -	$ -
Totals	$ 193,951,889	$ 3,879,038

Table 15 Runoff Detained ($11 Allowance)

	Detaining Cost	Runoff Detained	Cost/ Gal
Single-Family	$ -	-	$ -
Duplex	$ -	-	$ -
Apartment	$ -	-	$ -
Retail	$ 10,268,998	1,011,140	$ 10.16
Office	$ -	-	$ -
Parking	$ 1,594,481	157,536	$ 10.12
Totals	$ 11,863,479	1,168,676	$ 10.15

[93] 2004 assessed land value from the King County Assessor's Office's database was used to determine cost per square foot of assessed land value.
King County Department of Assessments. *eReal Properties.* http://info.kingcounty.gov/Assessor/eRealProperty/default.aspx (accessed June 5, 2014).

Under a $1.09 allowance cost, the entire basin would see no parcels implementing BMPs. All parcel owners would purchase stormwater allowances. Table 16 details the cost to parcel owners, while table 17 details the revenue to SPU. The revenue generated by the allowances is a little over $20 million. The total costs involved in this zero, as all the money is transferred SPU in the form of the allowances.

Table 16 Costs to Parcel Owners ($1.09 Allowance)

	BMP Cost	Opprotuntiy Costs	Allowance Costs	Total Costs	Annualized Cost
Single-Family	$ -	$ -	$ 14,377,099	$ 14,377,099	$ 287,542
Duplex	$ -	$ -	$ 2,898,247	$ 2,898,247	$ 57,965
Apartment	$ -	$ -	$ 1,794,349	$ 1,794,349	$ 35,887
Retail	$ -	$ -	$ 1,102,143	$ 1,102,143	$ 22,043
Office	$ -	$ -	$ 149,175	$ 149,175	$ 2,983
Parking	$ -	$ -	$ 171,714	$ 171,714	$ 3,434
Totals	$ -	$ -	$ 20,492,726	$ 20,492,726	$ 409,855

Table 17 SPU Revenue ($1.09 Allowance)

	Allowance Revenue	Annualized Revenue
Single-Family	$ 14,377,099	$ 287,542
Duplex	$ 2,898,247	$ 57,965
Apartment	$ 1,794,349	$ 35,887
Retail	$ 1,102,143	$ 22,043
Office	$ 149,175	$ 2,983
Parking	$ 171,714	$ 3,434
Totals	$ 20,492,726	$ 409,855

4.4.3 Scenario 3: BMP Credit Program

The third scenario involved creating a BMP credit program. The program compensated parcel owners that allowed the city to implement BMPs on their properties by eliminating the runoff fee. Under this scenario, duplex parcel owners were exempt from the program. With a BMP cost of $21.38 per gallon of stormwater detained, duplex parcel owners had a higher cost per gallon than the centralized infrastructure of $17.69. Due to this high BMP cost, duplex owners were not offered the credit option. All other parcel owners were given the option to implement BMPs and waive the runoff fee.

My analysis found that apartment and office parcel owners with opportunity costs of $6,004 and $17,619 had lower opportunity costs than the savings from the avoided runoff fee. Table18 outlines parcel behavior based on the opportunity costs and the avoided fees for all parcel owners. The revenues assumed an annual increase in rates of 3%, discounted at a rate of 5.5% for 50 years. With the apartment and office parcels allowing the SPU to use their land for BMPs, I calculated the expected reduction in runoff to be a little less than 1.8 million gallons of stormwater runoff. Parcel owners had costs of $42 million and a gain of $5 million, leading to a net cost of $38 million. Table 19 outlines the costs to each of the parcel owners. The total costs to parcel owners came out to roughly $39 million. Over the course of 50 years, SPU generated a little under $41 million in revenue, while experiencing costs of $24 million in BMP costs and waived revenue, leading to a net gain of $16 million. Table 20 outlines the costs to SPU. With a reduction in roughly 1.8 million gallons, the cost per gallon of stormwater detained came out to roughly $11.08 per gallon of stormwater detained. Table 21 outlines the total costs to detain the stormwater runoff and the cost per gallon of detaining runoff.

Table 18 Parcel Behavior BMP Credit[94]

	Opprotunity Cost	Runoff Fee	BMP Implemented
Single-Family	$ 22,435	$ 6,759	no
Duplex	$ 3,738	$ 4,584	no
Apartment	$ 6,004	$ 15,498	yes
Retail	$ 44,052	$ 29,062	no
Office	$ 17,619	$ 18,864	yes
Parking	$ 43,904	$ 22,264	no

Table 19 Costs to Parcel Owners[95]

[94] Duplex parcel owners are exempt from the BMP credit, BMP are too costly. 2004 assessed land value from the King County Assessor's Office's database was used to determine cost per square foot of assessed land value. King County Department of Assessments. *eReal Properties.* http://info.kingcounty.gov/Assessor/eRealProperty/default.aspx (accessed June 5, 2014).

[95] 2004 assessed land value from the King County Assessor's Office's database was used to determine cost per square foot of assessed land value.

	Opprotunity Cost	Avoided Fee	Runoff Fee	Total Cost	Annualize Cost
Single-Family	$ -	$ -	$ 33,844,643	$ 33,844,643	$ 676,893
Duplex	$ -	$ -	$ 4,446,267	$ 4,446,267	$ 88,925
Apartment	$ 1,843,178	$ (4,757,761)	$ -	$ (2,914,583)	$ (58,292)
Retail	$ -	$ -	$ 2,528,400	$ 2,528,400	$ 50,568
Office	$ 334,757	$ (358,418)	$ -	$ (23,661)	$ (473)
Parking	$ -	$ -	$ 378,480	$ 378,480	$ 7,570
Total Costs	$ 2,177,936	$ (5,116,180)	$ 41,197,790	$ 38,259,546	$ 765,191

Table 20 Costs to SPU

	BMP Cost	Forgone Revenue	Revenue	Total Cost	Annualized Cost
Single-Family	$ -	$ -	$ (33,844,643)	$ (33,844,643)	$ (676,893)
Duplex	$ -	$ -	$ (4,446,267)	$ (4,446,267)	$ (88,925)
Apartment	$ 18,543,721	$ 4,757,761	$ -	$ 23,301,482	$ 466,030
Retail	$ -	$ -	$ (2,528,400)	$ (2,528,400)	$ (50,568)
Office	$ 1,219,800	$ 358,418	$ -	$ 1,578,218	$ 31,564
Parking	$ -	$ -	$ (378,480)	$ (378,480)	$ (7,570)
Total Cost	$ 19,763,521	$ 5,116,180	$ (41,197,790)	$ (16,318,090)	$ (326,362)

Table 21 Runoff Detained

	Total Cost	Gallons Detained	Cost/Gal
Single-Family	$ -	-	$ -
Duplex	$ -	-	$ -
Apartment	$ 20,386,899	1,646,134	$ 12.38
Retail	$ -	-	$ -
Office	$ 1,554,557	136,857	$ 11.36
Parking	$ -	-	$ -
Total Costs	$ 21,941,457	1,782,991	$ 12.31

King County Department of Assessments. *eReal Properties.* http://info.kingcounty.gov/Assessor/eRealProperty/default.aspx (accessed June 5, 2014).

5 Discussion

5.1 Assumptions

This study made a variety of assumptions to estimate costs and outcomes. These assumptions have significant impacts on the results and conclusions reached. In my analysis I made assumptions on:

- Average parcel types
- One-year stormwater runoff data
- Optimal BMPs
- Transaction costs
- Opportunity costs
- The legal authority to implement scenarios

The following section details each of these assumptions in greater detail. I also identify how each assumption impacted the outcomes.

5.1.1 Average Parcel Types

The assumptions on the Ballard combined sewer overflow (CSO) basin included the use of representative average parcel types. The average parcels were extrapolated for the entire CSO basin, allowing my analysis to simplify the calculations for runoff and BMPs. The geographic information system (GIS) information used in my analysis did not include impervious area for the entire CSO basin. My calculations simplified the impervious surface coverage by taking an average parcel and examining it in greater detail. I used the average parcel to extrapolate an estimate on the impervious surface coverage for the entire area.

Using the simplified impervious surface coverage for the basin, I was create runoff and cost estimates for the entire CSO basin. These cost calculations are based on the assumption that average parcels accurately portray the impervious surface coverage on all parcels in the Ballard CSO basin. I took steps in selecting average parcels that were representative of each parcel type in the Ballard CSO basin. In choosing the parcel, I used the estimated average parcel size and building coverage for each parcel type. I chose parcels that reflected these calculated averages. Once the parcel was chosen, I was able to manually map the areas covered by impervious surfaces. Once each parcel types impervious surface was mapped, I calculated the total impervious surface coverage for the entire basin. The impervious surface calculations were then used to calculate runoff and the optimal BMPs for the parcels.

5.1.2 Runoff

To estimate runoff calculations for the Ballard CSO basin, I made a variety of assumptions. I made the assumption that runoff was a function of a one-year storm event and the impervious surface coverage. The EPA's NPDES permits mandates that no more than one overflow event occurs at each outfall per year.[96] The peak flow for the basin occurs during the largest storm event of the year, thus a one-year storm event represents the peak flow that causes an overflow for a typical year. To meet the EPA mandate of one overflow event per outfall per year, the system would need to handle the rainfall from this size of storm event. I also used a 24-hour rainfall period as the selected time frame for the storm event. Table 21 is the historical record for storm event rainfall measured in the Ballard area.

[96] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

Table 21 Ballard Historical Rainfall[97]

Duration (hr)	Precipitation (in) Recurrence Interval (years)						
	0.2 yr	0.5 yr	1 yr	2 yr	5 yr	10 yr	25yr
6	0.59	0.78	0.91	1.05	1.24	1.37	1.57
12	0.89	1.09	1.31	1.53	1.83	2.04	2.36
24	0.98	1.41	1.71	2.03	2.46	2.77	3.24
48	1.41	1.95	2.35	2.76	3.32	3.73	4.35
72	1.62	2.23	2.68	3.14	3.77	4.22	4.89
168	2.27	3.23	3.90	4.55	5.39	5.95	6.75

My calculated runoff is simplified as the amount of rain falling on impervious surfaces. A full hydrological assessment would typically consider the slope, soil types, and the types of impervious coverage to determine runoff. This results in varying runoff coefficients for different parcels. I made an assumption that the runoff calculation had a coefficient of one for impervious surfaces and zero for non-impervious surfaces. Each parcel type is assumed to have same runoff coefficient across for all parcels of that type. The runoff assumptions directly impacted the total runoff detainment and cost per gallon-detained calculations.

5.1.3 Optimal BMPs

This study picked three different BMP options for use on each of the parcel types. There were a variety of BMP options to choose from WERF's BMP cost estimation spreadsheets. My thesis chose rain gardens, curb-contained bioretention, and cisterns as the optimal BMP options. I used design, space, and cost as factors in determining the optimal BMPs for each of the parcel types. My analysis also considered green roofs, in-curb planter vaults, permeable pavements, swales, retention ponds, and extended detention basins. However, each of these BMP options

[97] Seattle Public Utilities. *Stormwater Manual: Stormwater Flow Control & Water Quality Treatment Technical Requirements Manula.* Manual, Department of Planning & Development, Seattle Public Utilties, Seattle: City of Seattle, 2009, 1-589.

was considered to be logistically inappropriate or cost prohibitive. Table 22 details the reasons for excluding each of the BMPs from my analysis.

Table 22 Other BMPs

BMP Option	Reason for Exclusion
Green Roof	Too costly, cisterns are cheaper
In-curb Planter Vaults	Too costly, curb-contained bioretention is cheaper
Permeable Pavements	Too costly, curb-contained bioretention is cheaper
Swales	Too costly, rain gardens are cheaper
Retention Pond	Space constraints, requires large areas
Extended Detention Basins	Space constraints, requires large areas

The cost estimator allowed for the customization of the cost estimates for the 50 year expected lifespan of each BMP. Tables 23, 24, and 25 outline the assumptions entered in the WERF calculator for each BMP choice. Rain garden costs were calculated using the WERF spreadsheets with the assumption that the drainage area was 52% of the parcel, or the impervious surface on the parcel. The garden is designed to be roughly 20% of the drainage area. They are designed to use rainfall from up to a 2-year storm event, and to detain runoff from up to 5-year storm event. The cost estimates for curb-contained bioretention assumed the drainage area to be the parking and walkway areas of the duplex, apartment, retail, office, and parking parcels. The curb-contained bioretention is designed to collect stormwater runoff from the impervious surfaces into a curbed planter. The curbed planter is a vegetated basin that is designed to retain water during large storm events and includes an overflow outlet to the stormwater sewer system. The curb planters replace 7% of the impervious surfaces on the parcel. The cost estimates for cisterns assumed to detain stormwater from the building rooftops of duplex, apartment, retail and office parcels. The cistern is designed to capture stormwater from a one-year storm event from each of the rooftops. The size of the tank is calculated by determining the amount of rainfall and the size of the roof. The materials for the tanks also differed depending on the size of the tanks, with plastic used for cisterns under 1,500 gallons and steel used for cisterns up to 15,000 gallons. Once the water is captured by the cistern, it is pumped and used irrigate planted vegetation or slowly released into the sewer system. These assumptions impacted the calculations for the cost of BMPs and the opportunity costs of the land occupied by the BMPs.

Table 23 Rain Garden Assumptions

	Drainage Area	Installation	Maintenance	Discount Rate
Single-Family	2660 sqft	Professional	Medium	5.5%

Table 24 Curb-contained Bioretention Assumptions

	Drainage Area	Impervious Coverage of Drainage Area	Underdrain	Maintenance	Retrofit	Discount Rate
Duplex	0.041 acres	100%	Yes	Medium	Yes	5.5%
Apartment	0.036 acres	100%	Yes	Medium	Yes	5.5%
Retail	0.080 acres	100%	Yes	Medium	Yes	5.5%
Office	0.052 acres	100%	Yes	Medium	Yes	5.5%
Parking	0.200 acres	100%	Yes	Medium	Yes	5.5%

Table 25 Cistern Assumptions

	Drainage Area	Rainfall Event	Tank Material	Maintenance	Discount Rate
Duplex	1933 sqft	1.71 inches	Plastic	Medium	5.50%
Apartment	3580 sqft	1.71 inches	Steel	Medium	5.50%
Retail	2981 sqft	1.71 inches	Steel	Medium	5.50%
Office	4145 sqft	1.71 inches	Steel	Medium	5.50%

5.1.4 Transaction Costs

In each of the scenarios I made the assumption that there were no transaction costs. Transaction costs refer to any of the costs in acquiring information, making decisions, and enforcement of the programs. Each participant in the three scenarios is a cost minimizer and has perfect information about the short and long term costs of each BMP and scenario. With this assumption, it is understood that both parcel owners and SPU will always choose the lowest cost option available to them and fully understand the rules and regulations under each scenario. By assuming there are no transaction costs, there are no costs associated with monitoring and enforcing the rules, calculating and assigning runoff to each parcel, and programmatic administrative costs in running each program. In the real world, there are costs associated with making any sort of transaction not captured in my analysis. This assumption impacts the cost estimates and behavior of each party in the three scenarios.

5.1.5 Opportunity Costs

Opportunity costs for parcel owners are assumed to be the value of the land occupied by each BMP. Implementing BMPs on properties imposes a cost to each property owner as they forgo the use of the land. I estimated the opportunity costs by calculating the value per square foot of the land occupied by each BMP. The assessed land values for each of the average parcels were taken from King County Department of Assessments online database.[98] Each property's assessed land value per square foot of the land was multiplied by the space occupied by each BMP. Single-family homes with rain gardens occupied roughly 20% of the drainage area, while cisterns and curb-contained bioretention occupied 7% of the land. Table 26 details each of the calculated opportunity costs for each parcel type. These calculations impacted costs incurred by parcel owners and determined the parcel behavior in the third scenario. In this scenario, the parcel participated in the credit only if the opportunity costs were lower than the expected savings from the avoided runoff fee.

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[98] King County Department of Assessments. *eReal Properties.* http://info.kingcounty.gov/Assessor/eRealProperty/default.aspx (accessed June 5, 2014).

Table 26 Opportunity Costs[99]

	Cost per Sqft	BMP Area	Opprotunity Cost
Single-Family	$ 42.16	532	$ 22,435
Duplex	$ 45.17	83	$ 3,738
Apartment	$ 74.99	80	$ 6,004
Retail	$ 95.09	463	$ 44,052
Office	$ 119.86	147	$ 17,619
Parking	$ 75.16	584	$ 43,904

5.1.7 Legal Authority

Another assumption I made in this thesis was the legal and logistical ability of SPU to implement the proposed scenarios. The first two scenarios require SPU to fundamentally alter how parcels account for stormwater runoff. The full capture and tradable permit assign the runoff figure directly to the parcel, requiring each parcel to be responsible for their runoff contribution. Requiring parcel owners to limit runoff can create political and legal battles for local jurisdictions and utilities.[100] I made the assumption SPU has the political and legal ability to change how stormwater runoff is accounted. All three scenarios assume SPU is able to monitor and account for stormwater runoff and is able to monitor the effectiveness of BMPs. The second scenario assumed SPU has the capability to run and monitor the tradable allowance program, while the third scenario assumed SPU is implementing and maintaining all BMPs through its 50-year lifespan.

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[99] The 2004 assessed land value from the King County Assessor's Office's database was used to determine cost per square foot.
King County Department of Assessments. *eReal Properties.* http://info.kingcounty.gov/Assessor/eRealProperty/default.aspx (accessed June 5, 2014).
[100] Parikh, Punam, Taylor, Michael A., Hoagland, Theresa. "At the Intersection fo Hydrology, Economics, and Law: Application of Market Mechanisms and Incentives to Reduce Stromwater Runoff." In *Economic Incentives for Stormwater Control*, edited by Hale W. Thurston, 167-192. Boca Raton, FL: CRC Press Taylor & Francis Group.

5.2 Limitations

The assumptions discussed above created limitations in my analysis. The following section discusses how changes to the assumptions result in different outcomes. I estimated how the assumption on costs affected the outcomes in each scenario. I also examined different assumptions on behavior of parcel owners altered BMP adoption. Finally, I explored how the legal and logistical assumptions affected SPU's ability to implement each of the scenarios.

5.2.1 Cost Estimates

Altering runoff assumptions impacted the overall cost estimates in my research. It was assumed the BMPs fully detained the runoff from impervious surfaces during a one-year storm event. BMP's capacity to detain stormwater runoff determined the overall cost per gallon of each BMP. I estimated the expected high and low cost per gallon of stormwater detained for each of the BMPs. These estimates calculated the cost per gallon from a 0.5-year storm event and 2-year storm event. If the BMPs detained only 0.5-year storm, the cost would increase by $2.62 or roughly 22%. A 2-year storm detention capacity would decrease costs to $1.80 or roughly 15%. Table 27 details the high and low cost estimates for each of the BMPs. Altering the assumption by decreasing the detention capacity increased the cost per gallon detained, while increasing detention capacity lowered the cost per gallon detained. I believe my assumption of a 1-year storm event detention capacity is relatively conservative, as most of the BMPs indicated a detention capacity greater than a 1-year storm event. The cost per gallon of detaining stormwater is likely lower throughout all three of the scenarios.

Table 27 High and Low BMP Cost Estimates

	Low Runoff Detaining Capacity (Gal)	Low Runoff Cost per Gal	High Runoff Detaining Capacity (Gal)	High Runoff Cost per Gal
Single-Family	2,172	$ 19.24	3,127	$ 13.36
Duplex	2,260	$ 25.93	3,254	$ 18.01
Apartment	4,421	$ 15.02	6,366	$ 10.43
Retail	9,583	$ 12.32	13,797	$ 8.55
Office	5,939	$ 13.78	8,551	$ 9.57
Parking	7,420	$ 12.64	10,683	$ 8.78
Average	5,299	$ 14.48	7,630	$ 10.06

If BMP detention capacity were in fact higher, the overall cost per gallon detained would decrease in all scenarios. The second scenario would see more parcels implementing BMPs at a lower allowance price. Assuming the low BMP cost per gallon estimates, an $11 allowance price, apartment, retail, office, and parking parcels would implement BMPs. More runoff could be detained at the same cost, lowering the cost per gallon of runoff detained. The behavior in third scenario would not change, as the rate of BMP adoption is based on opportunity costs. The overall cost per gallon would decrease, as SPU is able to manage more runoff at the same costs.

The opportunity costs were estimated in my analysis by taking the most recent assessed land value. This may not be truly reflective of the true opportunity costs of the land. A parcel owner could value parking space more than a grassed area, as a parking space is able to generate income. This could lead to a higher opportunity cost to parcel owner with large areas devoted to parking spaces such as apartment, office, retail and parking parcels. With a higher opportunity cost, the first scenario would see an increase in the total cost of detaining stormwater runoff. The behavior of parcel owners would change in both the second and third scenarios. In the second scenario, a higher opportunity cost increases the cost per gallon of runoff detained, leading to fewer parcels investing in BMPs. A higher allowance cost would be needed to detain the same amount of runoff, leading to a higher total cost. In the third scenario increasing opportunity costs would decrease adoption of BMPs. BMP adoption is based on the whether opportunity costs are lower than the avoided runoff fees. This would result in higher total costs to detain the same amount of stormwater.

Changes to the assumptions on runoff and opportunity costs have significant impacts on the overall costs of the detaining stormwater through BMPs. Runoff changes impact the overall cost per gallon, while changes to opportunity cost impact behavior and costs under each of the scenarios. It is important to consider how assumptions to runoff and opportunity cost affect the outcomes in each scenarios.

5.2.2 Parcel Behavior

My analysis made the assumptions there were no transaction costs in each of the scenarios. However, in any real world situation transaction costs can pose a significant cost to all parties involved. Parcel owners and SPU would likely incur a cost associated with the time and money devoted to acquire the necessary information to choose the most optimal BMP. Transaction costs are incurred in determining runoff from each property, calculating short-term and long-term costs of each BMP, finding suitable BMPs for each parcel, monitoring and enforcing the rules in each scenario, and administrative costs of running each of the programs. These costs can increase the total costs to both parcel owners and SPU, altering the behaviors in each of the scenarios. Transaction costs in the first scenario would likely increase total costs to parcel owners, as they would need information on runoff, appropriate BMPs, the full costs of the BMPs, and all information on the rules and regulations. SPU would experience costs in determining runoff, relaying information to parcel owners, monitoring and enforcement of the rules, and any administrative costs in running the full capture program. Transaction costs in the second scenario would see different behaviors among parcel owners, as there are increased costs to parcel owners and SPU similar to the first scenario. High transaction costs to parcel owners would lead to fewer BMPs being implemented, while high transaction costs to SPU would lead to lower total revenue. In the third scenario high transaction costs would likely affect SPU more, as they incur much of the transaction costs. Parcel owners incur only the transaction costs associated with understanding the rules and regulations of the program. Transaction costs to SPU include calculating runoff, relaying programmatic information to parcel owners, choosing appropriate BMPs for each site, and paying any of the administrative costs of running the credit program. In each of the scenarios, the transaction costs would have to be no greater than the savings to each party from BMPs than the centralized infrastructure to be considered a cheaper alternative.

5.2.3 Legal Issues

Legal aspects of the full BMP capture and tradable allowance program have not been considered in the analysis. SPU could face legal hurdles in changing the method used to assign responsibility for stormwater runoff. Property rights can play a significant role in allowing a utility to manage stormwater runoff. Any rules restricting property owners from allowing runoff could be considered a violation of the takings clause in the Fifth Amendment. The utility must consider a "reasonable use" approach to manage runoff when restricting property rights. These restrictions must be considered rational methods to meet the public health and environmental goals. Proving the link between restricting runoff and meeting environmental and health goals may prove costly in a court of law.[101]

[101] Parikh, Punam, Taylor, Michael A., Hoagland, Theresa. "At the Intersection fo Hydrology, Economics, and Law: Application of Market Mechanisms and Incentives to Reduce Stromwater Runoff." In *Economic Incentives for Stormwater Control*, edited by Hale W. Thurston, 167-192. Boca Raton, FL: CRC Press Taylor & Francis Group.

5.3 Interpreting the Results

This study has stated goals of determining whether BMPs are cost-effective and if so how stormwater management programs can incentivize the adoption of BMPs. Taking into account all of the previously discussed assumptions and limitations, my analysis found that BMPs are often more cost-effective forms of managing stormwater than centralized infrastructure. My scenarios indicated that different approaches to stormwater runoff management programs resulted in various levels of BMP adoption at lower total costs than centralized infrastructure. The second scenario produced the lowest total cost of managing stormwater runoff, however the limitations of the second scenario make the third scenario a more viable option. Furthermore, my findings indicated the current drainage fee for the Ballard CSO basin could be charging parcel owners inequitably.

5.3.1 Low Cost of BMPs

My findings indicate source point control of stormwater runoff are more cost effective than traditional centralized infrastructure. The average cost per gallon of detaining stormwater runoff is $11.86 for BMPs, compared to $18.86 per gallon for centralized infrastructure. Table 28 outlines the costs per gallon for each BMP technology and table 29 outlines the average costs for centralized infrastructure. However, my findings indicated duplex parcel owners had the highest BMP costs per gallon detained at $21.38 per gallon, making BMP options costlier than centralized infrastructure. The BMP technologies for retail and parking parcel owners are lowest, costing $10.16 and $10.12 per gallon. Both of these parcels had a significant portion of the parcel covered by parking spaces. Every parcel type except duplex parcels had lower BMP cost per gallon of detaining stormwater than the centralized infrastructure. These finding indicated that wider adoption of BMPs lower the cost of managing stormwater runoff.

Table 28 Average BMP Costs

	Total Cost	Runoff Detained (Gal)	Cost Per Gal
Single-Family	$ 41,794	2,634	$ 15.87
Duplex	$ 58,603	2,741	$ 21.38
Apartment	$ 66,407	5,362	$ 12.38
Retail	$ 118,034	11,622	$ 10.16
Office	$ 81,819	7,203	$ 11.36
Parking	$ 93,793	9,267	$ 10.12
Avgerage	$ 76,742	6,472	$ 11.86

Table 29 Average Centralized Infrastructure Costs[102]

	Total Cost	Runoff Detained (Gal)	Cost Per Gal
Inline Storage Tank	$ 4,560,000	240,000	$ 19.00
Offline Storage Tank	$ 13,650,000	682,000	$ 20.01
Inline Storage Tank	$ 2,324,000	165,523	$ 14.04
Average	$ 6,844,667	362,508	$ 18.88

5.3.2 Scenarios

The first two scenarios used quantity instruments to manage stormwater runoff, while the third scenario used a price instrument. Quantity instruments assign runoff figure to each parcel, while a price instrument places a price for the runoff. Both the quantity and price instruments internalize the cost of stormwater runoff by assigning responsibility for the runoff to those creating runoff.

The first scenario required parcel owners to fully internalize the cost of managing stormwater. The scenario established a situation where no infrastructure was needed to manage the runoff from parcels. I calculated nearly 19 million gallons of stormwater being detained at a total cost of $300 million to parcel owners. Parcel owners are the only group experiencing a cost in this scenario. The cost per gallon of managing stormwater is $15.95, lower than the $17.69

[102] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

cost per gallon of centralized infrastructure. To manage the 19 million gallons runoff at a cost of $17.69 per gallon, over $332 million would need to be invested in centralized infrastructure. Table 30 details the expected total cost calculations for BMPs and centralized infrastructure for detaining 19 million gallons of stormwater runoff. The first scenario ignores the existing infrastructure in the Ballard CSO basin. Some stormwater is managed in the existing combined sewer system, making a full stormwater capture scenario unrealistic.

Table 30 Cost Comparisons in Scenario 1[103]

	Gal Detained		Cost/ Gal	Total Cost
BMPs	18,800,666	x	$ 15.95	$ 299,910,512
Centralized Infrastructure	18,800,666	x	$ 17.69	$ 332,489,819

The Ballard CSO area currently has the ability to manage the majority of stormwater runoff entering the sewer system. During 2010 in the Ballard CSO basin had an average overflow event of 790,000 gallons .[104] Furthermore, the 2010 CSO amendment plan proposed a little over 1 million gallons to be managed through centralized infrastructure project. [105] Assuming the combined system was over capacity by roughly 1 million gallons, a reduction in 1 million gallons could lead to no overflow events in a typical year. The second scenario could potentially meet a target goal of detaining 1 million gallons of runoff by incentivizing the implementation of BMPs.

The second scenario in my analysis required SPU to create a tradable allowance system. SPU again would assign runoff to each parcel and create stormwater allowances. SPU establishes a set number of allowances or a price for the stormwater allowances and distributes them on the open

[103] Centralized infrastructure cost estimates calculated from proposed plans.
Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.
[104] Seattle Public Utilities. *Combined Sewer Overflow Reduction Program: 2010 - Annual Report.* Report, Restore Our Waters, Seattle Public Utilities, Seattle: City of Seattle, 2010, 1-71.
[105] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

market. My research simulated two price points for the allowances, an $11 per gallon of stormwater runoff price and a $1.09 per gallon of stormwater runoff price. The $11 per gallon price point simulated was used to get the basin to reduce runoff by 1 million gallons. The $1.09 price point generated enough revenue to cover the costs of centralized infrastructure in Seattle's proposed CSO plan.

Under the $11 per gallon allowance cost, retail and parking parcels implemented BMPs, reducing runoff by a total of 1.2 million gallons. The BMP cost per gallon detained for these parcels is lower the allowance cost, causing them to implement BMPs. The other parcels purchased $193 million worth of stormwater allowances. The total costs to parcel owners are lower than the first scenario, at $223 million. SPU experiences a net benefit of $193 million from the revenue. The revenue is collected and used to pay for existing infrastructure. However, without cost data on running the existing infrastructure, I cannot reach any conclusions on how the revenue would be spent. An $11 allowance price point results in a total cost of $11 million to detain 1.2 million gallons of stormwater. The cost per unit of stormwater detained drops to $10.15 per gallon of stormwater detained, significantly lower than the cost per gallon for centralized infrastructure. It would cost nearly $20 million to manage 1.2 million gallons with centralized infrastructure. This comes out to roughly $10 million more than under an $11 allowance cost in the second scenario. Table 31 compares the costs to detain 1.2 million gallons of stormwater in scenario 2 against the centralized infrastructure.

Table 31 Cost Comparison Scenario 2[106]

	Gal Detained		Cost/ Gal	Total Cost
BMPs	1,168,676	x	$ 10.15	$ 11,863,479
Centralized Infrastructure	1,168,676	x	$ 17.69	$ 20,668,032

[106] Centralized infrastructure cost estimates calculated from proposed plans.
Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

A $1.09 price point for allowances would see no parcel owners investing in BMPs. The parcels would all purchase credits, resulting in a cost of $20 million to parcel owners. SPU would see net revenue of $20 million. This revenue meets the costs of a centralized infrastructure project such as the one proposed in the 2010 CSO amendment plan.[107] However, this revenue would be unable to pay for any of the existing infrastructure. This price point demonstrates how changes in allowance prices can simulate differing levels of BMP adoption by parcel owners. This also demonstrates how allowances can be used to generate revenue for SPU to spend on the existing infrastructure.

The second scenario of a tradable allowance system requires parcels owners to pay the majority of costs in stormwater management. Parcels are forced to either pay the cost of detaining through BMPs or pay the cost of purchasing credits for their stormwater runoff. The tradable allowance system creates a straightforward mechanism to generate income for stormwater runoff, as it is directly related to the parcel's contribution to runoff. However, this method of control fundamentally changes how runoff is managed by placing the majority of the burden on parcel owners. As discussed previously, transaction costs associated with the second scenario could create significant legal and political barriers in implementation.

The third scenario in my simulation attempted to minimize the transaction costs and barriers while meeting the stated objectives. The BMP credit program allowed parcel owners to forgo their runoff fees if they allowed SPU to implement BMPs on their property. SPU is assumed to be responsible for operating and maintaining the BMPs over entire lifecycle. Duplex parcel owners were exempt from the program as they had a $21.38 per gallon BMP cost. This cost was

[107] Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

well above the centralized infrastructure cost of $17.69. Using opportunity costs as a determining factor in who would implement BMPs, the scenario saw apartment and office parcels opting to let SPU to implement BMPs on their property. The scenario detained a total of 1.8 million gallons of runoff at a total cost of $22 million, roughly $12.31 per gallon detained. The total costs to parcel owners are $38 million, while SPU received a net benefit of $16 million. The revenue estimates assumed the drainage rates increased at an annual rate of 3% with a 5.5% discount rate over 50 years. My calculations indicated that SPU would lose only $5 million in revenue over the 50-year period, roughly11% of the expected total revenues. SPU still generates $16 million to pay for operating the existing infrastructure in the Ballard CSO basin. The cost to detain 1.8 million gallons using centralized infrastructure costs is estimated to be $32 million, roughly $10 million more than the cost estimated in scenario 3. Table 32 compares the cost in scenario 3 against the estimated centralized infrastructure costs.

Table 32 Cost Comparison Scenario 3[108]

	Gal Detained		Cost/ Gal	Total Cost
BMPs	1,782,991	x	$ 12.31	$ 21,941,457
Centralized Infrastructure	1,782,991	x	$ 17.69	$ 31,532,200

My third scenario created a feasible scenario that reduced stormwater runoff at a lower cost than centralized infrastructure. Parcel owners are forced to internalize part of the costs of stormwater runoff through the drainage fee. The scenario also created an incentive program that promoted the adoption of cheaper BMPs. By utilizing the existing stormwater drainage fee many of the legal and political objections are avoided. The only change to the existing management program is the incorporation of a fee waiver for those allowing SPU to implement BMPs on their

[108] Centralized infrastructure cost estimates calculated from proposed plans.
Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

property and is completely voluntary. The scenario also minimized the burden of cost to parcel owners by sharing the BMP costs with all parcel owners and SPU. Parcel owners paid the opportunity cost, while SPU paid the BMP construction and operating costs. Part of the revenue from all parcels not participating in the fee waiver helped pay for the costs of implementing the BMPs. The majority of transaction costs are experienced by SPU. The burden of estimating runoff, determining appropriate BMPs, providing programmatic information to parcel owners, monitoring and enforcing the rules, and paying the administrative costs of running the program is placed on SPU in this scenario. The only transaction cost to parcel owners is in acquiring information on the program. Again, these transaction costs would need to be no greater than the expected savings from centralized infrastructure approach to be considered cost effective.

5.3.3 Equity in Runoff Fees

The current runoff fee system is based largely on the size of the parcel. For larger residential, commercial, and industrial lots, the fee considers impervious surface coverage. My findings discovered differing dollar charge per unit of runoff to parcels. Duplex parcels with 92% impervious coverage paid less than $0.06 per gallon of runoff, while apartment parcels with 70% impervious coverage paid more than $0.10 per gallon of runoff. Duplex parcels pay 30% less than the average price per gallon for the entire basin, while apartment parcels pay 20% more than the average. Table 33 outlines the fee per unit of runoff for each parcel and the difference from the average fee paid in the basin. If both single-family and duplex parcels are excluded, apartment parcels still end up paying 6% more than the average. The 70% impervious surface coverage of apartment parcels is significantly less than the retail, office, and parking parcels. Table 34 outlines the fees per gallon and difference from the averages for the area of apartment, retail, office, and parking parcels. These findings seem to indicate that parcels with lower impervious surface coverage seem to pay more for their share of runoff. The reduced fees for parcels with lower impervious coverage may not be low enough to reflect the reduced runoff these parcels generate. The discrepancy in fees could be due to off-site management of stormwater in the right of ways and parks, however SPU does not disclose how stormwater drainage fees are calculated and used. These findings indicate that runoff fees may not be truly reflective of stormwater runoff. The costs of stormwater management may be unfairly placing a greater share the of burden on some property owners.

Table 33 Runoff Fee per Gallon (All Parcels)

	Runoff Fee	Runoff (Gal)	Fee per Gal of Runoff	Difference from Avg
Single-Family	$ 1,175,994	13,189,999	$ 0.0892	3.3%
Duplex	$ 159,129	2,658,942	$ 0.0598	-30.7%
Apartment	$ 170,277	1,646,192	$ 0.1034	19.8%
Retail	$ 90,490	1,011,140	$ 0.0895	3.7%
Office	$ 12,828	136,857	$ 0.0937	8.6%
Parking	$ 14,342	157,536	$ 0.0910	5.5%
Average	$ 1,623,059	18,800,666	$ 0.0863	

Table 34 Runoff Fee per Gallon (Excluding SF and Duplex)

	Runoff Fee	Runoff (Gal)	Fee per Gal of Runoff	Difference from Avg
Apartment	$ 170,277	1,646,192	$ 0.1034	6.0%
Retail	$ 90,490	1,011,140	$ 0.0895	-8.3%
Office	$ 12,828	136,857	$ 0.0937	-3.9%
Parking	$ 14,342	157,536	$ 0.0910	-6.7%
Average	$ 287,936	2,951,725	$ 0.0975	

5.4 Further Research

Additional research can continue to refine the findings in my thesis. My study uses the limited information that is publicly available to determine costs and outcomes. To strengthen my findings, I propose additional research on runoff, increased BMP options, the costs of current infrastructure, and the environmental benefits of BMPs.

My study uses a simplified model to determine runoff or the Ballard CSO basin. Creating a more accurate runoff model could improve the findings presented in my thesis. The runoff model used in my research was based strictly on impervious surface coverage. A more complete hydrological analysis exploring soil types, impervious surfaces, and slope would provide more accurate runoff figures for the Ballard CSO basin. Absorption rates differ depending on the slope, soil, and surface cover and impact the runoff leaving parcels. My analysis did not consider these differences when calculating runoff. The hydrological analysis could also examine parcel-by-parcel runoff. My analysis simplified the runoff by using an average parcel to extrapolate runoff data for the entire area.

My study explored 10 BMP options for detaining stormwater runoff. My findings concluded that rain gardens, curb-contained bioretention, and cisterns as the only viable BMP options. The analysis did not take into account Ballard specific characteristics such as soil conditions and slope in determining whether the recommended BMPs would be effective in detaining the runoff. Many other BMP technologies exist to help reduce and manage stormwater runoff not considered in this paper. Exploring other options that are designed specifically for the conditions in the Ballard CSO can provide more accurate BMP cost estimates. My study also did not consider partial detention of stormwater runoff on parcels. My analysis only examined BMP options that detained all of the runoff. Smaller scale options that detain part of the runoff could potentially lower costs for implementation, allowing more parcels to reduce runoff at cheaper costs. Further research exploring these options can provide greater information on the costs of managing stormwater in the Ballard CSO basin.

My analysis lacked information on the existing stormwater infrastructure and runoff from parcels such as right of ways, parks, publicly owned land, and vacant lots. My research could have used more information on how much revenue is needed to manage all the runoff in Ballard CSO basin. My analysis only covered 62% of the basin. Exploring the true cost of running the existing system, along with the capacity of the system could potentially add valuable insight to my analysis. With cost data on running the system for the Ballard CSO basin, I could determine the true costs of running each scenario, leading to more accurate goals and outcomes for reducing runoff.

My study did not discuss many of the environmental benefits of BMPs. BMPs can reduce pollution loads in stormwater runoff through natural processes. BMPs filter contaminates and clean stormwater runoff effectively at very low costs.[109] Reducing pollutant loads have a beneficial impact that can be quantified. BMPs also provide aesthetic benefits to property owners, increasing property values. A study that quantifies the environmental and property value benefits of BMPs can lower the total costs in my analysis and provide more reasons for implementing BMPs.

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[109] Hinman, Curtis, Wulkan, Bruce. *Low Impact Development: Technical Guidance Manual for Puget Sound.* Manual, Washington State University Extension, Puget Sound Partnership, Puget Sound Partnership, 2012, 1-365.

6 Conclusion

This thesis set out to determine cost-effective methods to reduce combined sewer overflow (CSO) events in Seattle. More specifically, my analysis attempted to answer whether best management practices (BMP) source point controls of stormwater runoff were cost-effective, and if so how stormwater management programs could incentivize the adoption of BMPs on private property. I found most BMPs to be cheaper than centralized infrastructure, and I created a management program that promoted the adoption of BMPs on parcels at a lower total costs than centralized infrastructure.

My findings found BMPs to have lower cost per unit of stormwater runoff detained than centralized infrastructure. When implemented on parcels in the Ballard CSO basin, I identified three BMPs that had a lower cost per gallon than centralized infrastructure. For single-family residential parcel types in the Ballard CSO basin rain gardens produced lower costs. For apartment, retail, and office parcel types, the BMP options of cisterns and curb-contained bioretention produced lower costs. For parking parcel types, the BMP option of a curb-contained bioretention produced a lower cost. The only parcel type experiencing higher cost than centralized infrastructure was the duplex parcels with BMP options of cisterns and curb-contained bioretention. The average price of detaining stormwater through BMPs in the Ballard CSO basin is estimated to be \$11.86 per gallon detained, compared to \$18.88 per gallon detained under centralized infrastructure.

I simulated three alternative forms of managing stormwater runoff that incentivized the adoption of BMPs. The first scenario assigned stormwater runoff to each parcel under a full stormwater capture program. This required all parcels to detain all stormwater runoff on-site through BMPs, with parcel owners being responsible for the full cost of the BMPs. The second scenario assigned stormwater runoff to each parcel under a tradable allowance program. Parcel owners were given the option to purchase stormwater allowances or to detain stormwater on-site. Parcel owners paid the full cost of BMPs or the full cost of purchasing runoff allowances. The third scenario used the existing stormwater runoff fee with a BMP credit program. Parcel owners allowing SPU to implement BMPs on-site had their runoff fees waived. Parcel owners either paid the runoff fee or gave up the use of their land for BMPs. The cost to SPU is the construction and maintenance costs of BMPs and the forgone revenue from avoided runoff fees. Each of these scenarios had lower cost per gallon of managing stormwater runoff than centralized infrastructure.

My first scenario estimated the detention of 19 million gallons at a total cost of $300 million dollars. The second scenario produced the lowest costs of detaining stormwater. I estimated 1.2 million gallons being detained at a cost of $12 million. However, the first two scenarios fundamentally altered how parcels were assigned responsibility for stormwater runoff. This created many legal and logistical barriers to implementation. The third scenario utilized the existing mechanisms to assign responsibility for runoff, creating fewer barriers to implementation. The result is a more realistic scenario with an estimated stormwater runoff detention of 1.8 million gallons at a cost of $22 million. All three scenarios simulated lower total costs than traditional centralized infrastructure.

Each scenario required parcel owners to internalize the cost of stormwater runoff. The first two scenarios assigned the runoff quantity to each parcel, while third scenario assigned a cost to parcels based on runoff from each parcel. Each scenario promoted the adoption of BMPs on-site to manage runoff. The first scenario prompted all parcels to invest in BMPs, while the second scenario saw retail and parking parcels investing in BMPs. The third scenario created a situation where apartment and office parcels allowed SPU to build BMPs on their land. By assigning the responsibility and cost of stormwater runoff differently, differing levels of BMP adoption were observed. The third scenario shared the total cost of BMPs, resulting in the most desirable outcome.

6.1 Overall Implications for Seattle

It is highly unlikely for the city of Seattle to fundamentally change how stormwater runoff is managed in Seattle. SPU will likely continue to using the drainage fee to charge parcel owners for runoff. Despite demonstrating the potential cost savings of a quantity instruments such as those in the second scenario, it is highly unlikely for Seattle to adopt a runoff allowance program. The third scenario simulated how the current drainage fee could adopt a BMP credit to induce BMPs on private property. Seattle currently provides very few incentives to implement BMPs on existing developments. The residential Rainwise program offers rebates for cisterns and rain garden to single family parcels, while the drainage fee offers discounts to large residential, commercial, and industrial parcels using low impact development practices.[110] These programs provide little incentive to property owners to implement technologies that reduce stormwater runoff. My thesis demonstrates how incorporating a BMP credit to the existing stormwater management program can provide enough compensation to existing developments to reduce stormwater runoff through BMPs on private property.

The city is planning on investing a significant amount of money to reduce CSO events. The current stormwater drainage fee is expected to rise in the next couple of years, signaling that

[110]Seattle Public Utilities. "2010 CSO Reduction Plan Amendment." Restore Our Waters, Seattle Public Utilities, Seattle, May 2010.

perhaps runoff has been undercharged for years.[111] In calculating the fees associated with each parcel type, there were some indications that some parcels may be overpaying for stormwater runoff. The city should ensure the runoff fee is closely tied to the actual amount of runoff parcels produce. With the expected growth in Seattle housing, dense developments could increase on smaller residential parcels. This could lead to increased runoff with lower amount of revenue being generated by runoff fees. The city should take into account the growing changes to the urban development patterns to ensure equitable rates are charged to parcel owners.

The city of Portland has worked to improve transparency in stormwater billings. Portland's stormwater bill clearly outlines the contribution to on-site and off-site stormwater management. The on-site portion of the drainage bill allows property owners to receive discounts by implementing runoff-reducing technology.[112] Seattle's drainage fee is collected as part of the property tax on parcels. The fee only offers a slight low-impact development discount to large residential, commercial, and industrial parcels, but offers no discount to single family and smaller residential properties. Following Portland's example, Seattle could improve the transparency in how the drainage bill pays for stormwater infrastructure on-site and off-site. Furthermore, Seattle could incorporate discounts to smaller residential parcels, allowing more properties to control a portion of their drainage bill. As demonstrated my analysis, allowing customers to control some of the runoff fees can impact behavior on parcels.

In my thesis, I demonstrated how BMP source point stormwater runoff is cost effective method of managing stormwater runoff. I also demonstrated how stormwater management programs could create incentives for the adoption of BMPs. A BMP credit program using the

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[111] Thompson, Lynn. "Seattle Public Utilites Seeking Increase in Rates." *The Seattle Times*, April 24, 2014.
[112] City of Portland Bureau of Environmental Services. "Clean River Rewards Stormwater Discount Program." Policy, Auditor's Office, City of Portland, Portland, OR, 2012.

existing stormwater drainage fee can help promote the widespread adoption of BMPs with lower total costs of managing stormwater runoff.

Figures

Figure 1 Context Map

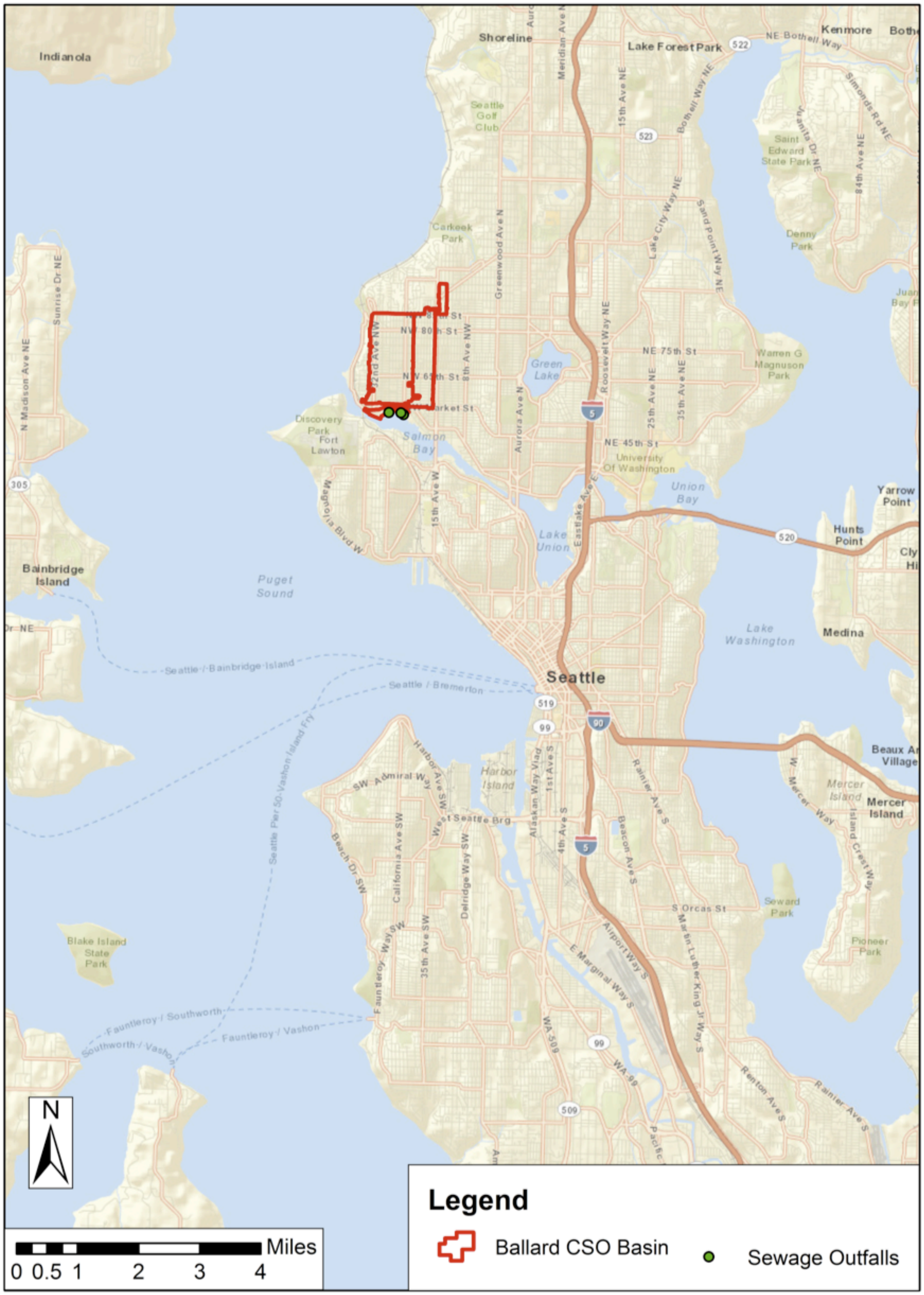


Figure 2 Ballard CSO Basin

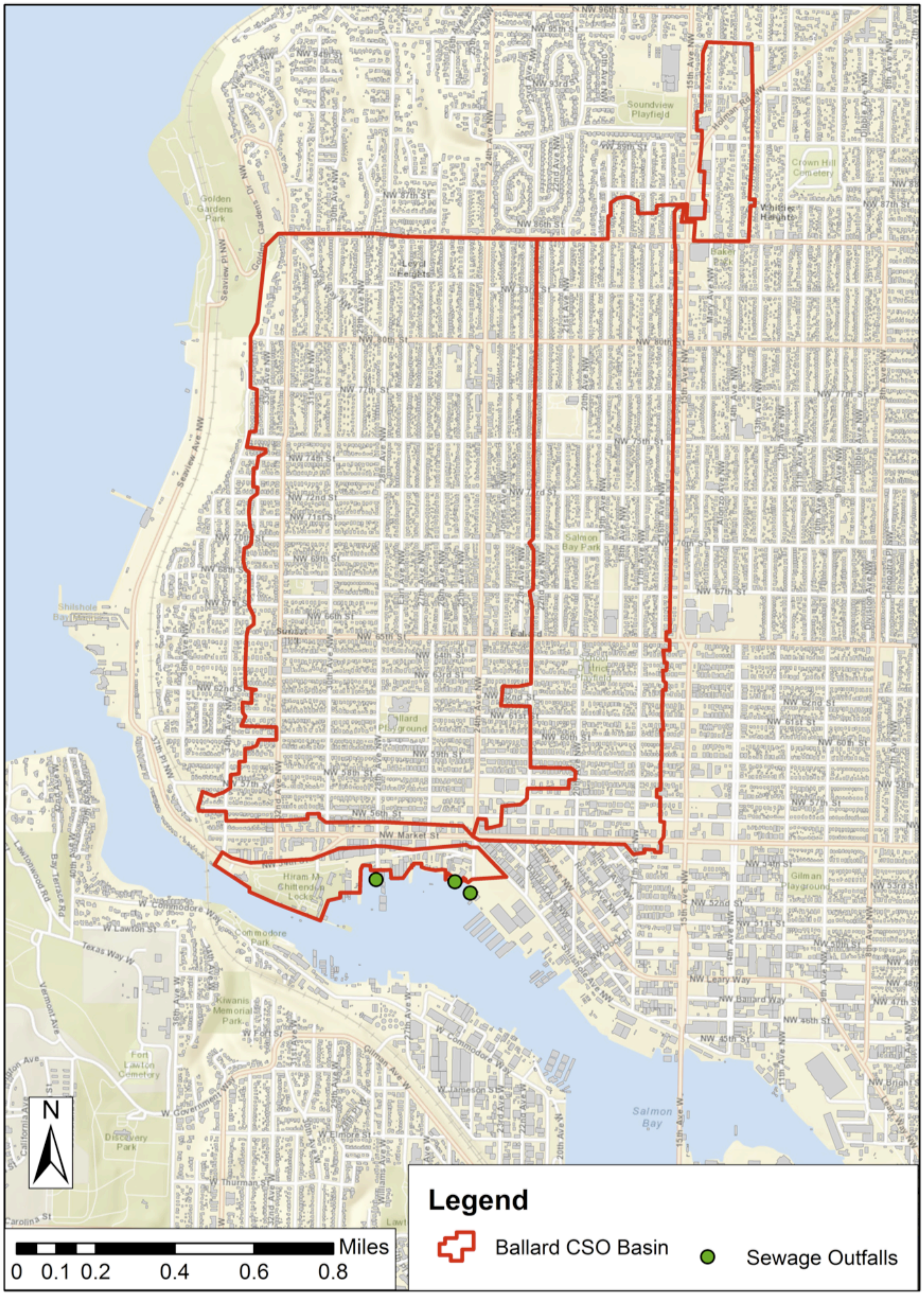


Figure 3 Ballard CSO Basin Parcel Types

Figure 4 Parcel Type Impervious Coverage

Single-Family
Impervious Surfaces:
Building and
Walkways

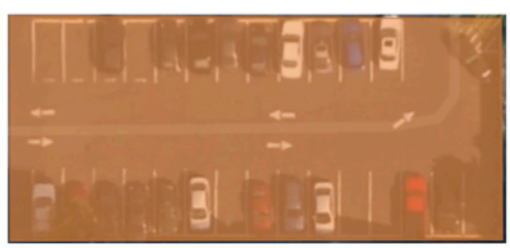
Duplex
Impervious Surfaces:
Building and
Walkways

Apartment
Impervious Surfaces:
Building, Parking, and
Walkways

Retail
Impervious Surfaces:
Building and Parking

Office
Impervious Surfaces:
Building and Parking

Parking
Impervious Surfaces:
Parking



Diagrams

Diagram 1 Stormwater Runoff

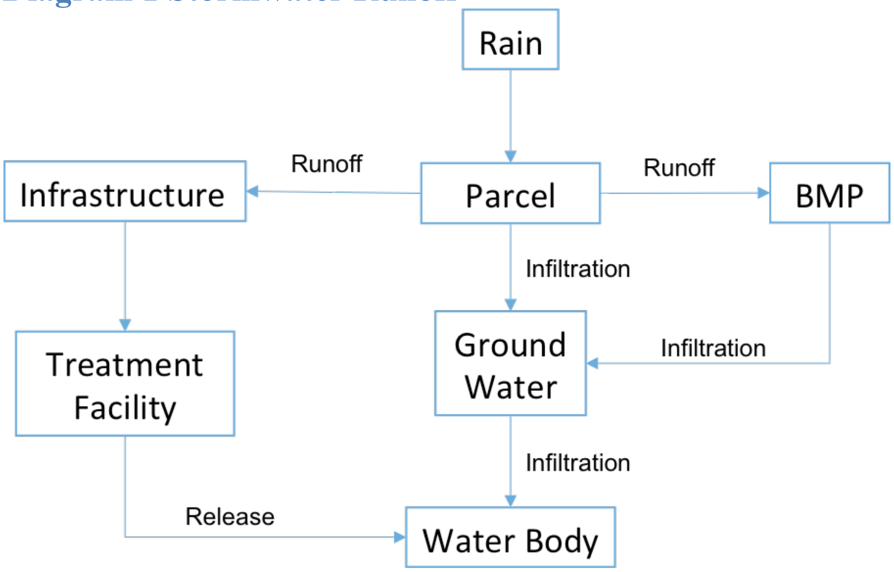


Diagram 2 Current Stormwater Drainage Fees

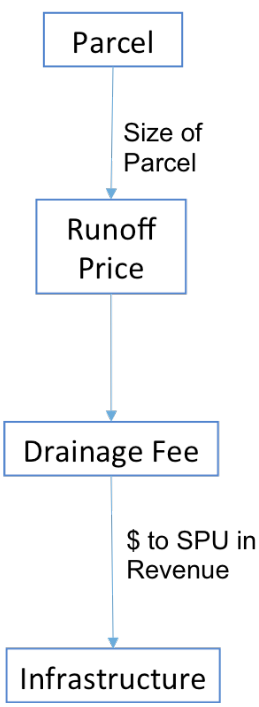


Diagram 3 Scenario 1

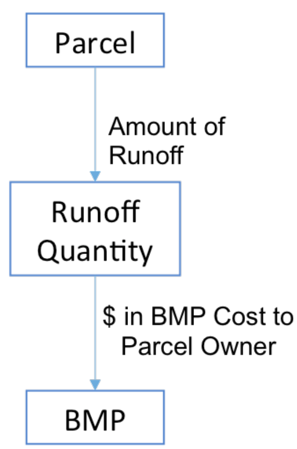


Diagram 4 Scenario 2

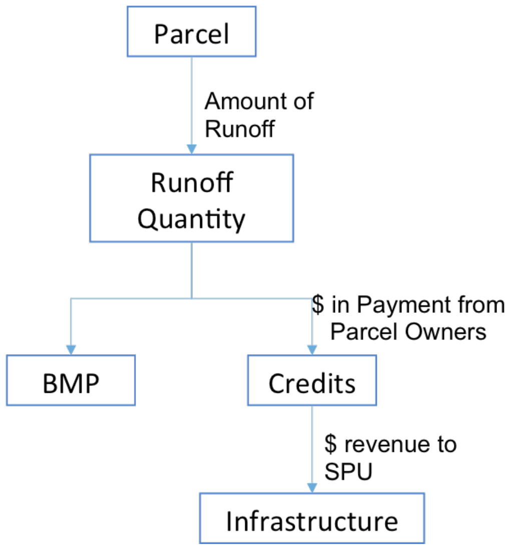
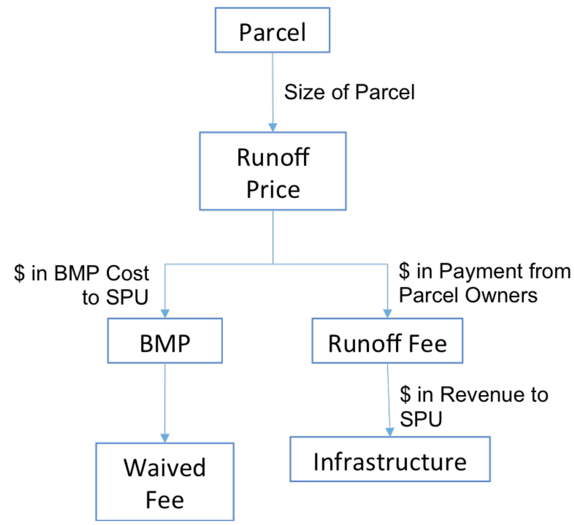


Diagram 5 Scenario 3



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Appendix A Parcel Drainage Rates [113]

Small Residential Annual rate per parcel (1)

	2013	2014
Under 3000 sq. ft.	$164.05	$180.96
3000-4999 sq. ft.	$212.92	$234.87
5000-6999 sq. ft.	$289.11	$318.92
7000-9999 sq. ft.	$365.97	$403.70

All Other Properties Annual rate per 1,000 square feet

	2013	2014
Undeveloped (0-15% Impervious)		
Regular	$23.31	$25.71
Low Impact (2)	$13.65	$15.06
Light (16-35% Impervious)		
Regular	$36.05	$39.76
Low Impact (2)	$28.35	$31.27
Medium (36-65% Impervious)		
Regular	$52.35	$57.75
Low Impact (2)	$42.11	$46.45
Heavy (66-85% Impervious)	$70.23	$77.48
Very Heavy (86-100% Impervious) (3)	$83.08	$91.65

(1) Single Family Residential & Duplex parcels less than 10,000 square feet which are charged a flat rate per parcel rather than a fee based on the percent impervious. Rates for other properties are per 1,000 square feet based on the percent of impervious surface.

(2) A customer in the Undeveloped, Light or Medium rate category with a significant amount of highly pervious (absorbent) surface may qualify for the Low Impact rate.

(3) "Very heavy" does not necessarily mean heavily developed. A parking lot would be classified as "very heavy" since it is 100% impervious.

[113] Seattle Public Utilities. "Drainage Rates Schedule." *Drainage Rates.* City of Seattle. http://www.seattle.gov/util/MyServices/Rates/DrainageRates/RateSchedule/index.htm (accessed April 24, 2014).

Appendix B Credit Options[114]

Summary of Credit Options					
Utility	**Eligible Users**	**Basis for Credit**	**Design Storm**	**Maximum Credit**	**Typical Credit**
Gainesville, Fla.	Nonresidential properties	Volume of onsite retention	25-year, 24-hour	100% of base fee	15%-35%
Orlando, Fla.	Commercial and multifamily residential	Onsite retention or detention	NA	42%	42%
Wichita, Kan.	Properties less than or equal to 50 ERUs	Two credits: volume of detention or retention	1. 100-year 2. Complete retention	1. 40% 2. 80%	Currently no applications
Louisville-Jefferson County, Ky.	Commercial properties	Onsite detention of peak flows	2-year, 10-year, and 100-year predevelopment runoff	82%	Varies with degree of control
St. Paul, Minn.	Nonresidential properties	Onsite detention of peak flows; acreage, peak flows	5-year and 100-year; release limited to (1.64 ft^3/ac/s)	10% (5-year) 25% (100-year)	Varies with degree of control
Charlotte, N.C.	Commercial, industrial, institutional, multifamily, residential, and homeowner associations	1. Peak discharge 2. Total runoff volume 3. Annual pollutant loading reduction	1. 10-year, 6-hour 2. 2-year, 6 hour 3. Reduction in loading	1. 50% 2. 25% 3. 25% Up to 100%	Varies with degree of control
Durham, N.C.	Nonresidential properties	Pollution credits for water quality and quantity controls	State standards for facility design; estimated pollutant runoff efficiency	25%	Few applications received
Cincinnati, Ohio	Commercial properties	Onsite retention	Limit discharge to predevelopment runoff	50%	Credit never used
Tulsa, Okla.	Privately maintained facilities	50% greater detention; maintenance costs of onsite facilities	NA	60%	Varies
Austin, Texas	Commercial properties	Onsite detention; inspection	NA	50%	50%
Bellevue, Wash.	All properties	Onsite detention; intensity of development	NA	Reduction of one rate (intensity of development) class	Varies
King County, Wash.	Commercial properties	Private maintenance	NA	Reduction of one rate class	Varies

[114] Doll, Lindsey. *Credits Bring Economic Incentives for Onsite Stormwater Management.* Bulletin, Water Envrionment Federation, Watershed & Wet Weather Technical Bulletin, 1999.

Appendix C Estimated Fee Revenues[115]

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Single-Family	$ 241.92	$ 249.17	$ 256.65	$ 264.35	$ 272.28	$ 280.45	$ 288.86	$ 297.53	$ 306.45	$ 315.65	$ 325.12	$ 334.87	$ 344.91
Duplex	$ 164.05	$ 168.97	$ 174.04	$ 179.26	$ 184.64	$ 190.18	$ 195.88	$ 201.76	$ 207.81	$ 214.05	$ 220.47	$ 227.08	$ 233.90
Apartment	$ 554.65	$ 571.29	$ 588.43	$ 606.08	$ 624.26	$ 642.99	$ 662.28	$ 682.15	$ 702.61	$ 723.69	$ 745.40	$ 767.76	$ 790.79
Retail	$ 1,040.11	$ 1,071.31	$ 1,103.45	$ 1,136.56	$ 1,170.65	$ 1,205.77	$ 1,241.94	$ 1,279.20	$ 1,317.58	$ 1,357.11	$ 1,397.82	$ 1,439.75	$ 1,482.95
Office	$ 675.13	$ 695.39	$ 716.25	$ 737.74	$ 759.87	$ 782.66	$ 806.14	$ 830.33	$ 855.24	$ 880.89	$ 907.32	$ 934.54	$ 962.58
Parking	$ 796.79	$ 820.70	$ 845.32	$ 870.68	$ 896.80	$ 923.70	$ 951.41	$ 979.96	$ 1,009.36	$ 1,039.64	$ 1,070.82	$ 1,102.95	$ 1,136.04

Year	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Single-Family	$ 355.26	$ 365.92	$ 376.90	$ 388.20	$ 399.85	$ 411.85	$ 424.20	$ 436.93	$ 450.04	$ 463.54	$ 477.44	$ 491.77	$ 506.52
Duplex	$ 240.91	$ 248.14	$ 255.58	$ 263.25	$ 271.15	$ 279.28	$ 287.66	$ 296.29	$ 305.18	$ 314.34	$ 323.77	$ 333.48	$ 343.48
Apartment	$ 814.52	$ 838.95	$ 864.12	$ 890.05	$ 916.75	$ 944.25	$ 972.58	$ 1,001.75	$ 1,031.81	$ 1,062.76	$ 1,094.64	$ 1,127.48	$ 1,161.31
Retail	$ 1,527.44	$ 1,573.26	$ 1,620.46	$ 1,669.07	$ 1,719.14	$ 1,770.72	$ 1,823.84	$ 1,878.55	$ 1,934.91	$ 1,992.96	$ 2,052.75	$ 2,114.33	$ 2,177.76
Office	$ 991.45	$ 1,021.20	$ 1,051.83	$ 1,083.39	$ 1,115.89	$ 1,149.37	$ 1,183.85	$ 1,219.36	$ 1,255.95	$ 1,293.62	$ 1,332.43	$ 1,372.41	$ 1,413.58
Parking	$ 1,170.12	$ 1,205.22	$ 1,241.38	$ 1,278.62	$ 1,316.98	$ 1,356.49	$ 1,397.18	$ 1,439.10	$ 1,482.27	$ 1,526.74	$ 1,572.54	$ 1,619.72	$ 1,668.31

Year	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052
Single-Family	$ 521.71	$ 537.37	$ 553.49	$ 570.09	$ 587.19	$ 604.81	$ 622.95	$ 641.64	$ 660.89	$ 680.72	$ 701.14	$ 722.17	$ 743.84
Duplex	$ 353.79	$ 364.40	$ 375.33	$ 386.59	$ 398.19	$ 410.14	$ 422.44	$ 435.12	$ 448.17	$ 461.61	$ 475.46	$ 489.73	$ 504.42
Apartment	$ 1,196.15	$ 1,232.03	$ 1,268.99	$ 1,307.06	$ 1,346.27	$ 1,386.66	$ 1,428.26	$ 1,471.11	$ 1,515.24	$ 1,560.70	$ 1,607.52	$ 1,655.75	$ 1,705.42
Retail	$ 2,243.09	$ 2,310.38	$ 2,379.69	$ 2,451.09	$ 2,524.62	$ 2,600.36	$ 2,678.37	$ 2,758.72	$ 2,841.48	$ 2,926.72	$ 3,014.53	$ 3,104.96	$ 3,198.11
Office	$ 1,455.98	$ 1,499.66	$ 1,544.65	$ 1,590.99	$ 1,638.72	$ 1,687.89	$ 1,738.52	$ 1,790.68	$ 1,844.40	$ 1,899.73	$ 1,956.72	$ 2,015.42	$ 2,075.89
Parking	$ 1,718.36	$ 1,769.91	$ 1,823.01	$ 1,877.70	$ 1,934.03	$ 1,992.05	$ 2,051.81	$ 2,113.37	$ 2,176.77	$ 2,242.07	$ 2,309.33	$ 2,378.61	$ 2,449.97

Year	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063
Single-Family	$ 766.15	$ 789.14	$ 812.81	$ 837.20	$ 862.31	$ 888.18	$ 914.83	$ 942.27	$ 970.54	$ 999.66	$ 1,029.65
Duplex	$ 519.55	$ 535.14	$ 551.19	$ 567.73	$ 584.76	$ 602.30	$ 620.37	$ 638.98	$ 658.15	$ 677.90	$ 698.23
Apartment	$ 1,756.58	$ 1,809.28	$ 1,863.56	$ 1,919.46	$ 1,977.05	$ 2,036.36	$ 2,097.45	$ 2,160.37	$ 2,225.19	$ 2,291.94	$ 2,360.70
Retail	$ 3,294.05	$ 3,392.88	$ 3,494.66	$ 3,599.50	$ 3,707.49	$ 3,818.71	$ 3,933.27	$ 4,051.27	$ 4,172.81	$ 4,297.99	$ 4,426.93
Office	$ 2,138.16	$ 2,202.31	$ 2,268.38	$ 2,336.43	$ 2,406.52	$ 2,478.72	$ 2,553.08	$ 2,629.67	$ 2,708.56	$ 2,789.82	$ 2,873.51
Parking	$ 2,523.47	$ 2,599.17	$ 2,677.15	$ 2,757.46	$ 2,840.19	$ 2,925.39	$ 3,013.15	$ 3,103.55	$ 3,196.66	$ 3,292.55	$ 3,391.33

[115] Based on 2014 drainage rates with an inflation of 3%. Seattle Public Utilities.
"Drainage Rates Schedule." *Drainage Rates.* City of Seattle. http://www.seattle.gov/util/MyServices/Rates/DrainageRates/RateSchedule/index.htm (accessed April 24, 2014).