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Seattle Public Utilities
Seattle, WA

Expanding the Benefits of Seattle's Green Stormwater Infrastructure

Examining Values Previously Unmeasured from Past and Potential Future Efforts in Seattle, Washington

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About the Green Infrastructure Technical Assistance Program

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls in undeveloped areas, the water is absorbed and filtered by soil and plants. When rain falls on roofs, streets, and parking lots, however, the water cannot soak into the ground. In most urban areas, stormwater is drained through engineered collection systems and discharged into nearby waterbodies. The stormwater carries trash, bacteria, heavy metals, and other pollutants from the urban landscape, polluting the receiving waters. Higher flows also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water. These neighborhood or site-scale green infrastructure approaches are often referred to as *low impact development*.

EPA encourages the use of green infrastructure to help manage stormwater runoff. In April 2011, EPA renewed its commitment to green infrastructure with the release of the *Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure*. The agenda identifies technical assistance as a key activity that EPA will pursue to accelerate the implementation of green infrastructure.

In February 2012, EPA announced the availability of $950,000 in technical assistance to communities working to overcome common barriers to green infrastructure. EPA received letters of interest from over 150 communities across the country, and selected 17 of these communities to receive technical assistance. Selected communities received assistance with a range of projects aimed at addressing common barriers to green infrastructure, including code review, green infrastructure design, and cost-benefit assessments. The City of Seattle was selected to receive assistance to quantify the economic value of several different benefits associated with green stormwater infrastructure efforts in the city.

For more information, visit *http://www.epa.gov/greeninfrastructure*.

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Contents

Executive Summary ES-1
Background ES-1
This Analysis ES-3
Report Organization ES-3
Results ES-4
1 Introduction 1
1.1 Purpose 1
1.2 Organization of Report 2
2 Approach and Methods 3
2.1 BMPs Included in the Analysis 3
2.2 Scenarios 4
2.3 Analytical Approach 4
3 Inventory of Seattle's GSI Facilities 8
4 Build-Out Scenarios 12
5 Economic Analysis 13
5.1 Stormwater Treatment Benefits 13
5.2 Water – Potable Water Treatment 17
5.3 Energy – Household Use 20
5.4 Greenhouse Gas Emissions and Sequestration 24
5.5 Air Quality 28
5.6 Small-Scale Habitat 32
5.7 Hydrologic Function 36
5.8 Mental Health 42
5.9 Ecological Literacy and Behavioral Change 45
5.10 Case Study: Embedded Energy 47
5.11 Case Study: Economic Impacts of GSI 50
6 Climate Change Resilience 58
6.1 Sanitary Sewer Overflows 60
7 Discussion and Summary 61
Appendix A. GSI Inventory A-1
1. GSI Facilities by Category A-1
2. Geographic Summary of Stormwater Treatment A-5

3. Seattle's GSI Projects in a Socioeconomic Context A-6
4. Conversion Factors A-7
Appendix B. Developing Build-Out Scenarios B-1
Appendix C. Seattle's Sewer System C-1
Appendix D. Combined Sewer Overflows D-1
Appendix E. Sanitary Sewer Overflows E-1

Figures

Figure 1. Analytical Steps 3
Figure 2. Total Economic Value 5
Figure 3. Spatial Distribution of GSI Facilities Included in the Inventory 10
Figure 4. Per-Acre Stormwater Management by GSI Facilities in the Inventory 11
Figure 5. Unhealthy and Very Unhealthy Air Quality Days in Seattle (1980–2011) 31
Figure 6. Illustrative Value of Benefits from Improving Fish Population Numbers 39
Figure 7. Average Annual Unemployment Rate 52
Figure 8. Project Costs and Management Volume for RainWise Facilities 56
Figure 9. RainWise Project Spending 57

Tables

Table 1. Description of BMPs Included in the Analysis 3
Table 2. Summary of Techniques Used to Estimate Economic Values in This Study 5
Table 3. Summary of Existing GSI Inventory (gallons managed per year) 8
Table 4. Summary of Existing GSI Inventory by Facility Type. 9
Table 5. Summary of GSI Implemented through 2050 12
Table 6. Summary of Approach by Benefit Category 13
Table 7. Summary of Avoided Treatment Costs in the Combined Sewer Basin 15
Table 8. Tree-Related Energy Savings (per tree per year) 21
Table 9. Summary of Tree-related Energy Benefits to Households 22
Table 10. Voluntary and Regulatory Carbon Markets (2011 Summary) 25
Table 11. Treatment-Related Emissions at West Point Wastewater Treatment Plant 26
Table 12. Summary of 100-Year Volume and NPV of GHG Benefits 27
Table 13. Air Pollution Removal by Urban Trees in Seattle 30
Table 14. Summary of 100-Year NPV of Air Quality Benefits 32
Table 15. Habitat Area (Acres) 35

Table 16. Lifecycle GHG Emissions of Two Projects.......... 50
Table 17. Summary of Economic Impacts in King County.......... 54
Table 18. Direct Impacts of Construction Costs in King County.......... 54
Table 19. Summary of RainWise Projects (as of September 2012) 56
Table 20. Summary of Contractor Characteristics.......... 57
Table 21. Summary of Direct Economic Impacts of RainWise.......... 58
Table 22. Summary of Simulation Scenarios and Estimated Number of SSOs per Year.......... 60
Table 23. Summary of Results.......... 61
Table 24. Summary of Results (100-year NPV of benefits per unit) 62
Table 25. Distribution of Benefits across Beneficiaries 63

Executive Summary

This report evaluates some of the economic benefits beyond stormwater treatment (co-benefits) associated with existing and potential future green stormwater infrastructure (GSI) facilities in Seattle, Washington. More specifically, this report identifies, describes, quantifies, and values a subset of previously undescribed environmental and socioeconomic effects of the existing inventory of GSI facilities in Seattle as well those of potential future GSI efforts in the city. By delving into Seattle's extensive site inventory, this report reveals a variety of ways that GSI can provide benefits to a community. The intention is to increase understanding of co-benefit categories most likely to have measurable (and previously unquantified or undescribed) economic value to utility/rate-payers, to the broader public, and to private individuals or sectors. The level of GSI implementation and wealth of inventory data for Seattle allow these expanded investigations.

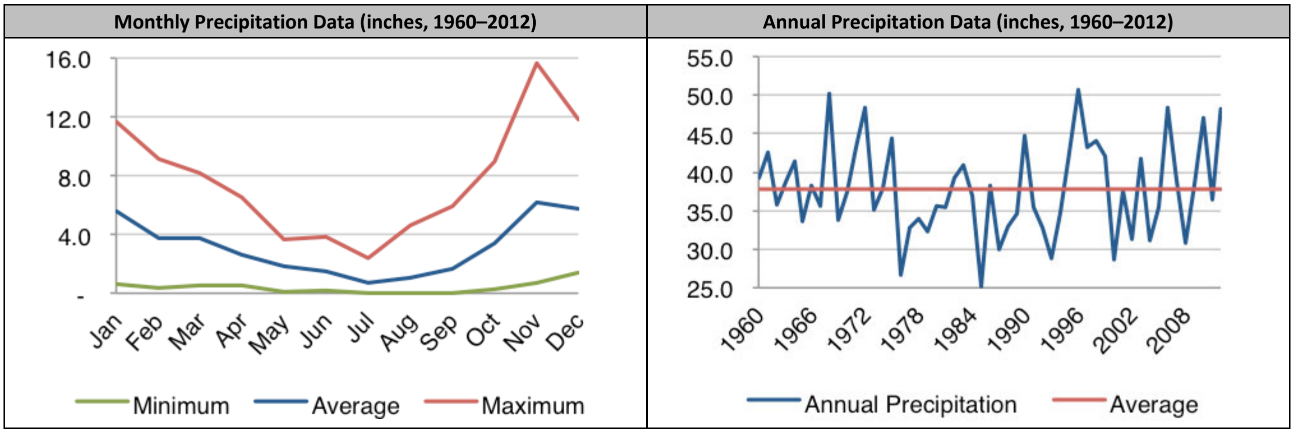
The results of this analysis as well as the analytical approach can help inform decision-making related to stormwater management across the country. Seattle has made a substantial investment in GSI and has compiled and tracked a wide array of quantitative and qualitative information about these assets. The intention is to identify the effects of these GSI efforts and assess how they align with demands and scarcities in Seattle and beyond to provide valuable goods and services. This analysis is based on local primary data to the fullest extent possible, while also employing nationally relevant information to corroborate and expand the applicability of the results. The results of this analysis shed light on the value of GSI-related benefits beyond those directly linked to stormwater management and can help decision makers compare their options holistically when deciding their own management approaches.

Background

According to historic precipitation data, Seattle's average monthly rainfall varies seasonally from a low of less than an inch in July to more than 6 inches in November (see Figure ES-1). In 2006, November rainfall totaled nearly 16 inches. The same data indicate that Seattle's average annual rainfall is approximately 38 inches. Recent research from the University of Washington's Climate Impacts Group suggests that, with climate change, the Seattle area can expect more precipitation and warmer temperatures that will decrease snowfall and increase rainfall upstream.[1] Together, these changes in temperature and precipitation have the potential to increase the city's vulnerability to flooding, back-ups and overflows, and underscore the value of adaptive management approaches.

[1] See, for example, University of Washington, Climate Impacts Group. 2009. *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*.

Figure ES-1. Monthly and Annual Precipitation Data (Seattle, Washington)

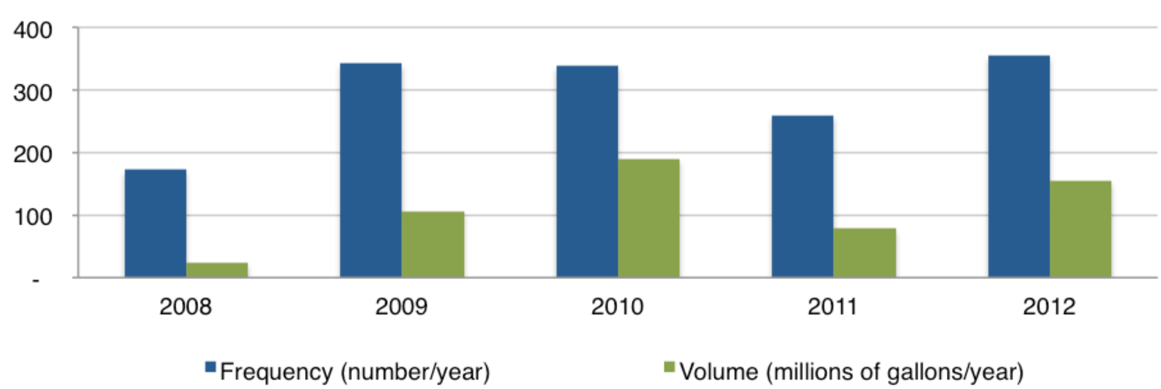


Source: Western Regional Climate Center. 2013. *Seattle Tacoma WSCMO AP, Washington (457473)*. Retrieved on June 28, 2013 from *http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa7473*.

Seattle relies on two types of sewer systems: a separate stormwater system in newer areas of the city collects stormwater and discharges it directly into nearby waterways, and a combined sewer system (CSS) in older areas that mixes stormwater with wastewater and conveys it to a treatment facility before discharging it into nearby waterways. During severe storm events, the volume of stormwater entering the CSS can overwhelm the system and cause overflows, resulting in untreated stormwater and wastewater spilling into nearby waterways.

The frequency of combined sewer overflows (CSOs) has declined from nearly 3,000 per year in the 1980s to fewer than 400 per year more recently (Figure ES-2). The city's objective is to reduce the frequency of CSO events to no more than one event per each of its 92 outfalls per year. To meet this objective of controlling a greater total share of total stormwater volume at the same time total stormwater runoff increases, Seattle must incorporate potential future trends in population growth and precipitation patterns into their approach and exploit all opportunities, actively seeking alternative management options in addition to enhancing existing gray infrastructure. Because GSI can be incrementally and relatively rapidly expanded and adapted as necessary, it presents an opportunity to expand the set of tools available to the city in managing its stormwater and in meeting CSO control objectives.

Figure ES-2. Frequency and Magnitude of CSO Events (2008–2012)



Source: Seattle Public Utilities. 2013. *2012 Annual Report CSO Reduction Program*.

This Analysis

In addition to managing stormwater, GSI efforts provide a number of co-benefits. This report examines the economic value of several of these benefits. In some cases, the benefits derived from implementing GSI are tangible and have real-life consequences for the balance sheets of municipalities, utilities, and households. In other cases, the benefits may not show up on financial balance sheets, but rather may incorporate themselves into the well-being of local and regional residents. This report considers both types of benefits.

These social and environmental co-benefits are quantified and valued in this report:

- Energy savings – household use.
- Energy savings – stormwater treatment.
- Avoided wastewater treatment costs.
- Greenhouse gas emissions savings.
- Carbon sequestration in biomass and soil.
- Preserved sewer system/pipe capacity (climate adaptation).
- Criteria air pollutant reductions.
- Job impacts.

Additionally, these environmental and social co-benefits are described qualitatively:

- Urban habitat patches.
- Improved hydrologic function.
- Potable water conservation.
- Mental health gains.
- Ecological literacy gains.

Report Organization

The report contains six parts: (1) a description of the analytical approach, (2) an inventory of GSI currently implemented citywide, (3) a description of the framework for defining future GSI build-out scenarios, (4) results of the economic analysis, (5) a discussion of how to view the results in the context of climate change, and (6) a discussion and summary of the overall results and possible future efforts to better understand GSI benefits.

Overall approach. Before beginning the analysis, a set of benefit categories potentially associated with GSI efforts was compiled, as well as a corresponding set of methodological approaches useful in analyzing those benefits in economic terms. Consultations with Seattle Public Utilities (SPU) staff determined which co-benefit categories were most likely to have measurable (and previously unquantified or undescribed) economic value to the utility/rate-payers, to the broader public, or to private individuals or sectors. Economic valuation methods were then applied that were feasible with available data and consistent with national precedents.

Inventory. SPU staff provided the necessary information to compile currently available data describing public and private GSI efforts in Seattle. GIS software was used to present the inventory spatially, and appropriate conversion factors were employed to quantify the volume of stormwater these facilities manage.

Build-out scenarios. SPU staff provided a set of assumptions that were used to create three build-out scenarios (Low, Medium, and High) that describe the potential for future GSI installations through 2050.

Economic analysis. The economic value of each benefit in a Seattle-specific context was quantified or described. Local sources were used where possible; evidence from the literature and from other municipalities that have looked into their own GSI-related co-benefits was also used. These benefits were considered spatially (i.e., distributed across different groups of individuals both within and outside of Seattle) and temporally (i.e., for each benefit, its value over the next 100 years was quantified or described to take into consideration differences in intergenerational and intragenerational equity as well as for standard discounting purposes). To clarify, the build-out scenarios incorporate GSI facilities installed through the year 2050, however the benefits derived from these facilities were quantified over the next 100 years.

Climate change. After analyzing the economic value of these GSI-related benefits GSI, stormwater management, benefits, and future conditions are considered within the context of climate change.

Discussion and summary. A brief summary of the results is provided along with recommendations for incorporating the value of these benefits into decision-making frameworks for public and private infrastructure investments.

Results

Table ES-1 summarizes the total volume of stormwater the existing inventory of GSI facilities manage[2] as well as the total volume of stormwater each build-out scenario would manage once fully implemented in 2050. Stormwater volumes are disaggregated by basin type. Table ES-2 identifies the categories of benefits analyzed and the pathway or mechanism by which GSI provides each benefit. Table ES-3 provides a brief description of results for each benefit. While the build-out scenarios incorporate potential future GSI efforts through 2050, the net present value (NPV) of those benefits was calculated over the next 100 years.

Table ES-1. GSI-Related Stormwater Management (gallons managed per year)

Sewer Basin Type	Current Inventory	Low Build-Out Scenario	Medium Build-Out Scenario	High Build-Out Scenario
Combined Sewer Basin	13.4 million	551 million	982 million	1.7 billion
Creek Basin	63.0 million	292 million	455 million	729 million
Direct Discharge Basin	10.0 million	510 million	694 million	703 million
Total	86.4 million	1.4 billion	2.1 billion	3.1 billion

Notes: Volumes for the build-out scenarios represent annual volumes managed in 2050, when each build-out scenario is fully implemented. A “combined sewer basin” is a tributary to a public combined sewer feature, including, but not limited to, a combined sewer overflow outfall, trunk line connection, pump station, or regulator. A “creek basin” flows into surface creeks with no gray infrastructure stormwater treatment. A “direct discharge basin” flows to a larger receiving water body.

[2] The volumes estimated for the existing inventory likely understate the actual volume of stormwater these facilities manage due to gaps in the data describing the full extent of these facilities across the city.

Table ES-2 Description of Benefits Analyzed

Benefit	Benefit Pathway/Mechanism
Stormwater Treatment	GSI facilities reduce stormwater treatment costs by reducing the volume of stormwater entering the combined sewer system and associated energy and materials.
Potable Water Conservation	Some GSI BMPs can reduce household demand for potable water. By reducing potable water demand, consumers benefit from lower water bills and society benefits from a number of avoided costs and outright benefits associated with reductions in potable water use. Data are not sufficient to quantify the reduction of potable water demand, however the analysis describes several of the values associated with a decrease in consumption.
Household Energy Use	Trees planted near homes have the capacity to affect the amount of energy households use for heating and cooling. Households realize the value of these benefits in the form of smaller energy bills.
Greenhouse Gas Emissions	GSI has the capacity to directly reduce energy-related greenhouse gas (GHG) emissions by decreasing household- and utility-related energy consumption. Furthermore, trees planted through GSI efforts sequester carbon from the atmosphere.
Air Quality	GSI can improve air quality by reducing energy-related emissions and by removing pollutants from the atmosphere through natural processes.
Urban Habitat	Some GSI BMPs (e.g., rain gardens, green roofs, and trees) provide habitat-related benefits to multiple types of urban wildlife including mammals, birds, and insects. These small-scale habitat benefits are valuable in that they help improve the health and diversity of local wildlife populations. People value some species directly, while these improvements can also support valuable ecosystem services such as pollination and pest predation.
Hydrologic Function	GSI has the capacity to improve hydrologic function in the Puget Sound Basin, which would help support a wide range of benefits individuals derive from a functioning ecosystem. Research suggests that households in Seattle and across Washington State place large values on freshwater, saltwater, and migratory fish populations. To the extent that GSI can help improve these fish populations, it could support many millions (even billions) of dollars in economic benefits.
Mental Health	Research shows that exposure to natural settings can help improve mental health in many ways, including improving community cohesion and reducing crime rates in specific neighborhoods. They can also provide a mental break for workers during their workday and during their daily commutes to and from work. While data are not sufficient to quantify the value of this benefit specific to Seattle, other studies have shown the avoided costs associated with improving mental health conditions, as well as the mental health effects associated with recent environmental disasters.
Ecological Literacy and Stewardship Behavior	Evidence from several fields demonstrates the numerous ways people experience benefits from the environment and how these benefits and social signals motivate actions that promote environmental quality. GSI facilities contribute to these beneficial behaviors through education, reminders, and opportunities to contribute to water quality improvement and other areas of environmental protection. It is difficult to isolate the incremental share attributable to GSI, but survey data suggest that there is a real effect.
Embedded Energy	GSI can provide conservation of resources that require energy to produce, treat or transport such as potable water or stormwater. This consequently conserves energy as well.
Economic Impacts	GSI installation and maintenance involve employment and materials both of which can be provided locally. To the extent that GSI involves more total labor as a share of costs, and more local materials than equivalent gray infrastructure treatment capacity, GSI can provide greater economic impacts for local jobs and businesses.

Table ES-3 100-year NPV of Evaluated Benefits

Benefit Category	Current Inventory	Low Build-Out Scenario	Medium Build-Out Scenario	High Build-Out Scenario
Stormwater Treatment	$66,000–$88,000	$1.8–$2.5 million	$3.3–$4.4 million	$5.5–$7.4 million
Water – Potable Water Conservation	$13,000–$22,000 per 1000 square feet of rainwater harvest.			
Energy – Household Use	$0.2–$0.5 million	$15–$37 million	$17–$43 million	$20–$49 million
Greenhouse Gas Emissions	$0.3–$3.3 million	$25–$284 million	$29–$331 million	$34–$379 million
Air Quality	< $0.3 million	$2.1–$21 million	$2.4–$24 million	$2.8–$27 million
Small-scale Habitat	$0.72 million	$30 million	$34 million	$39 million
Hydrologic Function	Improved hydrology of Seattle's waterways and promote wildlife populations that rely on those waterways. Potential for annual benefits to nearby households, and lesser benefits to regional residents.			
Mental Health	Improved mental health of residents interacting with GSI facilities and improve community cohesion throughout Seattle. Reduced healthcare costs and improved happiness.			
Ecological Literacy and Behavioral change	Improved environmental awareness and likely some improved environmental behavior.			
Embedded Energy	Reduced lifecycle greenhouse gas emissions of GSI relative to gray stormwater infrastructure.			
Economic Impacts	Increased local job and income creation from local GSI construction and operation.			
Climate Change	Decreased GHG emissions, increased carbon sequestration, and increased resilience to heightened temperature and storm variability and severity			

Another way to consider these results is in per-unit terms (e.g., per gallon managed or per tree planted). Table ES-4 summarizes the 100-year NPV of each economic benefit in the relevant units. The right side of the table identifies instances in which each benefit is realized in terms of basin and GSI BMP. For example, the 100-year NPV of benefits related to household energy use is about $130–$321 per tree. This benefit is associated with all trees regardless of basin. It is not, however, applicable to non-tree GSI BMPs.

Table ES-4. 100-year NPV of Evaluated Benefits per Unit

Benefit Category	Units	Per-unit 100-year NPV	Creek Basin					CSO Basin					Direct Discharge				
			Bioretention	Permeable Pavement	Green Roof	Rainwater Harvesting	Trees	Bioretention	Permeable Pavement	Green Roof	Rainwater Harvesting	Trees	Bioretention	Permeable Pavement	Green Roof	Rainwater Harvesting	Trees
Stormwater Treatment	per million gallons	$4,945–$6,594						X	X	X	X	X					
Household Energy Use (tree-related energy reduction)	per tree	$130 –$321					X					X					X
GHG Emissions (home cooling and heating)	per tree	$84–$324					X					X					X
GHG Emissions (stormwater treatment)	per million gallons	$1,842–$7,123						X	X	X	X	X					
GHG Emissions (tree sequestration)	per tree	$84–$1,656					X					X					X
Air Quality (tree filtration)	per tree	$13–$169					X					X					X
Air Quality (home cooling and heating)	per tree	$4					X					X					X
Air Quality (stormwater treatment)	per million gallons	$175						X	X	X	X	X					
Small-scale Habitat	N/A	positive	X		X		X	X		X		X	X		X		X
Reduced CSO Costs	N/A	positive						X	X	X	X	X					
Potable Water	1000 ft^2 harvest	$13,000-$22,000				X					X					X	
Hydrologic Function	N/A	positive	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mental Health	N/A	positive	X		X	X	X	X		X	X	X	X		X	X	X
Behavioral Change	N/A	positive	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Climate Change	N/A	positive	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

1 Introduction

This report examines the economic values of benefits associated with existing and potential green stormwater infrastructure (GSI) facilities in Seattle, Washington. Local, state, and federal agencies are increasingly considering GSI in their approaches to stormwater management because it offers a wide range of benefits beyond those specific to stormwater. GSI also offers, in certain contexts, stormwater treatment benefits not provided by conventional approaches. At the same time, GSI in Seattle and elsewhere is best thought of as part of a portfolio of approaches rather than a universally superior approach under all circumstances. GSI benefits accrue to government agencies, utilities, businesses, communities, and individuals across scales within and beyond Seattle.

1.1 Purpose

This analysis provides a more holistic understanding of the suite of economic benefits associated with GSI efforts in Seattle. The results of this analysis as well as this comprehensive approach can help inform decision-making related to stormwater management across the country. Seattle has made a substantial investment in its GSI and has compiled and tracked a wide array of quantitative and qualitative information about their GSI assets. The intention of this analysis is to identify the effects of these GSI efforts and assess how they align with demands and scarcities in Seattle and beyond to provide valuable goods and services. The analysis is based on local primary data to the fullest extent possible, while also employing nationally relevant information and corroboration to expand the applicability of results. The results of this analysis shed light on the value of GSI-related benefits beyond those directly linked to stormwater management and can help decision makers compare their options when deciding their own management approaches. By delving deeply into Seattle's GSI inventory, tangible explanations of how GSI can provide benefits to a community in practical ways are revealed.

Rain garden

In this effort to identify, quantify, and value the effects of Seattle's GSI, the intent was to investigate categories of benefits that typically have not received substantial attention. These benefits have not been evaluated frequently because quantitative information about supply and demand is not readily available. By bringing research to bear at the level of qualitative or quantitative information that was available, this report expands the set of benefits communities can consider when making tradeoff decisions involving stormwater management and community resources. Conducting the analyses in a transparent and step-wise fashion allows other communities to modify analyses and conclusions to fit their own context.

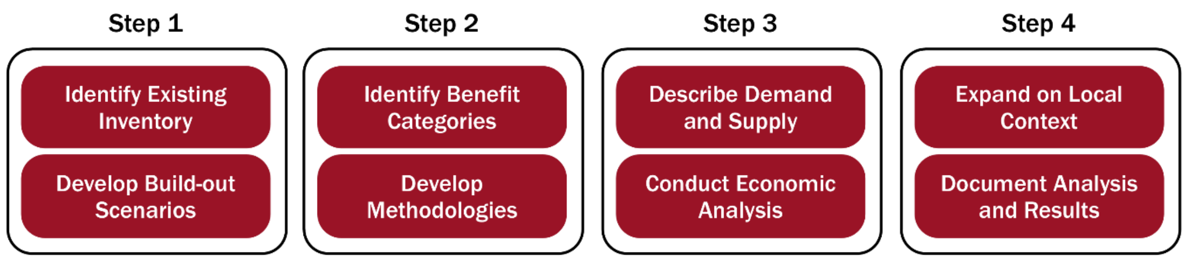
1.2 Organization of Report

- **Approach and methods.** This section discusses the analytical approach to calculating total economic value of GSI-related benefits, the approach to identifying appropriate methodologies, and how time affects present values.
- **Inventory of Seattle's GSI facilities.** This section describes the approach to compiling the inventory of existing GSI facilities in Seattle and briefly summarizes the results.
- **Build-out scenarios.** This section briefly describes the approach to developing three build-out scenarios (Low, Medium, and High) of the potential future extent of GSI in Seattle through 2050 and summarizes the features of each scenario.
- **Economic analysis.** Several different benefit categories associated with GSI in Seattle are identified. For each benefit category, the mechanism through which people derive benefits, methodology for analyzing its economic value, and results of the analysis are summarized.
- **Climate change.** This section describes the results of the economic analysis within the context of climate change and the potential differences between today's climatic conditions and those in the future.
- **Discussion and summary.** This summarizes the results of the report and provides guidance on future research efforts that would be useful to better understand GSI-related co-benefits applicable to both Seattle and other cities across the country.

2 Approach and Methods

The primary objective of this analysis is to identify and describe the economic value of the benefits associated with existing and potential future GSI facilities in Seattle, Washington. The analysis incorporates typical methodologies used to quantify the value of these benefits, but it also focuses on innovative approaches to benefit valuation within the context of GSI-related effects on society and the environment. Figure 1 summarizes the four-step approach to conducting this analysis. The remainder of this section has three parts, all of which are described within the context of the steps identified in the figure below: (1) a description of the GSI best management practices (BMPs) included, (2) a brief description of the scenarios analyzed, and (3) an outline of the approach to identifying and quantifying benefits and how time was incorporated into the analysis.

Figure 1. Analytical Steps



2.1 BMPs Included in the Analysis

As a first step toward collecting and organizing data and researching potential methods to quantify the value of GSI-related benefits in Seattle, a list of standard GSI BMPs was created. After compiling data describing the existing inventory of GSI facilities in Seattle, the list of BMPs to include only those currently used to manage stormwater. Table 1 identifies these BMPs and provides a brief description of how each manages stormwater in Seattle.

Table 1. Description of BMPs Included in the Analysis

BMP	Description
Bioretention/Biofiltration Facilities (distributed)	Distributed bioretention and biofiltration facilities slow and clean stormwater by capturing it close to where it falls as rain and directing it through plants (biofiltration) or through plants and specially engineered soil (bioretention).
Green Roofs	Roof areas covered in vegetation and other green roof materials. Green roofs reduce the volume of stormwater flowing from the roofs of buildings into the sewer system.
Permeable Paving Systems	Surfaces paved with porous materials that allow stormwater to filter through the surface of the pavement and make use of substrate. Examples include pervious concrete, permeable asphalt, pavers, etc.
Rainwater Harvesting Systems	Small-scale systems that capture and store rainwater temporarily, including rain barrels and on-site stormwater cisterns. In some cases, this water can be used to replace water consumption for non-potable uses (e.g., irrigation).
Trees	Deciduous and evergreen trees. It includes new trees planted specifically for GSI-related efforts, not the entire tree canopy in Seattle. Trees provide stormwater capture and treatment as well as co-benefits such as air filtration.

2.2 Scenarios

Typically, economic analyses consider differences in outcomes between a baseline scenario and one or more possible project scenarios. The baseline scenario describes the state of the world without a particular action. A project scenario describes the state of the world with some alternative action. The values associated with the project scenario are then compared to those associated with the baseline scenario to describe the net effect of the action and to choose among the options. It is important to note that the appropriate approach to comparing the benefits and costs of an action is to compare them to the benefits and costs of the baseline scenario, which is the state of the world "but for" the project, not the state of the world before and after the project.

For this technical assistance project, the baseline scenario included analysis of the marginal (incremental) value of benefits provided by Seattle's existing inventory of GSI facilities. Added to this analysis is a description and quantification of the benefits of expanding GSI implementation across Seattle relative to a scenario without GSI. The City of Seattle provided all the data used to compile the inventory of existing GSI facilities within the city. SPU staff provided the assumptions used to develop three build-out scenarios (Low, Medium, and High) for extending GSI implementation across Seattle through 2050.

2.3 Analytical Approach

This analysis focuses on understanding the value of benefits associated with GSI. This section describes the concept of total economic value; the approach to identifying specific benefit categories and identifying the most appropriate methodologies for describing, quantifying, and monetizing their economic values; and the importance of appropriate time horizons and discount rates.

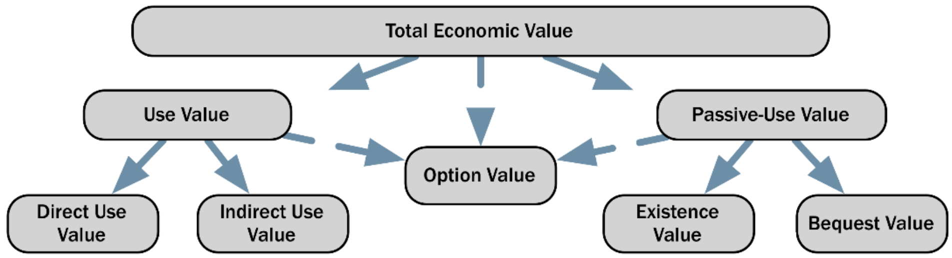
2.3.1 Total Economic Value

For the purposes of this report, total economic value is defined as the sum of several individual use values (direct, indirect, and passive) and option value for a given good or service. Figure 2 summarizes the major categories of economic value for market and non-market goods and services used in the analysis. The left side of the figure shows use value, which is perhaps the clearest type of economic value. Direct use value describes the value associated with the direct use of a good or service, such as using a stream to spend a day fishing. Indirect use value describes the goods and services that precede direct goods and services, such as the aquatic habitat that nurtures and provides refuge for the targeted fish.

The right side of the figure shows passive-use value, which represents nature's values that exist when there is no direct or indirect use of an ecosystem. Passive-use values are less obvious than use values but (in some instances) can represent a greater total value because a larger population often can enjoy them. Sometimes these are considered inherent values. The figure separates passive-use value into two categories. One, existence value, comes from people's desire for the continued existence of a species, landscape, or some other aspect of an ecosystem—or of the ecosystem as a whole—without any contact or use of the good or service. The other, bequest value, arises because people want to ensure that the benefit will be available for future generations. Typically, economists describe passive-use values in terms of an individual's willingness to pay for an object's current or future existence.

The middle of the figure shows another component of the total value, known as option value. Option value refers to the benefit of maintaining an opportunity to derive services from an ecosystem in the future. It can originate from either side of the figure. Market prices sometimes exist that provide information useful for quantifying option values, such as certain types of insurance.

Figure 2. Total Economic Value



2.3.2 Identifying Benefit Categories and Methodologies

To begin the process of identifying benefit categories for inclusion in the analysis, the existing literature examining the benefits of GSI was reviewed and a list of benefit categories that GSI can offer in a Seattle-specific context was compiled. For each benefit category, appropriate methodologies were identified to analyze their respective economic values. Table 2 describes several of the methodologies identified in the figure.

Table 2. Summary of Techniques Used to Estimate Economic Values in This Study

Valuation Method	Description of Methodology
Benefit Transfer	Estimate the value of a service at a particular site based on analyses estimating the value of a similar service in another geographic location.
Stated Preference (e.g. Contingent Valuation)	Estimate the value of a service with questionnaires asking respondents how much they would be willing to pay to protect the service, or other forms of questions to elicit willingness to pay for the service.
Hedonic Analysis	Estimate the value of a service by comparing property values of multiple households, controlling for several factors, and determining the impact of changes in quantity or quality of the service on property value.
Replacement/ Avoided Cost	Estimate the value of a service by identifying and estimating the cost for the best alternative projects or programs required to replace the identified service. This requires verification that the avoided or replacement cost would be incurred if not for the benefit, out of necessity or willingness-to-pay. For example, avoided costs of a filtration plant are valid if the plant would be necessary otherwise.

Note: For further description of these valuation methods and others, see: U.S. Environmental Protection Agency's Science Advisory Board. 2009. *Valuing the Protection of Ecological Systems and Services: A Report of the EPA Science Advisory Board* (EPA-SAB-09-012). Washington, DC.

It is important to take into account the demand for each type of benefit and the local scarcities. Urban contexts are often quite different from rural contexts for ecosystem-based benefits because populations and related demand are typically greater, and other supply sources are less abundant and therefore scarcity is also typically greater. For each benefit category, a mechanism was described through which GSI produces the specific benefit. Given the finite resources available to conduct the study, as well as which local relevant data sources were available, the project team determined which co-benefit categories were most likely to have substantial (and previously unquantified or undescribed) economic value to SPU/Seattle rate-payers, to the broader public, or to private individuals or groups. This sub-set of all possible co-benefits was prioritized and the methodologies adjusted to fit within data, time, and resource constraints.

Throughout this analysis, quantified benefits are presented as ranges. This approach explicitly recognizes the uncertainty regarding both the biophysical and engineering estimates of how much of a particular benefit may materialize (the quantity), and the price people are willing to pay to secure the benefit. Where possible, explanations help readers understand the sources of uncertainty and how they would affect the actual benefits and costs, particularly for strategies not yet implemented.

In many instances, insufficient data are available to quantify benefits in monetary or physical terms. Throughout the report, qualitative discussions are provided of these benefits to offer decision makers information about their potential likelihood, magnitude, and relative importance. For some of these benefits, economic quantification may be possible as science improves quantification of ecosystem services related to GSI, such as hydrologic function. Furthermore, as markets continue to develop for the provision of GSI-related ecosystem services, information about local willingness to pay and the value of some benefits may become available to estimate currently unquantifiable benefits.

Benefits that are not quantified with existing information are not necessarily less important than quantifiable benefits. It is important to recognize that if the existence of the benefit can be demonstrated, the value is greater than zero. Rather, decision-makers can and should consider the evidence of unquantifiable benefits alongside estimates of quantified benefits and weigh their relative importance.[3]

2.3.3 Time Horizon and Discounting

As a guiding principle, the time horizon used in a benefit-cost analysis should "be sufficient to capture major welfare effects" and should "reflect the welfare outcomes of those affected."[4] In other words, the time horizon should extend far enough into the future to include the duration of the project and all of its effects. The U.S. Environmental Protection Agency (EPA) guidance states that, "in most cases, primary considerations in determining the time horizon of the analysis will be the time span of the physical effects that drive the benefits estimates and capital investment cycles associated with environmental expenditures…the time horizon should be long enough that the net benefits for all future years (beyond the time horizon) are expected to be negligible when discounted to the present."[5] This analysis considers the value of benefits over a 100-year time horizon.

[3] U.S. Environmental Protection Agency. 2010. *Guidelines for Preparing Economic Analyses*. EPA 240-R-10-001.

[4] U.S. Environmental Protection Agency. 2010. *Guidelines for Preparing Economic Analyses*. EPA 240-R-10-001.

[5] U.S. Environmental Protection Agency. 2010. *Guidelines for Preparing Economic Analyses*. EPA 240-R-10-001.

Selecting a discount rate to account for time involves making a number of assumptions about public preference, the opportunity cost of the investment, and intergenerational equity. Discount rates (1) reflect general preference for present consumption as opposed to future consumption, (2) account for lost investment opportunity elsewhere, and (3) equalize intergenerational utility in a society where future generations are assumed better off than current generations.[6] Investments in natural capital are unique because they are not perfectly substitutable with other forms of capital.[7] Some natural capital assets, for example, will be scarcer in the future than they are today. With regard to these assets, future generations likely will be worse off than the current generation.[8] Therefore, the public may place a higher value on the future provision of these assets, yielding a lower discount rate for intergenerational benefits.

Social discount rates refer to the rates applied to social investments (projects or polices that benefit public welfare). Economists tend to agree that social discount rates are lower than market discount rates.[9] Government should consider the costs future generations may incur and the benefits they may derive from current action/inaction. Many economic analyses use a market-based discount rate as a proxy for the social discount rate. Several government agencies and other professionals conducting economic analyses use the federal opportunity cost of capital (represented by the real interest rate on treasury bonds) as a proxy.[10] As of December 2011, the real interest rate on 30-year treasury bonds was 2.0%.[11]

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[6] Henderson, N. and I. Bateman. 1993. *Intergenerational Discounting: Public Choice and Empirical Evidence for Hyperbolic Discount Rates.* Center for Social and Economic Research on the Global Environment, University of East Anglia and University College of London, Working Paper GEC 93-02.

[7] See, for example, Pearce, D. and R. Turner. 1990. *Economics of Natural Resources and the Environment*. Great Britain: Johns Hopkins University Press; Neumayer, E. 2004. *Weak Versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms.* Edward Elgar Pub; Henderson, N. and I. Bateman. 1993. *Intergenerational Discounting: Public Choice and Empirical Evidence for Hyperbolic Discount Rates.* Center for Social and Economic Research on the Global Environment, University of East Anglia and University College of London, Working Paper GEC 93-02.

[8] Saez, C. and J. Requena. 2007. "Reconciling Sustainability and Discounting in Cost-Benefit Analysis: A Methodological Proposal." *Ecological Economics.* 60: 712-25.

[9] Solow, R. 2008. "The Economics of Resources or the Resources of Economics." *Journal of Natural Resources Policy Research*. 1(1): 69-82.

[10] See, for example, Bazelon, C. and K. Smetters. 1999. "Discounting Inside the Washington D.C. Beltway." *Journal of Economic Perspectives.* 13(4):213-228; Kohyama, H. 2006. "Selecting Discount Rates for Budgetary Purposes." *Harvard Law School: Federal Budget Policy Seminar*. Briefing Paper No. 29.

[11] U.S. Office of Management and Budget. 2011. *Circular A-94 Appendix C.* Retrieved on September 4, 2012 from *http://www.whitehouse.gov/omb/circulars_a094/a94_appx-c*.

3 Inventory of Seattle's GSI Facilities

Seattle's existing inventory of GSI facilities has four main components: (1) facilities installed in the right-of-way as SPU capital investments, (2) facilities installed through code-triggered mechanisms, (3) facilities installed through SPU's RainWise Program, and (4) other voluntary, private and public efforts such as green roofs, rainwater harvesting systems, and one-off public infrastructure projects. Across these four categories of GSI facilities, several types of BMPs have been implemented, including trees, porous pavement, bioretention, green roofs, and rainwater harvesting. Appendix A contains a detailed description of how inventory data were compiled, how the volume of stormwater is quantified, and how the volume of stormwater is managed, including counts of facilities by type. The analysis understates the full extent of the existing inventory, because the data do not include all Seattle Department of Transportation-led efforts or the full extent of voluntary GSI efforts by households, community organizations, and businesses across Seattle.

Table 3 summarizes the total volume of stormwater that the existing inventory of GSI facilities manages by basin type and implementation mechanism. The three basin types included in the table are described further in Appendix C. In Seattle, stormwater flows into one of two types of systems: (1) a combined sewer system in which stormwater mixes with sewage and flows to a wastewater treatment plant where it is treated before being discharged into nearby waterbodies, and (2) a separate sewer system in which stormwater travels directly to nearby waterbodies without being treated. Within the separate sewer system, some stormwater flows into small creeks (this water is shown in the Creek Basin row of the table) and some stormwater flows into larger waterbodies (this water is shown in the Direct Discharge Basin row of the table). GSI often results in stormwater entering the groundwater, reaching aquifers or surface water after treatment.

The GSI facilities included in this inventory managed a total of about 86 million gallons of stormwater each year. GSI facilities installed through the right-of-way mechanism manage about 67 million gallons of stormwater each year. About 63 million gallons of the stormwater these facilities manage each year are in Seattle's creek basins. This means that, aside from the GSI facilities, this stormwater would have been discharged into nearby creeks without receiving treatment.

Table 3. Summary of Existing GSI Inventory (gallons managed per year)

Basin	Right-of-way	Code-triggered	RainWise	Other	Total
Combined Sewer Basin	4.4 million	3.3 million	2.3 million	3.4 million	13.4 million
Creek Basin	62.1 million	0.8 million	--	< 0.1 million	63.0 million
Direct Discharge Basin	0.3 million	4.6 million	0.2 million	4.9 million	10.0 million
Total	66.9 million	8.7 million	2.4 million	8.4 million	86.4 million

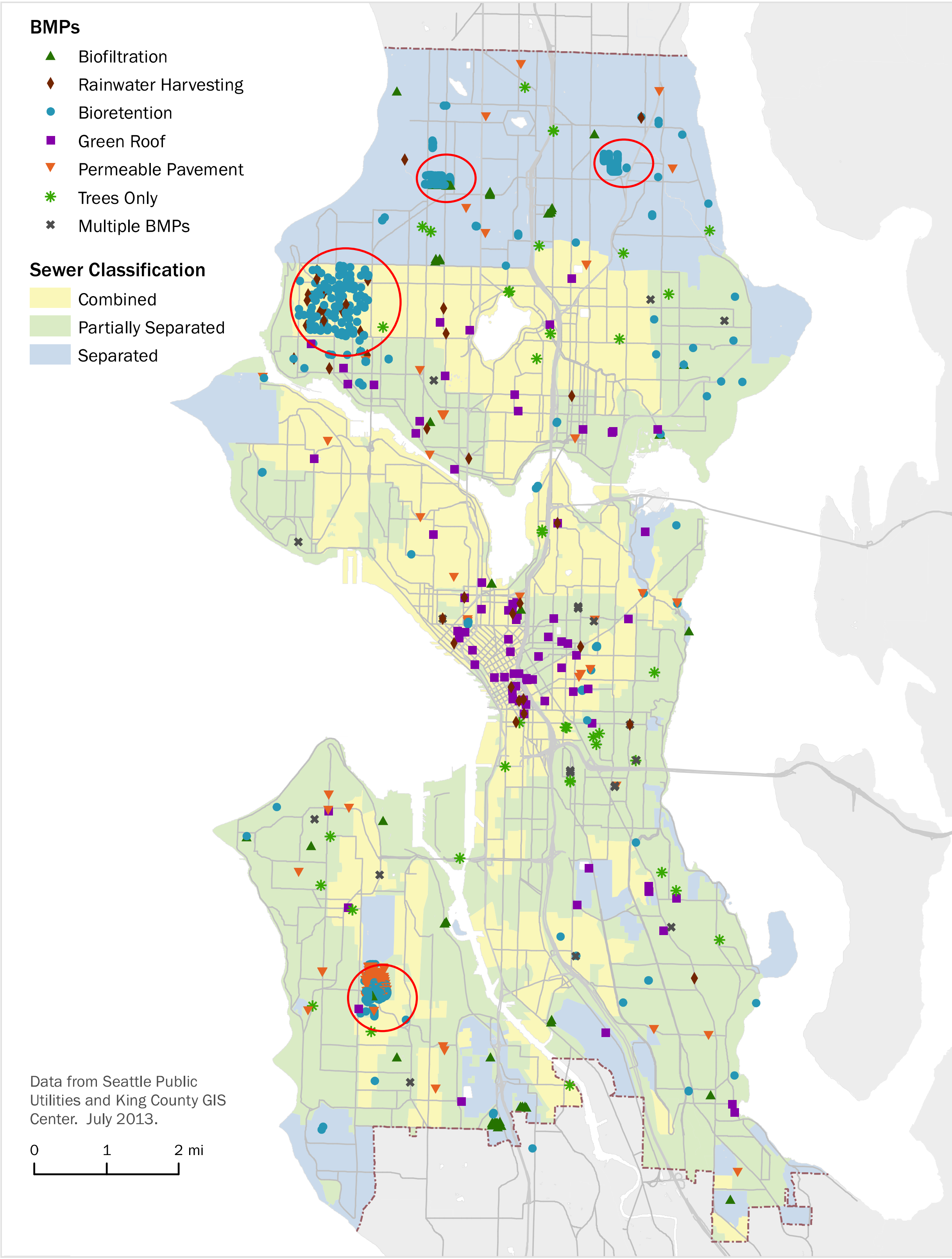
Notes: See Appendix A for more details on the existing inventory of GSI facilities in Seattle including counts of facilities by type. Values may differ slightly from values in this Appendix A due to rounding. Code-triggered values include projections from mid-2011 to the end of 2012 as described in Appendix A, assuming a weighted distribution across the three basin types based on the distribution of facilities installed prior to mid-2011.

Figure 3 shows the distribution of GSI facilities across Seattle. The figure shows the three basin types and identifies specific GSI facilities included in the analysis. Figure 4 shows how the volume of stormwater the inventory of GSI facilities manages is distributed across the city. The map is divided into census tracts. For each census tract, the volume of stormwater managed by GSI facilities was calculated per acre. The map shows that there are concentrations of GSI facilities in several parts of Seattle. It also highlights the areas that rely more heavily on traditional methods of stormwater management. The total number of existing facilities by type at the time of this writing is shown in Table 4 (see Appendix A for more detail).

Table 4. Summary of Existing GSI Inventory by Facility Type.

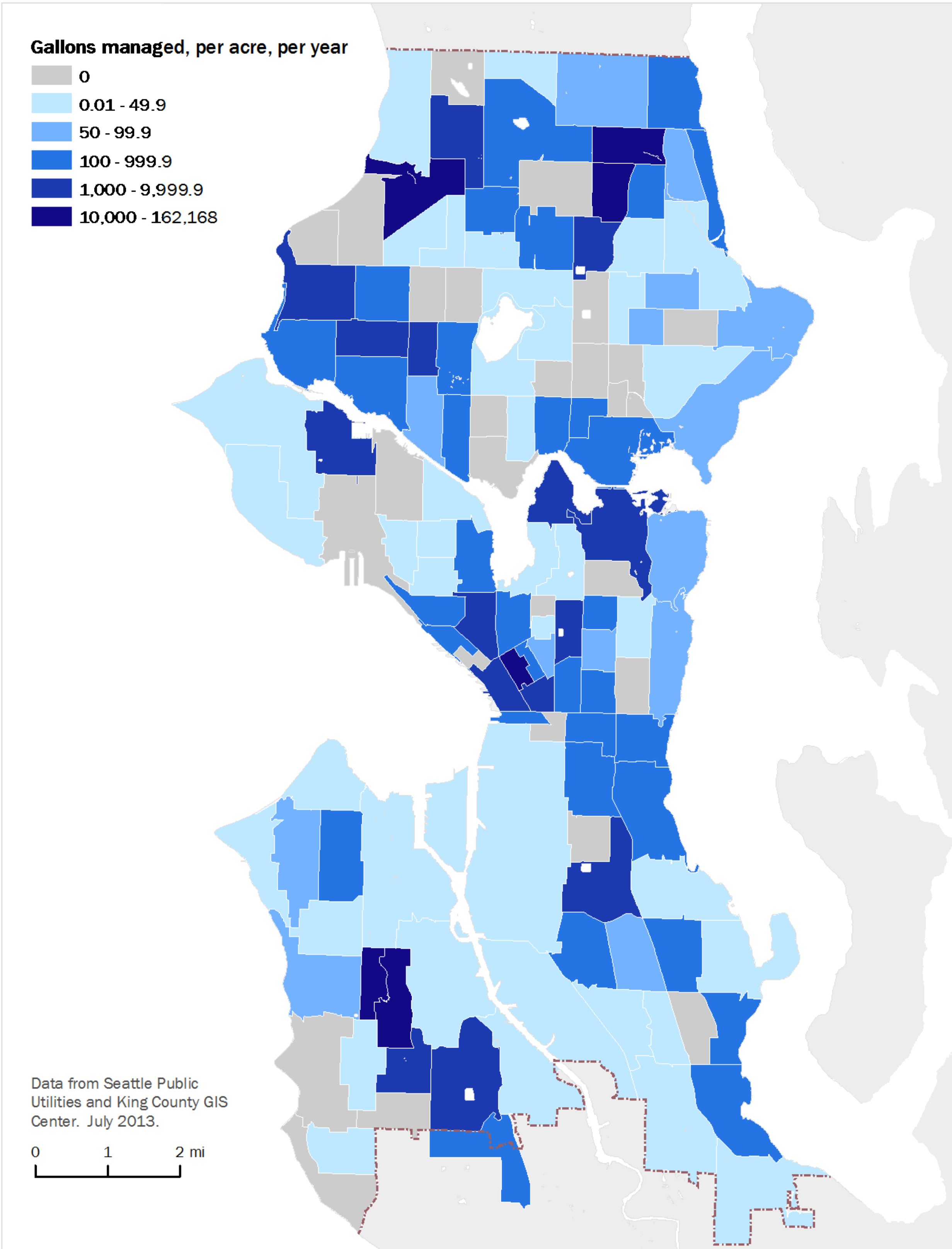
Type	Number of Facilities
Bioretention	674
Biofiltration	52
Green Roof	95
Permeable Paving	142
Rainwater Harvesting	31
Trees	114
Multiple BMPs	21

Figure 3. Spatial Distribution of GSI Facilities Included in the Inventory



Note: the GSI inventory only includes those planted for stormwater management purposes in Seattle, not the entire tree canopy.

Figure 4. Per-Acre Stormwater Management by GSI Facilities in the Inventory



4 Build-Out Scenarios

In addition to the benefits of existing GSI facilities in Seattle's inventory, three build-out scenarios (Low, Medium, and High) are examined that project the installation of GSI facilities through 2050. Appendix B contains a complete description of how existing data and conditions in Seattle were used, as well as assumptions provided by City of Seattle staff, to quantify the potential of the three build-out scenarios. The build-out scenarios include assumptions for right-of-way projects, code-triggered projects, and RainWise projects, but do *not* include assumptions about voluntary GSI efforts, public-private partnerships, or other types of GSI efforts initiated by SPU or other agencies in the city.

Each of the three build-out scenarios is based on the assumption that the installation rate for GSI facilities is evenly distributed through 2050. The top half of Table 5 summarizes the quantity of GSI facilities installed through 2050. Similar to the inventory data, conversion factors were applied to the BMP-specific metrics to quantify the volume of stormwater each facility manages in each build-out scenario. The bottom half of Table 5 summarizes the volume of stormwater GSI facilities manage under each of the three build-out scenarios by basin type. The volumes summarized in the table represent the total volume these GSI facilities would manage in 2050. These volumes would increase incrementally to the values presented in the table as more GSI facilities are installed under each build-out scenario. These stormwater volumes do not include the volume of stormwater the existing inventory manages now and in the future.

Table 5. Summary of GSI Implemented through 2050

GSI Facilities by Scenario and BMP (millions of gallons, full installation by 2050)				
BMP (units)	**Current Inventory**	**Low Build-Out Scenario**	**Medium Build-Out Scenario**	**High Build-Out Scenario**
Trees	0.5	592.8	764.4	936.1
Porous Pavement	2.8	92.6	92.6	96.1
Bioretention	64.1	395.6	826.9	1,361.9
Green Roof	8.4	6.1	6.1	6.1
Rainwater	0.1	1.5	3.1	4.6
Stormwater Managed by Scenario and Basin (millions of gallons, full installation by 2050)				
Basin	**Current Inventory**	**Low Build-Out Scenario**	**Medium Build-Out Scenario**	**High Build-Out Scenario**
Combined Sewer Basin	13.4	760.4	1,238.9	1,974.9
Creek Basin	63.0	231.2	418.4	715.9
Direct Discharge Basin	28.0	341.5	607.1	698.2
Total	104.4	1,333.0	2,264.4	3,389.0

Notes: See Appendices A and B for more details.

5 Economic Analysis

This section focuses on quantifying and describing the economic values of a sub-set of benefits stemming from Seattle's existing inventory and potential future build-out of GSI facilities. Each benefit category includes a brief introduction of the underlying concepts that connect the benefit to GSI, a description of the category-specific valuation methodology implemented, a review of the relevant literature and analysis of the available data within the context of Seattle's existing inventory of GSI facilities and the build-out scenarios identified in the previous section, and a summary of the results and description of the distribution of benefits across different groups. Table 6 summarizes the approach to analyzing each benefit category.

Table 6. Summary of Approach by Benefit Category

Benefit Category	Type of Analysis
Water Treatment	Quantitative: avoided cost analysis
Water – Potable Water Conservation	Quantitative: avoided cost analysis and revealed preferences
Energy – Household Use	Quantitative: avoided costs and revealed preferences
Greenhouse Gas Emissions	Quantitative: social cost of carbon and market prices
Criteria Air Pollutant Reductions	Quantitative: literature values based on willingness-to-pay
Small-scale Habitat	Quantitative: revealed preferences through market expenditures
Hydrologic Function	Quantitative: willingness-to-pay stated preferences Qualitative: avoided cost analysis
Mental Health	Qualitative: literature review
Ecological Literacy and Behavior	Qualitative: literature review
Embedded Energy	Quantitative: market prices for avoided costs Case study
Job Impacts	Quantitative: project cost data Case study

5.1 Stormwater Treatment Benefits

While stormwater treatment benefits are not a primary focus of this study, they do provide important inputs to other benefit analyses, as well as complementing the overall picture for the benefits of GSI. Most stormwater entering the combined sewer system is treated before it is discharged into nearby waterways. To the extent that GSI reduces the volume of stormwater entering the combined sewer system, it also decreases the volume of water requiring treatment. This reduces treatment-related costs.

5.1.1 Valuation Methodology

But for its GSI efforts, Seattle would treat stormwater entering the combined sewer system by conventional means: at wastewater treatment facilities. Therefore, valuation of avoided treatment costs applies the marginal cost of treatment to the reduction in stormwater runoff entering the combined sewer system. While GSI does have costs, at times greater than gray infrastructure, identifying the marginal benefits associated with stormwater treatment is necessary to assess the total economic value of GSI. The cost of treatment provides a low-end estimate of the total value associated with clean water. The total value of clean water (and hence, of treating stormwater) likely is generally greater than the cost of treating it. And with a regulatory driver to require treatment, the treatment cost does represent the value tradeoff. The methodology applied is based on data from King County's Wastewater Treatment Division and has three steps.

Step 1 – Estimate the volume of water diverted from the combined sewer system. In previous sections, the volume of stormwater that GSI manages was quantified in terms of the existing inventory of GSI facilities and potential future GSI facilities under three build-out scenarios. Those volumes are used here to quantify the change in treatment in the combined sewer system with GSI.

Step 2 – Estimate the marginal cost of treatment. Data from King County's Wastewater Treatment Division describing average treatment costs in the combined sewer system were used to estimate the marginal cost of treatment. Data are not sufficient to accurately quantify variable costs and the change in costs associated with stormwater reductions in the combined sewer basin. A number of assumptions are necessary to transform the average cost of treatment to a marginal cost. Reported average treatment costs range from $450 to $600 per million gallons, with an estimated 25 percent of this cost variable, for a marginal cost of $0.00011 to $0.00015 per gallon treatment cost.

Step 3 – Apply benefit estimates to the decrease in stormwater volume. The results from Step 1 and Step 2 are aligned to quantify the 100-year net present value (NPV) of the avoided treatment costs. Again, these values are illustrative and are not definitive due to the breadth of the assumptions needed to transform average costs to marginal costs. The value of stormwater that GSI facilities treat in the direct discharge or creek basins is not quantified in this section, but the value is described in section 5.7.

5.1.2 Review and Analysis

Reduction in stormwater volume in the combined sewer basin. As described in previous sections and in Appendix A, the existing GSI inventory manages 13.4 million gallons of stormwater runoff per year in the combined sewer basin. Below is a description of the volume of stormwater the build-out scenarios would manage in the combined sewer basin (additional details are provided in Appendix B).

- The Low Build-Out Scenario would manage a total of 760 million gallons of stormwater in the combined sewer basin per year by 2050.
- The Medium Build-Out Scenario would manage a total of 1.2 billion gallons of stormwater in the combined sewer basin per year by 2050.
- The High Build-Out Scenario would manage a total of 2.0 billion gallons of stormwater in the combined sewer basin per year by 2050.

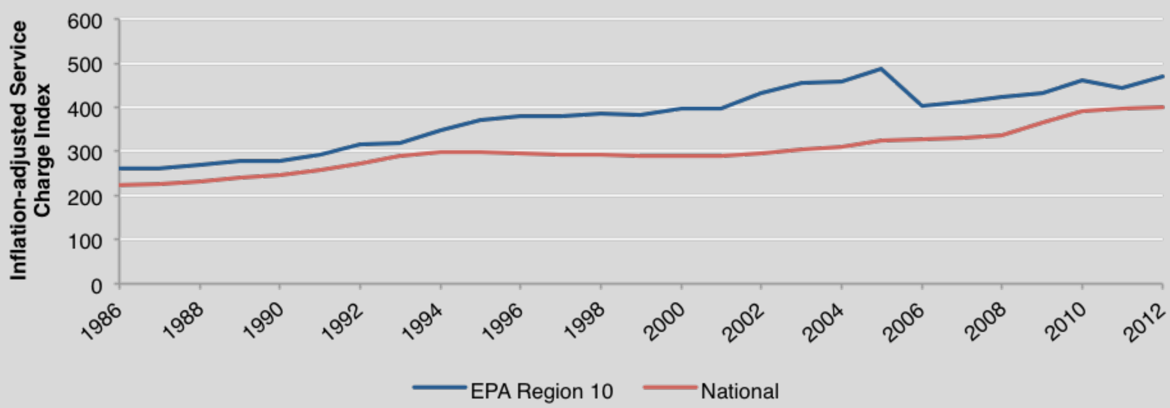
Treatment costs. Data from King County's Wastewater Treatment Division suggests that average costs at its wastewater treatment facilities range from about $450 to $600 per million gallons.[12] This average cost includes both fixed costs (such as equipment) and variable costs (such as operation). Decreasing the volume of stormwater runoff into the combined sewer system would decrease overall spending on variable costs, however it may not affect overall spending on fixed costs. Since these fixed costs have largely already been incurred and likely would remain constant, this analysis focuses on variable costs. Without data specifically describing the line-item costs included in average costs, the analysis relies on assumptions that offer a reasonable result.

[12] Personal Communication. Phillips, John. King County Wastewater Treatment Division. E-mail. June 14, 2013.

For this analysis, it is assumed that GSI-related reductions in stormwater runoff into the combined sewer system have no impact on fixed cost, and that variable costs account for 25% of current average costs. In other words, current variable costs total about $110–$150 per million gallons. In reality, however, GSI efforts have their own O&M costs. This exercise does not consider the net difference between O&M costs associated with treatment in the combined system and GSI-related O&M costs.

Rising Stormwater Rates

Since 1986, the stormwater fees households pay have increased, in real terms, by 87%. In EPA Region 10, which includes Seattle, household stormwater fees have increased by 90%. The figure below shows the National Association of Clean Water Agencies' service charge index from 1986 to 2012, adjusted for inflation using the Consumer Price Index. The figure shows that: (1) stormwater rates across the country have increased more rapidly than inflation, and (2) stormwater rates in EPA Region 10 are higher than the national index. Treatment costs play an important role in determining the rates households pay for stormwater services. Decreasing these costs (or minimizing the amount they increase over time) can reduce revenue requirements for utilities and can translate into savings for households.



Source: National Association of Clean Water Agencies. 2013. *2012 NACWA Service Charge Index*. Retrieved on July 3, 2013.

Results. Table 7 summarizes the results of the analysis. The first row in the table shows the total volume of stormwater managed each year, by 2050 and beyond, by the existing inventory and the three build-out scenarios. The second row shows the incremental increase in volume managed from 2013–2050 for the three build-out scenarios. The third row shows the 100-year NPV of the stormwater treatment benefits. Stormwater treatment costs (described above) were used to calculate the avoided treatment costs associated with these GSI facilities.

Table 7. Summary of Avoided Treatment Costs in the Combined Sewer Basin

	Inventory	Low Build-Out Scenario	Medium Build-Out Scenario	High Build-Out Scenario
Volume Managed by 2050	13.4 million gallons	556 million gallons	986 billion gallons	1.7 billion gallons
Additional Volume Managed each Year through 2050	—	15 million gallons	27 million gallons	45 million gallons
100-year NPV	$66,000–$88,000	$1.8–$2.5 million	$3.3–$4.4 million	$5.5–$7.4 million

5.1.3 Summary and Distribution

The value of avoided treatment costs associated with reductions in stormwater runoff flowing into the combined sewer basin for the 100-year NPV of the existing inventory of GSI facilities was estimated to be $66,000–$88,000. The 100-year NPV of this benefit for the build-out scenarios ranges from an additional $1.8–$2.5 million for the Low Build-Out Scenario to an additional $5.5–$7.4 million for the High Build-Out Scenario. The water quality benefit accrues to residents and visitors to Seattle as well as users of Puget Sound, and those who care about the ecological integrity of Puget Sound and other receiving waterbodies. Because GSI investments are often undertaken for the variety of benefits they provide beyond water quality, it is difficult to isolate the share of cost attributable to water quality, and therefore the avoided cost to ratepayers and residents.

Treatment Energy

The treatment described in this section requires energy. To the extent that GSI reduces the volume of stormwater entering the combined sewer system, it also decreases the amount of energy the system uses (which is one of the components of the treatment costs discussed earlier). King County's Wastewater Treatment Division owns and operates the wastewater treatment facilities that receive and treat Seattle's stormwater runoff from within the combined sewer basin. The county incurs energy-related costs while conveying and treating this stormwater.

Per-unit energy consumption and cost. King County's Wastewater Treatment Division has estimated the volume of water managed at the West Point Wastewater Treatment Plant as well as the total energy used to treat that water and the total energy costs. The table below summarizes these data for 2009 and 2010. On average, treatment-related energy costs at West Point totaled about $78 per million gallons of water treated.

Year	Electricity (kWh)	Gas and Propane (therms)	Average Annual Flow (millions of gallons)	Energy Costs ($/Year)	Energy Costs ($/million gallons)
2009	53.4 million	1.4 million	40,150	$2.9 million	$73
2010	52.1 million	1.5 million	35,040	$2.9 million	$83

Source: Hanley, M. 2009. *Fact Sheet for NPDES Permit WA-002918-1*. June; Personal Communication. Phillips, John. King County Wastewater Treatment Division. E-mail. June 12, 2013; Personal Communication. Phillips, John. King County Wastewater Treatment Division. E-mail. June 13, 2013.

Results. The table below summarizes the results of the analysis. The first row in the table shows the total volume of stormwater managed each year, by 2050 and beyond, by the existing inventory and the three build-out scenarios. The second row shows the incremental increase in volume managed from 2013–2050 for the three build-out scenarios. The third row shows the 100-year NPV of the avoided energy costs associated with the projected decrease in stormwater runoff into the combined sewer system. Energy costs (described above) were used to calculate the avoided costs associated with these GSI facilities. These costs are not in addition to the avoided treatment costs described earlier in this analysis. Rather, these costs represent one component of the total treatment costs.

	Inventory	Low Build-Out Scenario	Medium Build-Out Scenario	High Build-Out Scenario
Volume Managed by 2050 in the CSO Basin	13.4 million gallons	760 million gallons	1.2 billion gallons	2.0 billion gallons
Additional Volume Managed each Year through 2050	—	20.6 million gallons	33.5 million gallons	53.4 million gallons
100-year NPV	$45,000	$1.7 million	$2.8 million	$4.5 million

5.2 Water – Potable Water Treatment

Households and businesses in Seattle use potable water for nearly all of their water needs. Treating water to ensure that it is potable and conveying it to end users has several costs including operating costs, energy costs, other variable costs, and several indirect costs (e.g., GHG- and air quality-related costs associated with emissions from energy consumption). These indirect costs are discussed elsewhere in this report. Rainwater harvesting BMPs have the capacity to reduce demand for potable water by using stormwater to meet non-potable water demand. For example, water collected in a rainwater harvesting system can be used later for irrigation, flushing toilets, some cleaning purposes or other industrial needs, thus displacing the potable water that would have been used. To the extent that it decreases demand for potable water, GSI can (1) reduce potable water-related treatment costs for the utility, (2) reduce water-related utility bills for consumers, and (3) improve the health of instream ecosystems through avoided withdrawals.

5.2.1 Valuation Methodology

In order to quantify the volume of stormwater GSI facilities harvest and use, data are needed describing the degree to which the rainwater collected in stormwater cisterns (and other rainwater harvesting practices) is used onsite for non-potable uses (as opposed to released slowly to an infiltrating GSI technology). These data were not available. Below is an explanation of how, for the purposes of this report, the value of this benefit was quantified for a hypothetical facility. This methodology relies on an avoided cost approach in which the reduction of resources spent supplying and using potable water count as a benefit for using GSI BMPs that harvest stormwater for reuse. This approach allows estimation of per-unit benefits but does not support full estimation of total benefits currently from the inventory, or consequently under the various build-out scenarios. The methodology has three steps.

Step 1 – Estimate the potential volume of rainwater harvested. To quantify the volume of rainwater harvested, the average annual volume of rainfall is multiplied by the drainage area (roof area) and converted to gallons.

Step 2 – Estimate the reduction in potable water use. In some instances, rainwater harvested can be substituted for non-potable water uses (e.g., landscape irrigation and toilet flushing). Oftentimes, the total potential volume of rainwater harvested (as estimated in Step 1) cannot be used as a substitute. There are two main reasons for this: (1) some of the harvested rainwater may be lost due to evaporation, inefficiencies in the harvesting system, large storm events, and other factors, and (2) some households may increase their total water consumption by adding harvested rainwater to their existing use of potable water rather than substituting one for the other. A range of efficiency factors from the literature are applied to the volume quantified in Step 1.

Step 3 – Apply benefit estimates to decrease in potable water demand. There are several ways to quantify the value of benefits stemming from reductions in potable water demand.[13] This analysis focused on three benefits: (1) reduced household water bills, (2) reduced treatment and conveyance costs to utilities for potable water, and (3) preserved instream flow. Of these benefits, 1 and 2 should not be summed to avoid double-counting, but both are included here to consider the benefit from both perspectives.

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[13] See, for example, Raucher, R., et al. 2006. *An Economic Framework for Evaluating the Benefits and Costs of Water Reuse.* WaterReuse Foundation.

Combined Sewer Overflows

Combined sewer overflows (CSOs) occur when the volume of water entering the combined sewer system exceeds the system's capacity. When this happens, an untreated mix of stormwater and wastewater from the combined sewer system overflows from the system through one of 92 CSO outfalls. This untreated water then flows into nearby waterways. According to the 2010 CSO Reduction Plan, Seattle's CSO volumes have declined since the 1980s, when they averaged about 400 million gallons (and about 2,800 CSO events) per year. The goal of the plan, however, is to achieve an average of no more than one CSO event per outfall per year.

GSI can help reduce the frequency and volume of CSO events by managing some of the stormwater that would have entered the combined sewer system. Because it can reduce the frequency and volume of CSO events, GSI provides two types of benefits. One of these benefits represents the avoided costs of dealing with a CSO event once it has happened. The other benefit represents the avoided costs of relying solely on gray infrastructure techniques for managing stormwater.

Appendix D contains details describing the economic value of some of the benefits associated with reducing the frequency and magnitude of CSO events.

5.2.2 Review and Analysis

This section describes a hypothetical GSI facility that harvests rainwater. It assumes that, in total, the facility harvests stormwater from 1,000 square feet of impervious roof area.

Reduction in demand for potable water. Precipitation measurements from four Seattle-area weather stations show that Seattle receives about 38 inches of precipitation each year.[14] Assuming that a rainwater harvesting system collects rainwater from 1,000 square feet of impervious area, it could harvest up to 23,600 gallons of stormwater each year. Seattle's Department of Planning and Development has recommended using an efficiency rate of 90% for a conventional metal rooftop and an 85% efficiency rate for composite or asphalt shingles.[15] This range of efficiency rates is consistent with ranges reported in published studies.[16] Assuming an efficiency rate of 85%, a system that harvests rainwater from a 1,000-square foot surface in Seattle could displace about 20,000 gallons of potable water each year.

Reduced household water bills. By reducing potable water consumption, rainwater harvesting would reduce household water bills. SPU's residential commodity charges inside Seattle range from $0.006–$0.016 per gallon depending on total volume and peak time.[17] After applying these avoided costs (the full range of potential per-gallon residential commodity charges) to the decrease in potable water consumption of 20,000 gallons, the total avoided cost comes to about $120–$316 per year. Assuming this facility continues to function over the next 100 years and that SPU's residential commodity charge

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[14] National Oceanic and Atmospheric Administration, National Climatic Data Center. 2013. *2981-2010 Normals Data Access*. Retrieved on June 6, 2013 from http://www.ncdc.noaa.gov/land-based-station-data/climate-normals/1981-2010-normals-data. [Weather stations include: (1) Seattle Boeing Field, Seattle Portage Bay, Seattle Sand PT WSFO, and Seattle Tacoma International Airport]

[15] City of Seattle, Department of Planning and Development. No Date. *Fire Station Rainwater and Graywater Harvesting for Beneficial Reuse.* Retrieved on June 6, 2013 from https://www.seattle.gov/Documents/Departments/FireLevy/Consultants/Sustainability_TBRainwaterGreywaterHarvesting.pdf.

[16] See, for example, Texas Water Development Board. 2005. *The Texas Manual on Rainwater Harvesting*. Retrieved on June 6, 2013 from http://www.twdb.texas.gov/publications/brochures/conservation/doc/RainwaterHarvestingManual_3rdedition.pdf.

[17] Seattle Public Utilities. 2013. *Residential Drinking Water Rates*. Retrieved on June 7, 2013 from http://www.seattle.gov/util/MyServices/Rates/WaterRates/ResidentialRates/index.htm.

remains constant (in real terms), the 100-year NPV of these avoided costs (discounted at a rate of 2%) is about $5,300–$13,900.

Reduced treatment and conveyance costs to utilities. By reducing demand for potable water, rainwater harvesting would reduce the costs utilities incur while treating and conveying potable water. In 2010, SPU calculated the variable costs associated with treating and supplying potable water to its customers,[18] Variable operating costs include chemical costs for treatment and energy costs for treatment and pumping, and total about $80 per million gallons.

Increased instream flows. By reducing demand for potable water, rainwater harvesting would potentially increase the volume of water available for instream flow, upstream in the watershed. The value associated with increased instream flows is highly dependent on the timing of application and total quantity relative to baseline instream flows. Water applied during low-flow summer months in streams with minimal base flows supporting highly sensitive ecological resources would have the highest value. Water applied during high-flow winter months or flows that represent "a drop in the bucket" compared to existing base flows would have lower values, potentially much lower. The value of water for environmental purposes as represented by water transactions in Washington State from 1990–2003 ranges from $4–$420 per acre-foot per year (in 2012 dollars) with a median value of about $53.[19] Transactions since 2003 suggest a higher value may be appropriate for additional flows in some streams during the summer season when streamflows are most limited. The cities of Olympia, Lacey, and Yelm recently acquired water for instream flows to mitigate lower streamflows on the Deschutes River resulting from water withdrawn for municipal purposes for $1,500 and $3,000 per acre-foot per year.[20]

5.2.3 Summary and Distribution

Data are not sufficient to quantify GSI-related reduction in potable water demand, but consideration of hypothetical examples demonstrate thousands of dollars of potential benefit to a building harvesting rainwater. For this example, a hypothetical 1000 square feet harvest facility would provide $5,300-$13,900 in avoided potable water costs to the consumer (100-year NPV), and considering the 20,000 gallons annually harvested and a $3,000 cost per acre-foot to replace instream flows, this would provide an additional $7,936 (100-year NPV). This totals $13,000-$22,000.

Reclaimed Water Strategies

In March 2012, ECONorthwest conducted a benefit-cost analysis of King County's Reclaimed Water Comprehensive Plan. The analysis identified, quantified, and described the economic values of benefits and costs associated with three reclaimed water strategies relative to a baseline scenario in which no reclaimed water strategy was pursued. The benefits and costs included in the analysis represent the values associated with decreasing potable water use, treating water, and reusing that treated water. The types of benefits and costs considered in the analysis are similar to those associated with harvest-related GSI BMPs. The results of the analysis suggest that such strategies have the potential to provide benefits greater than costs.

Sources: ECONorthwest. 2012. King County Reclaimed Water Comprehensive Plan, Benefit-Cost Analysis of Reclaimed Water Strategies. March. King County, Washington.

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[18] Seattle Public Utilities. 2010. *An Economic Analysis of the North Seattle Reclaimed Water Project*. September 10.

[19] Brown, T.C. 2004. *The Marginal Economic Value of Streamflow from National Forests*. U.S. Forest Service, Rocky Mountain Research Station. December 28.

[20] City of Olympia and the Nisqually Indian Tribe. 2010. *McAllister Wellfield Mitigation Plan*. December.

This benefit has the potential to affect many groups of beneficiaries. Households with GSI would benefit directly from decreased utility bills. Utilities would benefit from decreased operations costs. Other residents in the region, across the state, and across the country would benefit from improvements in instream flow to the extent that they value improvements in aquatic habitat, water quality, and salmon populations.

5.3 Energy – Household Use

Some GSI BMPs have the capacity to decrease household energy consumption by decreasing demand for indoor heating during cold months and demand for indoor cooling during hot months. To the extent that GSI reduces household energy consumption, it can decrease household energy bills. Decreasing household energy consumption has additional benefits (e.g., GHG-related benefits and air quality-related benefits). These additional benefits are discussed elsewhere in this report.

5.3.1 Valuation Methodology

Research suggests that green roofs and trees are the two GSI BMPs most capable of reducing household energy consumption.[21] Primary research describing the potential for green roof-related energy savings specific to Seattle's climate has not been conducted to date, therefore this section focuses on tree-related benefits.

Research has identified three ways in which trees can help reduce household energy use: (1) shade from trees reduces the amount of radiant energy that homes absorb and store, (2) transpiration converts moisture to water vapor, which cools the air surrounding homes, and (3) wind reduction helps reduce heat loss in parts of homes that are conducive to heat loss (e.g., windows).[22] The general methodology applied here has three steps, described below.

Step 1 – Quantify number of trees. Data describing the existing inventory of GSI facilities in Seattle contains tree-specific data only for facilities installed through the code-triggered mechanism. Existing information describing tree potential in Seattle (as described elsewhere in this report) was used for the build-out scenarios. All trees in the inventory and the build-out scenarios are medium-sized trees that are about 10 years old. Since the literature does not distinguish between deciduous and evergreen trees, they were considered together.

Step 2 – Quantify energy savings. The literature provides multipliers to estimate tree-related energy savings for western Washington. These data rely on primary data collected in Portland, Oregon. For the purposes of this analysis, the energy savings in Portland are assumed to be similar to those expected in Seattle.

Step 3 – Align energy savings with energy costs. To calculate household savings, the number of trees (aligned with the energy saving factors and the projected energy savings over time with tree growth) were multiplied by residential energy prices. A range of residential electricity prices from Seattle City Light and a point estimate of natural gas prices from Puget Sound Energy were compiled.

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[21] Center for Neighborhood Technology. 2010. *The Value of Green Infrastructure: A Guide to Recognizing its Economic, Environmental, and Social Benefits.*

[22] McPherson, G. et al. 2002. *Western Washington and Oregon Community Tree Guide: Benefits, Costs and Strategic Planning*. Center for Urban Forest Research, U.S. Forest Service, Pacific Southwest Research Station. March.

5.3.2 Review and Analysis

Number of trees. The existing data describing trees planted in Seattle's GSI inventory record only those trees planted for code-triggered projects (for stormwater control purposes). In total, about 1,640 trees have been used through 2012 to manage stormwater on these projects. Trees will be installed on an annual basis through 2050 under each build-out scenario, both on code-triggered projects and within the public right-of-way. The Low Build-Out Scenario will install about 4,800 trees each year, the Medium Build-Out Scenario will install about 5,500 trees each year, and the High Build-Out Scenario will install about 6,300 trees each year (see Appendix B for details).

Energy savings. Research in western Washington and Oregon has estimated the household energy savings attributable to nearby trees (within about 60 feet).[23] Energy savings are described in terms of cooling energy (kWh) and heating energy (kBtu). Energy savings depend on the size of the tree and on its location relative to the household. For this analysis, it was assumed that all trees are medium in size and that they are 10 years old when they begin managing stormwater. In general, larger trees offer more energy-related savings, so future GSI planning should consider selecting tree sizes to maximize these tree-related benefits. Furthermore, the research has offered different savings factors depending on the tree's location relative to the household (east side, south side, west side, and public). For this analysis, the average of these factors was taken because data are not sufficient to precisely locate each tree relative to the nearest household. Table 8 summarizes the energy savings factors used in the analysis (per tree, per year).

Table 8. Tree-Related Energy Savings (per tree per year)

Age	Energy Savings (cooling | heating)	Age	Energy Savings (cooling | heating)
Year 5	3.75 kWh | (53.50) kBtu	Year 25	68.25 kWh | (83.75) kBtu
Year 10	20.25 kWh | (161.00) kBtu	Year 30	76.50 kWh | (39.00) kBtu
Year 15	41.50 kWh | (165.25) kBtu	Year 35	82.25 kWh | (0.25) kBtu
Year 20	57.25 kWh | (130.50) kBtu	Year 40 and beyond	86.25 kWh | (30.00) kBtu

Source: McPherson, G. et al. 2002. *Western Washington and Oregon Community Tree Guide: Benefits, Costs and Strategic Planning*. Center for Urban Forest Research, U.S. Forest Service, Pacific Southwest Research Station. March.
Notes: A linear distribution of energy savings is assumed between points identified in this table.

Results. Table 9 summarizes the results of the analysis. The existing inventory of trees has the capacity to reduce household energy consumption for cooling by about 13 million kWh over the next 100 years. The existing inventory of trees would potentially increase household energy consumption for heating by about 2.1 million kBtu over the next 100 years. All three build-out scenarios demonstrate a similar pattern in cooling benefits and heating costs.

Because these benefits accrue at the household scale, household energy costs are used to estimate the value of these energy savings. In 2013, the average residential rate for electricity from Seattle City Lights ranged from $0.0466–$0.1071 per kWh, and the average residential rate for natural gas from Puget Sound Energy was $0.0097 per kBtu.[24] These energy prices are multiplied by the annual changes in

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[23] McPherson, G. et al. 2002. *Western Washington and Oregon Community Tree Guide: Benefits, Costs and Strategic Planning*. Center for Urban Forest Research, U.S. Forest Service, Pacific Southwest Research Station. March.

[24] Seattle City Light. 2013. *Electric Rates and Provisions: Schedule RSC - Residential City*. Retrieved on June 17, 2013 from *http://www.seattle.gov/light/accounts/rates/docs/2013/Jan/January%202013%20-%20rsc.pdf*; Puget Sound Energy. 2013. Gas Summary Sheet No. S-3. Retrieved on June 17, 2013 from *http://pse.com/aboutpse/Rates/Documents/summ_gas_prices_2013_05_01.pdf*.

energy consumption and discount all future values to estimate the 100-year NPV of energy savings (the final column in the table). The 100-year NPV of the energy savings the existing inventory of trees provides is about $0.2–$0.5 million. The 100-year NPV of the energy savings provided by the trees associated with the build-out scenarios ranges from $15–$37 million under the Low Build-Out Scenario up to $20–$49 million under the High Build-Out Scenario.

Table 9. Summary of Tree-related Energy Benefits to Households[25]

	Number of Trees	100-year Energy Savings	100-year NPV
Code-Triggered Inventory	1,640	13.0 million kWh | (2.1 million) kBtu	$0.2–$0.5 million
Low Build-Out Scenario	4,800/year	1.1 billion kWh | (323 million) kBtu	$15–$37 million
Medium Build-Out Scenario	5,500/year	1.3 billion kWh | (373 million) kBtu	$17–$43 million
High Build-Out Scenario	6,300/year	1.5 billion kWh | (424 million) kBtu	$20–$49 million

While these trees have the potential to decrease cooling costs during summer months, individuals that do not use air conditioning or fans to cool their homes would not realize this benefit. To the extent that households in Seattle use cooling systems less frequently than assumed in the literature applied in this analysis (which is based on households in Portland, OR), these results may overstate the benefits. Furthermore, this analysis assumes that the energy rates households face will remain constant, in real terms over the next 100 years. The U.S. Energy Information Administration has identified five factors that influence energy prices: (1) fuel source, (2) power plants, (3) distribution network, (4) weather conditions, and (5) regulations.[26] Climate change, efforts to prevent/reduce the impacts of climate change, and other energy-related efforts have the capacity to influence all five of these factors, which could increase or decrease energy rates, in real terms, in the future.

As of this writing, inventory data on green roofs do not provide sufficient detail on the building uses or green roof characteristics to allow estimation of the energy savings from reduced heating and cooling with green roofs in Seattle. Seattle has 1.8 million square feet of green roofs and roof gardens (Table 15). A study of avoided energy costs for a 40,000 square foot green roof in Portland found annual energy savings of $1480.[27] This equates to $66,600 annually in energy benefits, and a 100-year NPV at 2 percent discounting of $2.87 million. Both green roofs and trees would also contribute to reduced heat island effects, although the natural temperature buffering of Puget Sound reduces the importance of avoiding extreme high temperatures. The increasing potential for the importance of these benefits with climate change is discussed later.

[25] While the annual number of trees planted appears high relative to the documented code-triggered inventory, it is based on existing proportions for share of GSI management in the inventory, and relationships between number of trees and volumes managed. See Appendix B for greater detail.

[26] U.S. Energy Information Administration. 2012. *Many Factors Impact Electricity Prices*. Retrieved on June 26, 2013 from *http://www.eia.gov/energyexplained/index.cfm?page=electricity_factors_affecting_prices*.

[27] MacMullan, E., Reich, S., Puttman, T., & Rodgers, K. 2008. Cost-Benefit Evaluation of Ecoroofs. In *Low Impact Development for Urban Ecosystem and Habitat Protection* (pp. 1-10). ASCE. November.

Tree Size and Location Matters

As stated in this section, the size of trees and their location on a property play important roles in determining their potential effect on household energy use. To demonstrate the magnitude of this effect, the potential energy savings are modeled for small, medium, and large trees planted on west-facing, south-facing, and east-facing yards as well as trees planted in public areas. While trees planted in public areas may not provide any direct shading benefits to homes, they do provide neighborhood-wide benefits associated with reduced temperatures and wind speeds. The tables below show the 100-year NPV of cooling benefits, heating benefits, and the combination of cooling and heating benefits, per tree. Energy rates of $0.0769/kWh are assumed for cooling benefits and $0.0097/kBtu for heating benefits. All values are discounted at a rate of 2%.

100-year NPV of Cooling Benefits (per tree)					100-year NPV of Heating Benefits (per tree)				
	West	South	East	Public		West	South	East	Public
Small	$1,897	$1,048	$788	$365	Small	$(338)	$(1,099)	$(827)	$462
Medium	$3,011	$2,418	$1,640	$934	Medium	$213	$(832)	$(426)	$1,190
Large	**$4,340**	$3,230	$2,639	$2,004	Large	$1,521	$185	$739	**$2,549**

100-year NPV of Cooling Benefits and Heating Benefits (per tree)				
	West	South	East	Public
Small	$1,559	$(51)	$(38)	$826
Medium	$3,224	$1,586	$1,215	$2,124
Large	**$5,861**	$3,415	$3,378	$4,553

The best options are highlighted in the tables. Large trees on the west side of homes offer the most cooling benefits, while large trees on public lands offer the most heating benefits. After combining cooling and heating benefits, large trees on the west side of homes offer the greatest NPV of benefits over 100 years. In general, however, trees planted on public land offer both cooling and heating benefits to households and likely represent a good opportunity for public efforts aimed at reducing household energy consumption.

5.3.3 Summary and Distribution

In this section, the economic value of GSI's impact on household energy use is discussed and calculated. Energy metrics from the literature are applied to the number of trees in SPU's GSI inventory as well as under the three build-out scenarios to quantify total changes in household energy demand. The existing inventory supports about 1,600 trees, and all three build-out scenarios would support about 1,000 trees on single-family properties as part of the code-triggered mechanism for GSI implementation.

Existing trees have the potential to reduce household energy use for cooling by about 13 million kWh, but they may increase household energy use for heating by 2.1 million kBtu over the next 100 years. The 100-year NPV of this benefit totals about $0.2–$0.5 million. Similarly, trees associated with the build-out scenarios have the potential to reduce household energy use for cooling, but they may increase household energy use for heating. The 100-year NPVs of this benefit range from $15 to $50 million across the build-out scenarios. The benefits of reducing household energy use accrue primarily to Seattle residents with trees near their homes, although some residual benefit extends beyond immediately adjacent buildings. Additional benefits associated with reduced energy consumption are discussed elsewhere in this report.

5.4 Greenhouse Gas Emissions and Sequestration

Extensive research shows that Seattle and other parts of the Pacific Northwest already have experienced noticeable changes in climate, and predicts that more change will occur in the future.[28] Research has identified several types of anthropogenic greenhouse gas (GHG) emissions that contribute to climate change; chief among them is the emissions of CO_2. In 2004, CO_2 accounted for approximately 77% of greenhouse gases emitted into the atmosphere. Since 1850, the concentration of CO_2 in the atmosphere has increased from 280 to 379 parts per million, and has grown by an average of 1.9 parts per million per year since 1995.[29] Airborne pollutants such as CO_2 and other GHGs are the primary contributors to climate change. This section quantifies the volume of atmospheric reductions in GHGs associated with GSI and monetize the value of the benefit.

5.4.1 Valuation Methodology

The analysis of the value of reducing atmospheric GHG concentrations has three parts.

Step 1 – Estimate avoided GHG emissions. In previous sections, different ways that GSI can reduce energy consumption were described. For all quantified reductions in energy consumption, the total amount of energy is calculated in base units (e.g., kWh, kBtu), and multiplied by emission factors from the relevant utility.

Step 2 – Estimate GHG sequestration. In previous sections, the number and growth rate of existing and new trees in the GSI inventory and in each of the scenarios are described. These tree data are aligned with sequestration factors from the literature that quantify the volume of tree-related GHG sequestration.

Step 3 – Apply the value of carbon. This analysis relied on two per-unit values representing the potential costs associated with CO_2 emissions: (1) an estimate of the social cost of carbon, and (2) a range of market prices for carbon emissions from efforts to trade and tax emissions across the world.

5.4.2 Review and Analysis

Carbon values. Economists use the social cost of carbon to estimate the value of changes in greenhouse gas emissions. The social cost of carbon represents "the full global cost today of emitting an incremental unit of carbon at some point of time in the future, and it includes the sum of the global cost of the damage it imposes on the entire time it is in the atmosphere."[30] There are currently over 200 different estimates of the social cost of carbon. One review of the literature found values ranging from about $7 to over $100 per ton of CO_2e (or CO_2 equivalent).[31]

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[28] See, for example, University of Washington, Climate Impacts Group. 2009. *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*.

[29] Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: Synthesis Report*. Geneva, Switzerland.

[30] Shaw, M., L. Pendleton, et al. 2009. *The Impact of Climate Change on California's Ecosystem Services*. California Climate Change Center. CEC-500-2009-025-F.

[31] Shaw, M., L. Pendleton, et al. 2009. *The Impact of Climate Change on California's Ecosystem Services*. California Climate Change Center. CEC-500-2009-025-F.

Over the past decade, several voluntary and regulatory carbon markets have emerged around the world along with several attempts at taxing carbon. Table 10 summarizes the total volume, total value, and per-unit value of carbon traded in voluntary and regulatory carbon markets around the world in 2011. The average carbon price across these markets was about $15.50 per ton of CO_2e. In addition to these carbon markets, many public agencies around the world have proposed or implemented carbon tax schemes (e.g., South Africa, India, Japan, South Korea, Australia, New Zealand, Denmark, Finland, and France). In 2008, British Columbia passed the Carbon Tax Act, which consumers pay when they purchase fossil fuels in the Province. The carbon tax rate has increased each year, and in July 2012 was set at about $27 per ton of CO_2e.[32]

Table 10. Voluntary and Regulatory Carbon Markets (2011 Summary)

Carbon Market	Tons of CO_2e (millions)	Total Market Value (millions)	Average Value per Ton ($/Ton of CO_2e)
Voluntary Carbon Markets	86	$576	$5.50
European Union Emission Trading Scheme	7,124	$147,848	$17.08
Primary Clean Development Mechanism	264	$3,320	$10.35
Secondary Clean Development Mechanism	1,653	$23,250	$11.58
Kyoto Protocol	43	$318	$6.14
Regional Greenhouse Gas Initiative	109	$249	$1.88
Annex 1 Market (Kyoto Protocol)	4	$12	$2.72
New Zealand Carbon Market	24	$351	$11.79
California Carbon Allowance	4	$63	$14.29
Others	24	$40	$1.40
Total	**9,334**	**$176,027**	**N/A**

Source: Ecosystem Marketplace. 2012. Developing Dimension: State of the Voluntary Carbon Markets 2012. May 31.

A recent publication from the U.S. Interagency Working Group on Social Cost of Carbon recommends using even higher values than those described above.[33] The group's estimate is based on the value of potential damages associated with incremental increases in carbon emissions including agricultural productivity, human health, property damages, and ecosystem services. The group's estimates range from about $12 to $58 (in 2012 dollars) per ton of CO_2 in 2013 depending on the discount rate (5.0% to 2.5%). The group also suggests that at the high end of the 95% confidence interval, the social cost of carbon could be as high as about $100 per ton of CO_2 in 2013.

To account for carbon values in existing markets, government taxes, and the Interagency Working Group on Social Cost of Carbon estimates, a range of $15 to $58 per ton of CO_2e will be considered. Furthermore, it is assumed that this value increases, in real terms, by 2.5% per year, to fold in expectations that the value of the social costs would increase at an annual rate of 2%–3% as damages related to climate change mount.[34]

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[32] British Columbia, Ministry of Finance. 2013. *Carbon Tax Review, and Carbon Tax Overview*. Retrieved on February 12, 2013 from http://www.fin.gov.bc.ca/tbs/tp/climate/carbon_tax.htm.

[33] U.S. Interagency Working Group on Social Cost of Carbon. 2013. *Technical Support Document: Technical Update to the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*.

[34] Nordhaus, W. 2008. *A Question of Balance: Weighing the Options on Global Warming Policies*. Yale University Press, New Haven, CT.

Emissions reduction from home-related cooling and heating. Elsewhere in this report, the household energy savings associated with trees was quantified. The inventory and the Low, Medium, and High Build-Out Scenarios reduce energy consumption for cooling by about 13.0 million, 608 million, 785 million, 961 million kWh, respectively, over the next 100 years. The inventory and the Low, Medium, and High Build-Out Scenarios increase energy consumption for heating by about 2.1 million, 174 million, 225 million, 275 million kBtu over the next 100 years. For marginal emissions from electricity generation, Seattle City Light uses an emission factor of about 1.1 lbs. of CO_2e per kWh.[35] For emissions from natural gas, EPA uses an emissions factor of 0.1 lbs. of CO_2e per kBtu.[36] Over the next 100 years, the inventory would reduce emissions by about 7,000 tons of CO_2e. The Low, Medium, and High Build-Out Scenarios would reduce emissions by about 323,000 tons, 416,000 tons, and 510,000 ton of CO_2e over the next 100 years, respectively.

A range of carbon values ($15–$58, increasing at a real rate of 2.5% per year) are used to quantify the economic value of this benefit. The 100-year NPV of the avoided emissions stemming from the inventory's impact on household energy consumption totals about $0.1–$0.5 million. The 100-year NPV of avoided emissions is about $6.6–$25.6 million under the Low Build-Out Scenario, $8.5–$33.1 million under the Medium Build-Out Scenario, and about $10.5–$40.5 million under the High Build-Out Scenario.

Emissions reduction from reduced treatment. King County's Wastewater Treatment Division has estimated the volume of water managed at the West Point Wastewater Treatment Plant as well as the total energy used to treat that water and the total energy costs. Emission factors are applied to these energy units to quantify emissions volumes.[37] Table 11 summarizes these data for 2009 and 2010. On average, treatment-related energy emissions at West Point totaled about 1.0 tons of CO_2e per million gallons of water treated.

Table 11. Treatment-Related Emissions at West Point Wastewater Treatment Plant

Year	Electricity (kWh)	Gas and Propane (therms)	Average Annual Flow (millions of gallons)	MWh/million gallons	Tons of CO_2e/million gallons
2009	53.4 million	1.4 million	40,150	2.4	0.9
2010	52.1 million	1.5 million	35,040	2.8	1.0
				Average	**1.0**

Source: Hanley, M. 2009. *Fact Sheet for NPDES Permit WA-002918-1*. June; Personal Communication. Phillips, John. King County Wastewater Treatment Division. E-mail. June 12, 2013; Personal Communication. Corinne Grande. Seattle City Lights. E-mail. April 22, 2013; U.S. EPA. 2013. *Clean Energy Calculations and References*. Retrieved on June 14, 2013 from http://www.epa.gov/cleanenergy/energy-resources/refs.html.

As described in previous sections and in Appendix A, the existing inventory of GSI facilities manages 13.4 million gallons of stormwater runoff per year within the combined sewer basin. Below are the volumes of stormwater the build-out scenarios manage within the combined sewer basin (additional details are provided in Appendix B).

- The Low Build-Out Scenario would manage a total of 760 million gallons of stormwater in the combined sewer basin per year by 2050.

[35] Personal Communication. Corinne Grande. Seattle City Light. E-mail. April 22, 2013.

[36] USEPA. 2013. *Clean Energy Calculations and References*. Retrieved on June 14, 2013 from http://www.epa.gov/cleanenergy/energy-resources/refs.html.

[37] Emission factor for electricity generation used in this analysis is 0.54 tons of CO2e per MWh. Emission factor for natural gas used in this analysis is 0.16 tons of CO_2e/MWh.

- The Medium Build-Out Scenario would manage a total of 1.2 billion gallons of stormwater in the combined sewer basin per year by 2050.
- The High Build-Out Scenario would manage a total of 2.0 billion gallons of stormwater in the combined sewer basin per year by 2050.

To calculate the 100-year NPV of this benefit, the volume of stormwater managed each year is aligned with the avoided emissions and the range of carbon values described earlier. The 100-year NPV of the existing inventory's treatment-related emissions reductions totals $25,000–$96,000. The 100-year NPVs for the Low, Medium, and High Build-Out Scenarios total $1.2–$4.6 million, $1.9–$7.5 million, and $3.1–$12.0 million, respectively.

Carbon Sequestration

Sequestration by trees. The U.S. Department of Energy has compiled data estimating carbon sequestration rates for trees in urban and suburban areas.[38] According to these data, younger trees tend to sequester less carbon than older trees, and coniferous trees tend to sequester less carbon than deciduous trees. A 10-year-old tree sequesters 13–48 lbs. of CO_2 per year, while a 50-year-old tree sequesters 88–450 lbs. of CO_2 per year. It is assumed all trees, both those in the inventory and those in the build-out scenarios, are 10 years old when they are installed, and the full range of sequestration rates across both deciduous and coniferous varieties are used. Trees associated with the inventory could sequester a total of about 6,800–34,700 tons of CO_2 over the next 100 years with a 100-year NPV of about $0.1–$2.7 million. These values can range up to nearly 4 million tons of sequestration worth over $300 million under the High Build-Out Scenario (Table 12).

Table 12. Summary of 100-Year Volume and NPV of GHG Benefits

100-Year Volume of GHG Emissions Reductions and Sequestration				
	Reduced Emissions from Household Energy Consumption	**Reduced Emissions from Reduced Treatment**	**Tree-Related CO_2 Sequestration**	**Total CO_2 Reductions**
Inventory	7,000 tons	1,300 tons	6,800–34,700 tons	< 0.1 million tons
Low Build-Out Scenario	599,000 tons	44,000 tons	0.56–2.9 million tons	1.2–3.5 million tons
Medium Build-Out Scenario	692,000 tons	77,000 tons	0.65–3.3 million tons	1.4–4.1 million tons
High Build-Out Scenario	786,000 tons	131,000 tons	0.74–3.8 million tons	1.7–4.7 million tons
100-Year NPV of Benefits Related to GHG Emissions Reductions and Sequestration				
	Reduced Emissions from Household Energy Consumption	**Reduced Emissions from Reduced Treatment**	**Tree-Related CO_2 Sequestration**	**Total 100-Year NPV**
Inventory	$0.1–$0.5 million	< $0.1 million	$0.1–$2.7 million	$0.3–$3.3 million
Low Build-Out Scenario	$12–$48 million	$0.87–$3.4 million	$12–$233 million	$25–$284 million
Medium Build-Out Scenario	$14–$55 million	$1.5–$6.0 million	$14–$270 million	$29–$331 million
High Build-Out Scenario	$16–$62 million	$2.6–$10 million	$15–$306 million	$34–$379 million

[38] U.S. Department of Energy, Energy Information Administration. 1998. *Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings*. Retrieved on June 17, 2013 from ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/sequester.pdf.

Sequestration by soil. Bioretention facilities such as rain gardens typically utilize soil, as do tree plantings. Modeling by the U.S. EPA assumes that 1/5th of the carbon content of soil amendments such as compost are stored long-term in soil.[39] Inventory data do not currently allow an estimation of the compost or other carbon amendment shares or totals for soils associated with GSI facilities in Seattle. Considering a ton of soil is roughly 40 cubic feet in volume, and if half the soil volume were carbon amendments such as compost, 1/5th storage of original volume would net a tenth of a ton of carbon sequestration for each ton of soil utilized. In the future, tracking soil volumes and carbon amendment shares will allow estimation of this potentially large contribution of GSI in Seattle to soil carbon sequestration.

5.4.3 Summary and Distribution

This section quantifies the value of avoided GHG emissions and GHG sequestration associated with GSI's capacity to reduce energy consumption and to filter GHGs out of the atmosphere. Energy savings from other sections of this report were used along with emissions data from local utilities to estimate the change in emissions over time. Tree data with per-tree values of carbon sequestration were aligned to quantify the reduction in atmospheric GHG concentrations over time. A range of economic values associated with markets for GHG emission and the social cost of carbon were used to quantify the economic value of this benefit (\$15–\$58 per ton of CO_2e, increasing at a real rate of 2.5% per year). Table 12 summarizes the results of the analysis. The top half of the table shows the volume of GHGs for each scenario and for each of the three forms of GHG reductions. The bottom half of the table shows the values associated with these GHG reductions. To the extent that the effects of climate change are global, reducing the concentration of GHG in the atmosphere benefits all of society. These benefits may be different for different parts of the world, but the economic values used in this analysis reflect average effects across the globe.

5.5 Air Quality

GSI has the capacity to improve air quality in two ways: (1) by decreasing energy demand, GSI indirectly decreases the volume of harmful pollutants emitted into the atmosphere, and (2) some forms of GSI (trees and vegetation) remove harmful pollutants from the atmosphere through biophysical processes. Improvements in air quality have economic value in that they reduce the costs associated with air pollution (e.g., health-related costs from respiratory illness and habitat destruction). In this section, local emission factors and air filtration rates are used along with avoided emissions-related costs, to quantify the value of air quality benefits.

5.5.1 Valuation Methodology

The literature provides a proven method for quantifying the value of air quality-related benefits associated with reductions in emissions and vegetative filtration. Typically, this methodology has two steps: (1) calculating the volume of airborne pollutants that would have been emitted into the atmosphere and the volume of pollutants filtered out of the atmosphere by vegetation, and (2) multiplying those volumes by per-unit values (e.g., dollars per ton of SO_2) describing the value of the benefits of improvements in air quality.

Step 1 – Quantify change in air quality. By reducing energy consumption, GSI has the capacity to reduce energy production and, consequently, to improve air quality. To calculate the change in emissions associated with GSI, emissions rates specific to Washington State are applied to changes in energy

[39] U.S. EPA. 2013. Waste Reduction Model. *https://www.epa.gov/warm*.

consumption from other parts of this analysis. In addition to the indirect improvements in air quality from reductions in energy consumption, some GSI BMPs (e.g., street trees and green roofs) have the capacity to improve air quality by filtering harmful pollutants out of the atmosphere. To calculate the contributions of these GSI facilities to improved air quality, average filtration rates from the literature that describe per-unit pollutant removal in terms of trees and vegetated surfaces are applied.

Step 2 – Align changes in air quality with avoided costs. Quantifying the economic value of changes in local air quality requires complex climate, epidemiological, and economic modeling efforts. For this analysis, average costs associated with changes in air quality from the national perspective are used. These costs represent the health costs individuals incur due to air pollution. By improving air quality, GSI has the capacity to reduce air quality-related health costs in Seattle as well as other places that generate electricity.

5.5.2 Review and Analysis

This section summarizes the analysis of three forms of air quality improvements: (1) tree-related air filtration, (2) reduced emissions from reduced household energy consumption, and (3) reduced emissions from reduced treatment-related energy consumption. Energy data from other sections in this report are used throughout this analysis.

Tree-related air pollution removal. Trees intercept and remove air pollutants from the atmosphere and break them down through a series of biological processes and mechanisms. Nowak (2006) estimated pollution removal rates in terms of canopy cover across 55 cities in the U.S., including Seattle.[40] Pollutant-specific per-gram values for pollutant removal were used, which represent median externality values (from a national perspective) associated with costs typically linked to air pollution (e.g., health costs).[41] Average canopy widths of 21–37 feet were used to convert these canopy cover figures to per-tree estimates.[42] Table 13 summarizes the conversion from pollutant removal to value per tree per year. According to these assumptions, the value of tree-related pollutant removal by a mature tree in Seattle totals $0.59–$7.69 per year. Not all trees included in this analysis are mature, however data are not sufficient to extrapolate pollution removal over time as trees grow. For this analysis, it was assumed that, on average, trees included provide air pollution benefits of $0.29–$3.85 per tree per year.

The existing inventory of GSI facilities includes a total of 1,640 trees.[43] The Low, Medium, and High Build-Out Scenarios would increase the number of trees by about 4,810, 5,560, and 6,310, respectively, each year, through 2050. As discussed above, it is assumed that, on average, trees included in this analysis provide air quality benefits (in terms of air pollutants removed from the atmosphere) of $0.29–$3.85 per tree per year. The 100-year NPV of these benefits for the existing inventory is about $21,000–$0.28 million. Not including the benefits from the existing inventory, the 100-year NPV of these air quality benefits is about $1.5–20 million for the Low Build-Out Scenario, $1.8–$23 million for the Medium Build-Out Scenario, and $2.0–$26 million for the High Build-Out Scenario.

[40] Nowak, D., D. Crane, and J. Stevens. 2006. "Air Pollution Removal by Urban Trees and Shrubs in the United States." *Urban Forestry & Urban Greening*. 4:115–123.

[41] Murray, F., L. Marsh, and P. Bradford. 1994. *New York State Energy Plan, Volume II*. New York State Energy Office, Albany, NY.

[42] Center for Neighborhood Technology. 2010. *The Value of Green Infrastructure: A Guide to Recognizing its Economic, Environmental, and Social Benefits.*

[43] Data were not sufficient to quantify the number of trees associated with some of the GSI mechanisms, so this likely understates the actual number of trees currently supporting stormwater management efforts.

Table 13. Air Pollution Removal by Urban Trees in Seattle

Pollutant	Pollutant Removal (grams/square meter of canopy cover/year)	Value of Pollutant Removal ($/gram)	Value of Pollutant Removal ($/tree/year)
CO	0.6	$0.0011	$0.01–$0.03
NO_2	0.7–1.9	$0.0077	$0.09–$0.73
PM10	1.2–4.8	$0.0051	$0.10–$1.23
SO_2	0.7–2.5	$0.0019	$0.02–$0.24
O_3	0.7–4.3	$0.0077	$0.09–$1.65

Source: Nowak, D., D. Crane, and J. Stevens. 2006. "Air Pollution Removal by Urban Trees and Shrubs in the United States." *Urban Forestry & Urban Greening*. 4:115–123.
Notes: To convert from per-square meter of canopy cover units to per-tree units, a range of 32–100 square meters of canopy cover per tree was assumed. Chemical abbreviations: CO – carbon monoxide, NO_2 – nitrogen dioxide, PM10 – particulate matter up to 10 µm in size, SO_2 – sulfur dioxide, O_3 - ozone

Emissions reduction from home-related cooling and heating. Elsewhere in this report, the household energy savings associated with trees was quantified. The inventory and the Low, Medium, and High Build-Out Scenarios reduce energy consumption for cooling by about 13.0 million, 1.1 billion, 1.3 billion, and 1.5 billion kWh, respectively, over the next 100 years. The inventory and the Low, Medium, and High Build-Out Scenarios increase energy consumption for heating by about 2.1 million, 323 million, 373 million, 424 million kBtu over the next 100 years. A factor of 3,412 kBtu/MWh is used to convert energy used for heating into a common metric.[44]

When fossil fuels such as coal and natural gas are used to generate electricity, harmful pollutants are emitted into the atmosphere. Data describing Seattle-specific utilities and their emissions rates are not available however EPA provides state-level emissions factors. According to EPA, Washington State's emissions profile includes emissions factors of 0.087 lbs. of SO_2/MWh and 0.4236 lbs. of NO_x/MWh.[45] Relative to other parts of the country, Washington's emissions factors are low, primarily due to its heavy reliance on renewable energy sources (over 70% of all of the state's energy comes from hydro facilities). Applying the same pollutant values from above suggests that reducing energy consumption in Seattle reduces the costs of air pollution by about $0.08/MWh for SO_2 and about $1.48/MWh for NOx. While energy generation emits other harmful pollutants (e.g., PM10, SO_2, O_3), data describing the extent to which generation facilities in Washington emit these pollutants are not sufficient for inclusion in this analysis.

A value of $1.55 per MWh of energy consumption avoided due to tree-related reductions in demand for cooling and heating was applied. The 100-year NPV of these air quality benefits for the inventory total about $6,700. The 100-year NPV of these air quality benefits total about $0.47 million for the Low Build-Out Scenario, about $0.54 million for the Medium Build-Out Scenario, and about $0.61 million for the High Build-Out Scenario.

Emissions reduction from reduced treatment. King County's Wastewater Treatment Division has estimated the volume of water managed at the West Point Wastewater Treatment Plant, as well as the total energy used to treat that water and the total energy costs. As shown in Table 11, treatment at West Point requires an average of 2.6 MWh per million gallons. As described in previous sections and in

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[44] International Energy Agency. 2013. *Unit Converter*. Retrieved on June 26, 2013 from http://www.iea.org/stats/unit.asp.

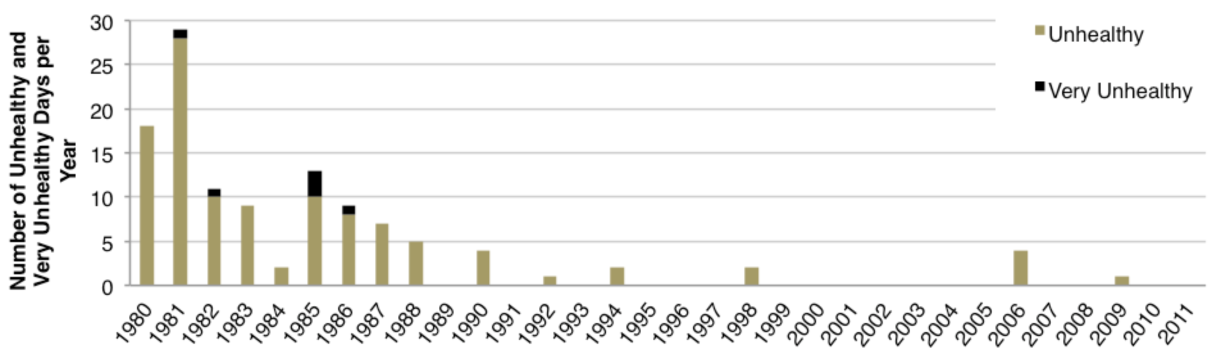
[45] U.S. Environmental Protection Agency. 2013. *eGRIDweb - State Level Data (Washington)*. Retrieved on June 24, 2013 from http://cfpub.epa.gov/egridweb/view_st.cfm.

Appendix A, the existing inventory of GSI facilities manages 13.4 million gallons of stormwater runoff per year within the combined sewer basin. The Low Build-Out Scenario would manage a total of 556 million gallons of stormwater in the combined sewer basin per year by 2050. The Medium Build-Out Scenario would manage a total of 986 million gallons of stormwater in the combined sewer basin per year by 2050. The High Build-Out Scenario would manage a total of 1.7 billion gallons of stormwater in the combined sewer basin per year by 2050.

To calculate the 100-year NPV of this benefit, the volume of stormwater managed each year is aligned with the avoided emissions and the range of carbon values described earlier. The 100-year NPV of the existing inventory's treatment-related emissions reductions totals about $2,000. The 100-year NPVs for the Low, Medium, and High Build-Out Scenarios total < $0.1 million, $0.11 million, and $0.20 million, respectively.

Figure 5 shows the number of unhealthy and very unhealthy air quality days in Seattle from 1980–2011. The data suggest that air quality in Seattle has improved over the past three decades. In fact, from 2007–2011, there was only one unhealthy day and no very unhealthy days. To some extent, the values contained in this section may overstate the marginal costs avoided due to improvements in air quality.

Figure 5. Unhealthy and Very Unhealthy Air Quality Days in Seattle (1980–2011)



Source: Puget Sound Clean Air Agency. 2012. *2011 Air Quality Data Summary Appendix*. November. Retrieved on July 8, 2013 from *http://www.pscleanair.org/airq/reports.aspx*.

Heightened Importance of Air Quality in Seattle

A 2012 survey commissioned by the Puget Sound Partnership compiled data from 2,003 residents across the Puget Sound region. One of the tasks that respondents faced was to identify the top two things about the Puget Sound region's natural resources that they value most. About 8% of King County respondents listed clean air and another 8% listed the scenery as one of the top two things they value.

Individuals consider a number of factors when deciding where to live, such as employment opportunities, family, friends, and environmental quality and resources. A 2008 study used a series of variables (wage data, housing data, and other amenities including heating and cooling degree days, sunshine, coastal proximity, air quality, and other social variables) to rank states and metropolitan areas in terms of desirability. Washington State ranked seventh on the list of states. The Seattle-Tacoma-Bremerton CMSA ranked 30th on the list of 241 metropolitan areas included in the analysis.

Source: Puget Sound Partnership. 2012. *General Public Opinion Survey*. Prepared by PRR Inc.; Albouy, D. 2008. *Are Big Cities Really Bad Places to Live? Improving Quality of Life Estimates Across Cities*. NBER Working Paper Series. Working Paper 14472.

5.5.3 Summary and Distribution

In this section, the value of air quality improvements associated with GSI's capacity to reduce energy consumption and filter pollutants out of the atmosphere is quantified. Energy savings from other sections of this report are used, along with state-level emissions factors, to estimate the change in emissions over time. Tree data with per-tree values of air filtration also is aligned to quantify the reduction in air pollution over time Pollutant-specific values representing avoided costs of air pollution are used to quantify the economic value of this benefit. Table 14 summarizes the results of the analysis.

Table 14. Summary of 100-Year NPV of Air Quality Benefits

100-Year NPV of Benefits Related to Air Quality Improvements from Emissions Reductions and Tree Filtration				
	Tree-Related Air Filtration	**Reduced Emissions from Household Energy Consumption**	**Reduced Emissions from Reduced Treatment**	**Total**
Inventory	\$21,000–\$0.3 million	\$6,700	\$2,000	\$0.3 million
Low Build-Out Scenario	\$1.5–\$20 million	\$0.47 million	< 0.1 million	\$2.1–\$21 million
Medium Build-Out Scenario	\$1.8–\$23 million	\$0.54 million	\$0.12 million	\$2.4–\$24 million
High Build-Out Scenario	\$2.0–\$26 million	\$0.61 million	\$0.20 million	\$2.8–\$27 million

Some of these benefits likely would accrue locally to residents in the Seattle area, while others would accrue elsewhere. Specifically, Seattle-area residents would probably benefit from tree-related filtration of pollutants out of the atmosphere because those trees would help improve/maintain local air quality. Other air quality benefits described in this section (e.g., reduced emissions stemming from reduced energy consumption) likely would accrue outside Seattle, closer to the areas surrounding energy generation facilities.

5.6 Small-Scale Habitat

Some GSI BMPs (e.g., rain gardens, green roofs, and trees) provide habitat-related benefits to urban mammals, birds and insect species/pollinators. Small-scale habitat in urban areas is valuable in that it helps improve the health and diversity of local wildlife populations. Individuals benefit from these habitat improvements insofar as they value the wildlife that habitat improvements and expansions support. Recent larger-scale habitat restoration efforts in Seattle have come at a cost of \$2,800–\$28,000 per acre. These costs shed light on the extent to which the city and the public value functioning habitat patches in urban areas. Data are not sufficient to quantify the habitat-specific value of these areas isolated from other benefits considered in this analysis, but researchers are continuing to increase their understanding of these small-scale habitat effects in urban areas, and are aligning their results with economic factors describing the value of their benefits. For example, how do bird populations change in Seattle as a result of GSI facilities? How do flowers and home gardens perform as a result of pollinators and pest predators that utilize GSI facilities? The answers to these questions will improve understanding of the habitat functions of GSI in Seattle and similar environs.

One way of considering the economic value of habitat improvements, however, is to identify demand for habitat improvements, as evidenced by restoration efforts funded in the local area. In addition to these terrestrial habitat benefits, GSI has the capacity to improve aquatic habitat by reducing the volume of stormwater entering nearby waterways through untreated sewer systems. This section focuses primarily on terrestrial habitat improvements, but aquatic habitat is discussed elsewhere in this report (see section on hydrologic function).

5.6.1 Valuation Methodology

The literature does not provide sufficient evidence of the quantified effects of GSI on improvements in small-scale habitat (e.g., percentage increase in urban bird populations per unit of GSI implementation) to quantify habitat-specific economic values. Furthermore, the types of wildlife populations that GSI tends to support (birds and insects) are not well represented in the economic literature describing society's demand for wildlife. Past restoration efforts in Seattle, however, provide cost estimates that reflect the public's demand for urban habitat. The approach to quantifying this illustrative value has three steps (described below). These values may double-count some of the values described in other sections of this report. For example, most habitat restoration efforts provide numerous benefits already included in this report (e.g., carbon sequestration, air quality improvements, water quality improvements).

Step 1 – Conduct literature review. The first step was to look through the literature to see if this kind of analysis had been done before. Several instances were identified in which GSI facilities have changed wildlife conditions in the local community. Ways in which GSI efforts in Seattle can support habitat-related benefits are described.

Step 2 – Quantify the change in habitat area. Some forms of GSI increase the amount of small-scale habitat in Seattle's urban environment. Inventory data, data from the build-out scenarios, and conversion factors are used to quantify the area of new habitat that GSI efforts support. Only habitat resulting from GSI projects is included, as opposed to all habitat in the Seattle area.

Step 3 – Quantify restoration costs and align with GSI-related habitat. The Green Seattle Partnership's 20-Year Plan offers a cost breakdown of habitat restoration efforts at a per-acre level. This range of costs is aligned with the area of GSI-related habitat from the inventory and the build-out scenarios to estimate a one-time value of the benefit.

5.6.2 Review and Analysis

This section summarizes the review and analysis in three parts: (1) a literature review describing the effects of GSI on small-scale habitat, (2) the analysis of the area of the habitat GSI supports, and (3) the quantification of the value of this habitat based on past restoration costs.

Literature review. Different types of habitat provide different sets of services from which individuals derive benefits. Many GSI facilities cover too little land to provide quantifiable habitat value; however, these sites may provide ecological benefits to habitat and biodiversity conservation to the extent that they contribute to patches of urban green space. In terms of habitat provision, cities are highly fragmented environments composed of a mosaic of natural patches of various sizes and types. While this type of fragmentation does reduce the quality, quantity, and pattern of habitats, it is not necessarily a limiting factor in population persistence of some species. In some cases, urban green spaces may provide habitats for a rich and diverse range of plants and animals.[46]

[46] Angold, P.G., J.P. Salder, M.O. Hill, A. Pullin, S. Rushton, K. Austin, E. Small, B. Wood, R. Wadsworth, R. Sanderson, and K. Thompson. 2006. "Biodiversity in urban habitat patches." *Science of the Total Environment* 360(1-3): 196-204.

Urban habitat, such as the kind of habitat some GSI BMPs provide, can increase overall vegetation cover, which contributes to biological diversity.[47] Urban green spaces also help conserve habitat, species, and genetic biodiversity within ecosystems by creating interconnected networks that minimize the impacts of habitat fragmentation and provide habitat corridors. For example, one study found small and medium-sized mammals use urban greenways as wildlife corridors, which allow for the exchange of individuals between populations, increasing genetic diversity and reducing instances of inbreeding.[48]

GSI exhibits many of the characteristics of urban habitats. In particular, GSI may provide an important role in supporting wildlife corridors, particularly when cities adopt a systematic approach to planning and managing the spatial distribution of these sites across local authority boundaries. GSI also may increase linkages and connectivity between patches of open spaces and diverse types of urban wildlife habitats. One recent paper argues that, when properly applied, green infrastructure could "bring together a coherent network of components, such as open spaces, green corridors, and woodlands for the benefit of people and wildlife."[49]

When designers in the United Kingdom addressed wildlife demands in their GSI planning, researchers observed the return of increasingly rare species in some areas. Brown roofs provided habitat benefits for several local bird species, thus prompting a renewed growth in their local population. In the case of green roofs in London, researchers noticed a similar regeneration of rare spider and insect populations.[50] Rain gardens provide similar habitat-related benefits. Research shows that they attract birds, butterflies, and insects while improving the habitat quality of downstream waterways for aquatic organisms.[51] The value associated with these benefits will likely increase over time. The literature suggests that as urban areas encroach into rural habitats and agriculture reduces the quality of rural habitat, these small-scale urban green spaces will become an increasingly important refuge for native biodiversity.[52]

There are no data describing the extent to which GSI facilities in Seattle are providing benefits related to small-scale habitat. Many of the GSI facilities are currently too new to provide many habitat-related benefits, but likely will attract wildlife in the future when they are fully developed (e.g., as street trees and vegetation in rain gardens mature).[53]

GSI-related habitat in Seattle. Data describing the inventory of GSI facilities and the assumptions used to develop the three build-out scenarios do not explicitly quantify the area of habitat that GSI facilities provide. For this analysis, available data were used describing the area of relevant GSI facilities, conversion factors aligning the BMP area with the impervious management area and stormwater

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[47] Bratton, S.P. 1997. "Alternative models of ecosystem health." In: Costanza, R., B.G. Norton, B.D. Haskell. *Ecosystem Health: New Goals for Ecosystem Management*. Island Press: 170-189. Washington D.C.

[48] Opdam, P., E. Steingrover, S. van Rooij. 2006. "Ecological networks: a spatial concept for multi actor planning of sustainable landscape." *Landscape and Urban Planning* 75: 322-332; Flores, A., S.T.A. Pickett, W.C. Zipperer, R.V. Pouyat, and R. Pirani. 1998. "Adopting a modern ecological view of the metropolitan landscape: A case of green space system for the New York City region." *Landscape and Urban Planning* 39: 295-308.

[49] Douglas, I. and J.P, Sadler. 2010. "Urban wildlife corridors: Conduits for movement or linear habitat?" In Douglas, I., D. Goode, M. Houck, and R. Wang (eds). *The Routledge Handbook of Urban Ecology*. Taylor and Francis: 274-288.

[50] Gredge, D. 2003. From Rubble to Redstarts. Proceedings from Greening Rooftops for Sustainable Communities, First North American Green Roof Infrastructure Conference. May. Chicago.

[51] Drew, B., B. Yim, D. Lo, and I. Liu. 2011. An Investigation into Rain Gardens. University of British Columbia.

[52] Goddard, M., A. Dougill, T.G. Benton. 2010. "Scaling up from gardens: biodiversity conservation in urban environments." *Trends in Ecological Economics* 25(2): 90-98.

[53] Personal Communication. Spencer, Bob. Seattle Public Utilities. Telephone. June 3, 2013.

management, and other relationships to estimate the total BMP area of bioretention, trees, and green roofs for the inventory and the three build-out scenarios. Table 15 summarizes the habitat area for the inventory and for each of the three build-out scenarios by implementation mechanism.

Madison Valley Stormwater Project, SPU. Photo: Mark Buckley

In total, Seattle's inventory of GSI facilities supports about 51 acres of habitat area. Most of this area (about 42.2 acres) is supported by green roofs and roof gardens, which are not included as a stand-alone implementation mechanism for the three build-out scenarios. The inventory data included in the table do not include habitat supported by code-triggered GSI facilities, because data were not available describing the BMP area. Instead, the data directly quantified the area of impervious surfaces managed by each facility. The Low, Medium, and High Build-Out Scenarios implement an additional 45.3, 60.5, and 76.4 acres of habitat each year, respectively, through 2050. Trees account for about half of the habitat area the build-out scenarios support.

Table 15. Habitat Area (Acres)

	Inventory	Low Build-Out Scenario (per year)	Medium Build-Out Scenario (per year)	High Build-Out Scenario (per year)
RainWise	0.3	0.1	0.2	0.3
Green Roof and Roof Garden	42.2	N/A	N/A	N/A
Right-of-way	8.6	12.3	24.5	36.7
Code-triggered	-	67.4	67.4	67.4
Total	**51.0**	**79.7**	**92.0**	**104.4**

Notes: This analysis assumes that each tree supports about 710 square feet of habitat (the average of the range of canopy width per tree used elsewhere in this report). For all other habitat area estimates, this analysis applies average conversion factors by implementation mechanism to the total stormwater volume estimates described in Appendix B. "Code-triggered" refers to projects resulting from stormwater code compliance.

Value of GSI-related habitat. GSI facilities could help support ongoing efforts in Seattle to improve urban habitat quality. In 2004, the Green Seattle Partnership published its 20-Year Plan, which outlines an actionable set of goals for improving the city's urban habitat.[54] In the plan, an inventory was conducted, which thoroughly describes the city's existing habitat. The plan prioritized parks in terms of the existence of volunteer support, high-value forests, fish-bearing streams, and other factors. It used

[54] Green Seattle Partnership. 2004. *20-year Strategic Plan*. Retrieved on July 8, 2013 from http://greenseattle.org/20-year-strategic-plan.

the same prioritization model to rank sites within parks. The restoration was conducted in four phases: (1) invasive removal, (2) secondary invasive removal and planting, (3) plant establishment, and (4) long-term maintenance. The restoration costs associated with the plan's restoration efforts range from $2,800–$28,000 per acre, depending on the "tree-iage" category, which is based on tree composition value and threat.

For this analysis, a one-time restoration cost of $14,000 (midrange) was applied to each acre of habitat supported by GSI. For the build-out scenarios, this per-acre value in the year the GSI is implemented is applied and discounted to calculate the NPV through 2050 of the benefit.

Results. Using the methodology described above, the habitat value of Seattle's inventory of GSI facilities totals about $715,000. The NPVs of the habitat supported by the Low, Medium, and High Build-Out Scenarios total about $30 million, $34 million, $39 million, respectively. Utilizing the higher end of the value range would correspondingly double these values. And this avoided cost approach doesn't capture the full surplus value of these sites, but the availability of substitute opportunities does suggest that this represents an appropriate representation of the financial tradeoff. As previously described, a number of Seattle's existing GSI facilities that likely support habitat benefits were not included in this analysis due to insufficient data describing their geographic extent. Furthermore, this analysis makes a number of normalizing assumptions to quantify the habitat area GSI efforts implemented through the build-out scenario support. Unlike other benefits discussed in this report, these habitat values represent one-time restoration costs that society has been willing to pay, in the past, for habitat restoration actions in Seattle. In other words, these values do not accrue annually. Rather, they accrue in the year that the GSI effort is undertaken.

5.6.3 Summary and Distribution

This section includes some of the mechanisms through with GSI can improve small-scale habitat in Seattle and how individuals derive benefits from these habitat improvements. Data were not sufficient to quantify the value of these benefits, however the literature provides evidence of GSI-related improvements in some wildlife populations (e.g., insects and birds). Economic literature has shown that people value healthy wildlife populations. Data, however, are not sufficient to transfer these benefits across to those species potentially supported by GSI. Past efforts in Seattle, such as those described in the Green Seattle Partnership's 20-Year Plan, however, demonstrate local demand for improvements in the quality of urban habitat. These one-time restoration costs were used as a proxy for society's demand for habitat improvements, and applied the low end of the range of restoration costs to GSI-related habitat improvements to provide an estimate of the benefit.

Individuals living near GSI facilities likely benefit the most from improved habitat conditions because they can observe the change in wildlife most directly. To the extent that others in Seattle and across the country are concerned about urban habitat conditions, they too may derive benefits from GSI-related habitat improvements in Seattle.

5.7 Hydrologic Function

Development across the Pacific Northwest has altered the hydrology in and around Seattle from pre-settlement conditions. Altering the region's hydrology has had a number of indirect effects (e.g., changes in floodplains, changes in aquatic habitat, and changes in species abundance and health). Currently, many efforts aim to counter these alterations to the region's hydrology in hopes of improving ecosystem-wide conditions, and shifting back toward pre-settlement conditions. Insofar as GSI helps improve hydrologic function, it also helps support the broad suite of benefits associated with improvements in hydrologic function. The complexity of tracing the individual effects of GSI facilities on nearby surface hydrology makes specific valuation estimates infeasible. It would require means to estimate how quantitatively streams change as a result of GSI facilities, such as increases in baseflows, less flashy peak flows, and lower water temperature. Then one could consider how these changes provide valuable benefits to society. Investigations for Piper's Creek in northeast Seattle suggest potential benefits of GSI to reduce discharge peaks and peak durations to better match historical or reference rural land use conditions.[55]

As GSI contributes to providing improvements to aquatic ecosystems via return to the natural flow regime, GSI also contributes to the benefits such a natural flow regime provides. Healthy and functional streams can provide a wide array of benefits to communities via aesthetics, recreation opportunities, protection of public health, and improvements to wildlife populations. A common focal benefit for stream restoration benefits in the Puget Sound region is improvements to fish populations. Freshwater, saltwater, and migratory fish populations are indicators of benefits from hydrologic health improvements.

5.7.1 Valuation Methodology

In the remainder of this section, the extent to which existing efforts in the Puget Sound represent public demand for the restoration of hydrologic function are described briefly. In addition, an illustrative example of how survey data can be used to quantify the economic value of improving the health of local fish populations is provided.

5.7.2 Review and Analysis

Existing efforts. There are currently several efforts underway specifically designed to improve the hydrologic function within Puget Sound and waterways in the Seattle region. Below, four specific vehicles through which public agencies are currently addressing water-related issues in and around Seattle are identified and described. These efforts represent public demand for improvements in the region's hydrologic function. As GSI facilities help address mutual concerns (e.g., water quality, salmon habitat), they can support ongoing efforts and decrease the need for other restoration efforts in the future.

- **Water Resource Inventory Area (WRIA) 8 and 9.** In 1971, the Washington State legislature formalized 62 Water Resource Inventory Areas (WRIAs) that identify specific watersheds and provide the Washington Department of Ecology an organizational framework to implement its water-related efforts. Seattle covers parts of WRIA 8 (Cedar-Sammamish) and WRIA 9 (Duwamish-Green). Many of the recent efforts in these two WRIAs have involved habitat restoration for salmon, as well as water quality-related efforts aimed at improving the health of salmon populations.[56]
- **Puget Sound Partnership.** The partnership's objective is to enact a real Action Agenda that brings together citizens, governments, tribes, scientists, and businesses in an effort to restore and protect Puget Sound. The agenda prioritizes cleanup and improvement projects, coordinates resource streams, and ensures stakeholder cooperation while relying on science-based solutions to Puget Sound's environmental problems.[57] Expenditures associated with the Puget Sound Partnership's Action Agenda are annually in the tens to hundreds of millions of dollars.

[55] Tackett, T., D. Jacobs, C. Carlstad, J. Scheller, J. Zhen, and J. Riverson. Unpublished. Evaluating and Implementing Seattle's Green Stormwater Infrastructure Approaches at a Creek Watershed Scale.

[56] For more information, see *http://www.ecy.wa.gov/water/wria/*.

[57] For more information, see *http://www.psp.wa.gov/*.

- **King County Flood Control District.** The District was formed in 2007 to provide a proactive, regional approach to flooding as well as funding to improve King County's aging and inadequate flood protection facilities. The District's resources total about $36 million per year, and its strategy includes: (1) actions to reduce flood risks, (2) research to increase understanding of flood risk, and (3) efforts to communicate flood risks to stakeholders and the public.[58]
- **Lower Duwamish Waterway Superfund Site.** In February 2013, EPA released the *Proposed Plan for the Lower Duwamish Waterway Superfund Site*. The plan presents EPA's preferred alternative to clean up the waterway, which has been contaminated due to over 100 years of industrial and urban use. The cleanup strategy has three components: (1) identification and cleanup of the most contaminated areas, (2) control of sources of contamination, and (3) cleanup of remaining contaminations in the waterway.[59]

Focus on aquatic habitat and fish populations. Seattle's stormwater runoff flows into three general water bodies: (1) Puget Sound, (2) Lake Washington, or (3) smaller waterways (creeks and rivers) in and around Seattle. Stormwater runoff directly entering surface waterways quickly flows into Puget Sound or Lake Washington. Given the relatively short distance between where these waterways receive stormwater runoff and where they flow into larger water bodies, it is assumed there is little in-channel stormwater treatment during storm events. Consequently, delivery of untreated stormwater ultimately to Puget Sound is assumed. Untreated surface stormwater runoff contributes to water contamination that reduces the health of fish populations instream and downstream in Puget Sound. In addition, as GSI promotes natural flow regime conditions that are conducive to fish population health, it can further promote population numbers.

People derive value from fish in many ways. One method of estimating the value people place on fish is asking them how much they would be willing to pay to increase fish population numbers. People are willing to pay for fish recovery for several reasons, including: (1) an understanding of their function and contribution to the greater ecosystem, (2) a future option of fishing for, eating, or viewing fish in the wild, and (3) an appreciation for the existence of fish in the region.

Economic value of improving the health of fish populations. To shed light on the potential value of the benefits of improving hydrologic function in the Seattle area, this section focuses on public demand for improvements in fish populations, as they provide an indicator of the magnitude of overall hydrologic function. This analysis relies on a 1999 economic study done in Washington State that surveyed households regarding their willingness to pay for programs aimed at increasing fish populations in western Washington and the Puget Sound area.[60] The study (referred to as the LBP Study) asked households how much they would be willing to pay each month, for 20 years, for a range of increases in fish populations guaranteed by the end of the 20-year period. The LBP Study examined five types of fish species. The results of three of these groups in western Washington and Puget Sound are summarized here: (1) freshwater fish, (2) Pacific migratory fish, and (3) saltwater fish. GSI has the capacity to support improvements in these three fish populations through several mechanisms, including: improving water quality in Seattle's waterways and in Puget Sound and improving instream flows during storm events in Seattle's waterways.

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[58] For more information, see *http://www.kingcountyfloodcontrol.org/*.

[59] For more information, see U.S. EPA, Region 10. 2013. *Proposed Plan: Lower Duwamish Waterway Superfund Site*. Retrieved on June 18, 2013 from *http://www.epa.gov/region10/pdf/sites/ldw/pp/ldw_pp_022513.pdf*.

[60] Layton, D., G. Brown, and M. Plummer. 1999. *Valuing Multiple Programs to Improve Fish Populations*. Washington State Department of Ecology. April.

Applying the results of the LBP Study requires specific information describing the increase in fish populations tied to GSI. At this point, GSI's effect on local fish populations remains too uncertain to quantify. Figure 6 shows ranges of annual household willingness to pay for improvements (5%, 20%, and 50%) in the three different fish populations. The blue bars represent freshwater fish, the green bars represent migratory fish, and the orange bars represent saltwater fish. For example, the blue bar at the bottom of the figure shows that households in Washington would be willing to pay about $100–$300 per year, for 20 years, for a 5% increase in western Washington and Puget Sound freshwater fish populations. The low end of the range represents household willingness to pay, assuming that these fish populations would remain steady for the next 20 years (but for the action). The high end represents their willingness to pay assuming that these fish populations would decline over the next 20 years (but for the action).

For this example, it is assumed that beginning in 2013, GSI efforts in Seattle would support a 5% increase in freshwater, migratory, and saltwater fish in western Washington and Puget Sound by 2033. At this 5% level, households across Washington would be willing to pay about $110–$200 per year for freshwater fish, $140–$190 for migratory fish, and $140–$210 for saltwater fish. According to the U.S. Census, there were about 2.7 million households in Washington in 2010. Using the combined annual household willingness to pay for these population improvements (about $390–$600) to all households in the state over a 20-year period, with a 2% discount rate, generates a net present value of about $17.5–$27.1 billion across all three fish groups.

Figure 6. Illustrative Value of Benefits from Improving Fish Population Numbers

GSI, at sufficient level of implementation and function, could help streams attain higher levels of beneficial uses. A study of small stream restoration found nearby households each on average willing to spend $36-$60 annually for improvements in habitat function, scenic value, or swimmability.[61] A national 1993 study found a similar WTP annual average household value of $70 to maintain national water quality standards at a fishable level.[62] Given the iconic importance of salmon in the Seattle region and fisheries in general, it can be assumed that households in the vicinity of streams in Seattle would be willing-to-pay for demonstrable improvements, especially if they can be connected to fish populations.

5.7.3 Summary and Distribution

As understanding of the benefits of GSI for hydrologic function in Seattle increases, the benefits of healthy surface waters can be attributed to GSI investments. Healthy streams provide an array of social, cultural, and ecological benefits. As an example, the results of a 1999 economic study conducted in Washington were applied that estimated the willingness of households to pay for policies and programs that increase fish populations in the Puget Sound Basin. If there are real improvements to fish populations, households across the state would be willing-to-pay for these benefits.

As scientific understanding of the hydrologic effects of GSI improves, it will be possible to align these effects with outcomes that matter to society. It likely will be possible to generate watershed-specific values of fish population improvements as well as aesthetic, recreational, and public health benefits. There can also be important social and environmental justice benefits accrued by low-income and minority populations who rely upon fish for sustenance or see high cultural value.

[61] Collins, A., R. Rosenberger, and J. Fletcher. 2005. The Economic Value of Stream Restoration. Water Resources Research 41.

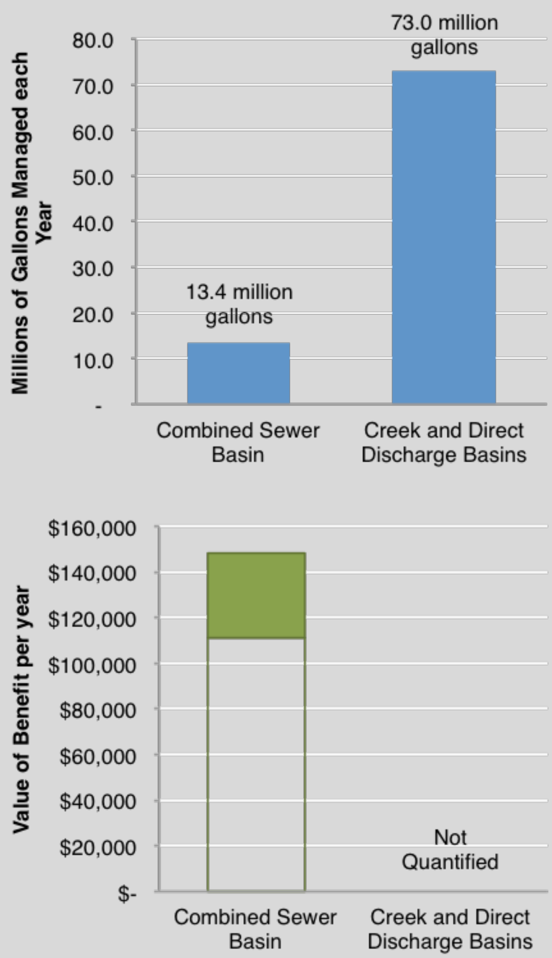
[62] Carson, R. and Mitchell, R. 1993. The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable, and Swimmable Quality Water. *Water Resources Research*, *29*(7), 2445-2454.

Stormwater Discharges in Seattle's Creeks

While most of the stormwater traveling through Seattle's sewer system is discharged into large water bodies (e.g., rivers, lakes), some of the stormwater is discharged directly into urban creeks. Stormwater discharges directly into small creeks require a separate discussion due to the sensitivity and vulnerability of these ecosystems. Untreated stormwater discharged into these water bodies is not as polluted as the water discharged during CSO events but it still transports pollutants directly into creeks, rivers, lakes, and Puget Sound.

The figure below shows that Seattle's existing inventory of GSI facilities manage over six times more stormwater in the direct discharge and creek basins than they manage in the combined sewer basin. The avoided treatment costs associated with the reduction in stormwater runoff in the combined sewer basin total $110,000-$150,000 per year. The water quality benefits in the creek basins though considering no equivalent avoided treatment cost would be diverse, and associated with benefit categories described in terms of aquatic habitat, aquatic fish and wildlife, aesthetic views, recreation, human health, and all the other ways that Puget Sound and its contributing waterways provide benefits.

The level of expenditure directly undertaking activities associated with enjoying Puget Sound, traveling to do so, and purchasing property that facilitates benefits (e.g. homes on or with views of the Sound) combined with governmental protection expenditures all reveal the magnitude of these benefits. Consequently, it can be assumed that benefits from treating discharges to urban creek basins are likely well into the hundreds of thousands of dollars annually.



5.8 Mental Health

Researchers have been analyzing the link between human health and environmental factors for decades. Much of this research has focused on how environmental factors influence physical health. Recently, however, several researchers have shifted their attention to the links between mental health and exposure to the natural environment. Exposure to the natural environment can directly improve mental health by providing settings for cognitive respite and reducing stress. Natural spaces can indirectly improve mental health by promoting activities and interactions (e.g., physical activity and social interactions) that are known to improve mental health. *Human Dimensions of Urban Forestry and Urban Greening*, a project at the University of Washington's School of Environmental and Forest Science, has identified several of these direct and indirect effects, which are described below.[63]

- **Reduce stress.** Research shows that exposure to natural features helps reduce stress and reduce other physiological symptoms associated with stress.
- **Improve social capital.** Natural features promote social interactions among neighbors and among individuals visiting the community. Increasing social capital in a community can improve relationships and help foster social ties and a stronger sense of place.
- **Decrease crime and improve public safety.** Crime, vandalism, and littering are less common in spaces with natural features than in spaces without them. Safer public spaces can reduce danger-related stress and anxiety among community residents, as well as visitors to the community.
- **Increase physical activity.** Research suggests that individuals living in communities with green spaces are more physically active than those without green spaces. Improving physical health can help improve mental health by reducing health-related stress and anxiety.

GSI provides the types of urban greening that can contribute to improved mental health. Mental health protection and improvements have value shown by health and relaxation expenditures, as well as avoided healthcare costs from effects of stress and other outcomes due to poor mental health. As research demonstrates a link between the environment and mental health, opportunities are arising to recognize such benefits from GSI. As described below, studies demonstrate a connection between GSI and mental health. The next step will be quantifying degrees of change in mental health due to GSI facilities, and possibly conducting surveys to assess what people would be willing-to-pay to achieve such mental health improvements. Investigations might also seek examples of expenditures that people have made for equivalent levels of mental health improvement. It might be possible to use property sales data to estimate the premium that some people pay to live in areas that provide environmental conditions that benefit mental health, although it is likely difficult to isolate this share of the value of an environmental amenity. The remainder of this section briefly summarizes the literature describing some of the mechanisms through which GSI can help support improvements in mental health, as well as some of the economic literature describing the economic value of improving mental health.

5.8.1 Review and Analysis

This section briefly summarizes the literature describing the mechanisms through which GSI can help support improvements in mental health, as well as the economic literature describing the economic value of improving mental health. These topics are discussed in four parts: (1) mental health benefits to local residents, (2) mental health benefits to the workforce, (3) mental health benefits to commuters, and (4) the economic value of improvements in mental health.

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[63] University of Washington, Urban Forestry/Urban Greening Research. 2013. *Green Cities: Good Health*. Retrieved on May 31, 2013 from *http://depts.washington.edu/hhwb/*.

Benefit to local residents. This desire for contact with nature serves an important role in supporting psychological restoration and improvements in mental health.[64] These benefits occur not only in the presence of nature alone, but are also positively correlated with the quality of nature in an individual's surrounding.[65] Ulrich (1986) used a survey-based approach to show that American and European groups have a strong preference for nature above human-created surroundings, particularly when trees and vegetation are present. These views tend to have positive effects on emotional and psychological states. The study found that trees can reduce stress or anxiety, and that responses to trees are positively linked to mental health.[66] Several other studies have also found that individuals can improve their mental health by increasing the amount of time they spend in urban green spaces.[67] In another nationwide survey among residents of the Netherlands, 95% of respondents said a visit to nature is a helpful way to reduce stress.[68]

Madison Valley Stormwater Project, SPU. Photo: Mark Buckley

Beyond the psychological benefits, such as stress reduction, people also feel a strong emotional response to natural spaces, even if they do not interact with them directly. This is called existence value. Hull (1992) found that after Hurricane Hugo damaged infrastructure in Charleston, South Carolina, over 30% of those surveyed found urban forests the most significant feature that was damaged, regardless of their past or intended use of the forested areas. Of those responses, the largest percentage of respondents (11%) stated that the reason this feature was special to them was the "positive feelings or emotions" it invoked. Findings like these suggest that nature evokes positive and relaxing emotions. While the literature is not specific to GSI-related effects on mental health, it is related insofar as GSI improves environmental conditions and increases the quantity of green space and natural features in urban settings.

64 Van den Berg, A., T. Hartig, H. Staats. 2007. *Preference for Nature in Urbanized Societies: Stress, Restoration, and the Pursuit of Sustainability.* Journal of Social Issues. 63.1: 79-96.

65 Peacock, J., R. Hine, G. Willis, M. Griffin, and J. Pretty. 2005. *The Physical and Mental Health Benefits of Environmental Improvements at Two Sites in London and Welshpool.* Report for the Environmental Agency. March.

66 Ulrich, R. 1986. *Human Responses to vegetation and landscapes.* Landscape and Urban Planning. 13: 29-44.

67 See, for example, Korpela, K., M. Yien, L. Tyrvainen, and H. Silvernnoinen. 2008. "Determinents of Restorative Experiences in Everyday Favorite Places." *Health & Place*. 14(4):636-652.

68 Van den Berg, A., T. Hartig, H. Staats. 2007. *Preference for Nature in Urbanized Societies: Stress, Restoration, and the Pursuit of Sustainability.* Journal of Social Issues. 63.1: 79-96.

Benefit to workforce. Views of and access to natural settings have been shown to improve worker mood, productivity, and satisfaction. Hull (1992) found that urban green spaces produce positive moods for visitors, even if the visits are shorter than 30 minutes.[69] In addition to the effect on mood, research shows that access to nature in the workplace is related to lower levels of perceived job stress and higher levels of job satisfaction, and that seeing natural features, even if it is from a window, is an effective means of relieving stress and improving well-being. Workers with a view of trees and flowers felt that their jobs were less stressful and were more satisfied with their jobs than others who could only see built environments from their window. In addition, employees with views of nature reported fewer illnesses and headaches.[70] GSI facilities could contribute to these work-related improvements in mental health and productivity because they offer natural features for workers to either look at while working, or escape to during their free time.

Benefit to commuters. GSI-related improvements in the quality of the natural views along transportation corridors may offer benefits to cyclists and drivers. To achieve these benefits, planners must consciously consider how to implement GSI facilities in ways that help support these types of benefits. GSI facilities that help diversify transportation options, ease traffic, and increase the quality of natural landscapes surrounding transportation corridors can alleviate stress and anxiety associated with travel. The literature describing mental health benefits for cyclists and drivers is discussed below.

Roadside bioretention. Photo: MIG|SvR

Cyclists may gain increased utility as the aesthetics improve. For example, two researchers report that being in an attractive environment is mentioned as one of the most positive aspects of cycling, although this statement was not statistically confirmed.[71] Improvements in aesthetics may draw increased numbers of users, because some riders switch from driving to cycling and some riders who are already bicycle commuters deviate from their current routes to use routes with GSI. Krizek (2007) found cyclists are willing to travel an average distance of 2.61 miles out of their way to use a high-quality off-street bicycle facility.[72] Stinson (2003) found that cyclists are willing to tolerate about 10% longer travel times to use routes on residential streets and routes with dedicated bike lanes on bridges rather than routes on roads.[73] To the extent that

[69] Hull, R.B. 1992. *Brief Encounters with Urban Forests Produce Moods that Matter.* 322-324.

[70] See, for example, Berto, R., M. Baroni, A. Zainaghi, and S. Bettella. 2010. "An Exploratory Study of the Effect of High and Low Fascination Environments on Attentional Fatigue." *Journal of Environmental Psychology.* 30(4):494-500; Heinen, E., B. Wee, and K. Maat. 2010. *Commuting by Bicycle: An Overview of the Literature*. Transport Reviews. January. 30.1: 59-96; Kaplan, R. and S. Kaplan. 1989. *The Experience of Nature: A Psychological Perspective*. Cambridge University Press; Lohr, V., C. Pearson-Mims, and G. Goodwin. 1996. "Interior Plants may Improve Worker Productivity and Reduce Stress in a Windowless Environment." *Journal of Environmental Horticulture.* 14:97-100; Shibata, S. and N. Suzuki. 2002. "Effects of the Foliage Plant on Task Performance and Mood." *Journal of Environmental Psychology*. 22:265-272.

[71] Gatersleben, B. and D. Uzzell. 2007. *Affective Appraisals of the Daily Commute: Comparing Perceptions of Drivers, Cyclists, Walkers, and Users of Public Transport.* Environment and Behavior. 39.3: 416-431.

[72] Krizek, K., A. El-Geneidy, K. Thompson. 2007. *A detailed analysis of how an urban trail system affects cyclists' travel.* Transportation. 34: 611-624.

[73] Stinson, M., and C. Bhat. 2003. *Commuter Bicycle Route Choice: Analysis Using a Stated Preferences Model.* Transportation Research Record: Journal of the Transportation Research Board. Vol. 1828. 107-115.

existing and potential future GSI in Seattle improve the quality of cycling routes, cycling benefits would increase through the quality and quantity of trips.

Drivers who use roads adjacent to well-positioned GSI facilities would derive mental health benefits insofar as the increase in exposure to natural landscapes helps them recover more quickly from current stress and immunizes them to future stress. Parsons (1998) found that survey participants who viewed nature-dominated drives experience quicker recovery from stress and greater immunization to subsequent stress than participants who viewed artifact-dominated drives.[74] In addition to drivers, cyclists may reap similar health benefits, though a study of this kind has not been done.

5.8.2 Summary and Distribution

In this section, mechanisms through which GSI can improve the mental health of individuals throughout Seattle were discussed. To date, research describing the relationship between GSI and mental health in a Seattle-specific context is not sufficient to quantify the economic value of the potential benefits. The literature does, however, identify several ways in which GSI can improve mental health, as well as examples of ways to quantify the economic value of improved mental health. To the extent that GSI reduces anxiety and stress, it also has the potential to support economic benefits in terms of avoided mental health-related costs (e.g., medical costs) as well as improved relationships and output through improvements in work performance.

Since exposure to GSI facilities is crucial in deriving mental health-related benefits, the main beneficiaries are individuals in Seattle with GSI on their properties, in their neighborhoods, or near their workplaces. Individuals that encounter GSI facilities on their commute or during other parts of their day may also derive valuable mental health benefits from their experiences.

5.9 Ecological Literacy and Behavioral Change

There is an extensive body of literature documenting the kinds of information and experiences that induce environmentally responsible behavior. The general reasoning holds that when people have environmental values, or they care about a natural resource for their own benefit, for the benefit of others (such as their children), or because they recognize protection of natural resources to be a social responsibility, they make choices that reduce pollution, resource use, and other means of environmental degradation.[75] Environmental behavior can be tied to how closely connected people see themselves to the environment.[76] Consequently, individuals take on environmentally responsible behaviors when they:

- See a personal or community connection to the environment.
- Feel a responsibility to protect the environment.
- Experience or expect real effects of environmental degradation on themselves and others.

The costlier or inconvenient the behavior, or the weaker the connection, the less likely people are to undertake it. For low-cost behaviors, however, people might just need information about the appropriate behavior. For example, placing small fee on plastic shopping bags has been shown to

[74] Parsons, R., L. Tassinary, R. Ulrich, M. Hebl, M. Grossman-Alexander. 1998. *The View from the Road: Implications for Stress Recovery and Immunization.* Journal of Environmental Psychology. 18: 113-139.

[75] See, for example, Hungerford, H., and T. Volk. 1990. "Changing Learner Behavior through Environmental Education." *Journal of Environmental Education*. 21(3): 8-22; Karp, D. 1996. "Values and their Effect on Pro-environmental Behavior." *Environment and Behavior*, 28(1): 111-133.

[76] Davis, J., J. Green, and A. Reed. 2009. "Interdependence with the Environment: Commitment, Interconnectedness, and Environmental Behavior." *Journal of Environmental Psychology*. 29(2): 173-180.

dramatically decrease their use.[77] The fees on plastic bags are negligible as a share of a typical grocery bill, but the social pressure and signal on social responsibility, combined with a moral sense of self, are responsive to the signal the bag fee provides.

GSI has the potential to contribute information, signals, and opportunities for environmentally responsible behavior. Seattle residents and visitors are highly aware of Puget Sound, the importance of its pristine water quality, and the charismatic fish and wildlife it supports.[78] People care about protecting Puget Sound, and communities like Seattle have made major financial and nonfinancial commitments towards this end. Still, people don't always recognize how stormwater and individual behavior and land use contribute to the problems, focusing on the ideas of large industrial and municipal point-source polluters. This is reflected in surveys from Portland, Oregon, in which some respondents see stormwater and wastewater as a government responsibility, not an individual one.[79]

GSI has the potential to contribute to increased environmentally responsible behaviors in three ways: (1) by providing information about the connection between individual choices/actions and water pollution, (2) by providing social signals that highlight responsible behavior, and (3) by providing opportunities to engage directly in environmentally responsible behavior. GSI facilities tend to have explanatory kiosks, and highly visible pools and vegetation that make the purpose, the operation, and the effect of personal behavior more evident and relatable to water quality. To the extent that GSI efforts can help people and businesses better understand how they influence stormwater pollution and its connection to water quality, habitat, and wildlife, they can provide motivation for behaviors and investments that provide benefits.

5.9.1 Valuation Methodology

It is not possible, with the tools and information available at this time, to quantify the incremental contribution of GSI efforts in Seattle to changes in behavior that generate environmental benefits. Seattle residents and businesses are already aware of the high quality of their environment, and the importance of individual and business responsibility to maintain this quality. Still, as illustrated by the surveys in Portland, people don't always realize how stormwater and water quality are related. It seems likely that highly visible GSI facilities that are aesthetically attractive, provide explanatory information, and demonstrate comprehensible function are likely to teach and at least remind people of environmental connections and responsibilities. GSI also provides opportunities for particularly motivated individuals and businesses to increase their contribution to environmental benefits through investments and installations on their property and with their financial and nonfinancial (labor, materials, etc.) contributions. Surveys might elicit how likely experiences with GSI facilities are to inform Seattle residents about ecological phenomena, and how this affects their environmental behavior.

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[77] Convery, F., S. McDonnell, and S. Ferreira. 2007. "The Most Popular Tax in Europe? Lessons from the Irish Plastic Bags Levy." Environmental Resource Economics. 38: 1-11.

[78] The Puget Sound Partnership has conducted multiple studies demonstrating the importance of Puget Sound health to area residents. For example, see *http://www.psparchives.com/our_work/education/education_research.htm*.

[79] See, for example, Action Media. 2011. *Keeping Polluted Waters Out of Puget* Sound. August; Hansa, G. and ECONorthwest. 2008. *Private Motivations to Invest in Stormwater Management Facilities: A Qualitative Exploration and Quantitative Assessment*." Retrieved on July 10, 2013 from *http://www.portlandonline.com/bes/index.cfm?a=250709&c=50541*; Vivek, S., A. Nelson, et al. *Tabor to the River Program: An Evaluation of Outreach Efforts and Opportunities for Engaging Residents in Stormwater Management*. City of Portland, Bureau of Environmental Services, Retrieved on July 10, 2013 from *http://www.portlandonline.com/bes/ index.cfm?a=335473&c=50500*.

5.9.2 Review and Analysis

Evidence from Seattle and similar areas[80] suggests that learning and social suggestion (persuasion) can lead to real changes in behavior that improve environmental quality and reduce costs of its maintenance. Seattle's GSI facilities, particularly visible and educational ones, and those on private property, likely contribute to these benefits.

5.9.3 Summary and Distribution

The benefits of changes in behavior that improve the quality of water and associated natural systems accrue to society as a whole and particularly to those who use and experience the resources. Areas where these actions take place, such as reduced littering, driving, or private property installations, are likely to experience proportionally more of the benefit. The psychology and sociology literature, such as that referenced earlier, suggests that the actors experience benefits from socially responsible, moral, and admirable behavior directly. For businesses, this might contribute to positive marketing and advertisement benefits.

5.10 Case Study: Embedded Energy

Recently, researchers have explored the embedded energy associated with specific sets of materials and construction efforts. By estimating embedded energy, this research attempts to account for GHG emissions at all stages of production. In this section, how this approach has been used in the context of stormwater management is described and the application of this approach on two illustrative stormwater management projects in Seattle is summarized. While these results are not readily transferable across all forms of GSI or other stormwater infrastructure, they help shed light on the types of materials typically required for large stormwater projects, and identify specific components of these projects with particularly large impacts on embedded energy and GHG volumes.

5.10.1 Valuation Methodology

In this section, the embedded GHG emissions associated with the materials used in the construction of two stormwater infrastructure projects is analyzed. Only construction materials are examined, and GHG emissions associated with labor during construction are not estimated. GHG emissions are defined as the total CO_2e released over the lifecycle of a material, including extraction and manufacturing. Transportation costs associated with the purchase and delivery of construction materials are not considered. The two stormwater infrastructure projects considered in this analysis are described below. The first represents a gray infrastructure project, while the second uses GSI BMPs to manage stormwater.

- **The Genesee Area CSO Reduction Project.** This project combines additional storage and transmission pipeline intended to manage a total of about 0.6 million gallons of stormwater each year. The ability to install GSI BMPs in the area was limited due to geographic constraints.[81] The total cost of this facility is about $19.7 million, which includes construction and labor costs.

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[80] See, for example, Action Media. 2011. *Keeping Polluted Waters Out of Puget* Sound. August; Hansa, G. and ECONorthwest. 2008. *Private Motivations to Invest in Stormwater Management Facilities: A Qualitative Exploration and Quantitative Assessment*." Retrieved on July 10, 2013 from http://www.portlandonline.com/bes/index.cfm?a=250709&c=50541.

[81] Seattle Public Utilities. 2013. *Genesee Basins*. Retrieved on June 12, 2013 from http://www.seattle.gov/util/EnvironmentConservation/Projects/DrainageSystem/SewageOverflowPrevention/CSOReductionProjects/GeneseeBasin/index.htm.

- **The Pinehurst Natural Drainage Project.** This project was completed in 2006. The project provides enhanced drainage in the Pinehurst neighborhood and improves the quality of runoff into Thornton Creek. The project includes new sidewalks, roadways, and landscaping in addition to bioretention cells designed to manage a total of 9.7 million gallons of stormwater.[82] The total costs of this facility were about $2.2 million, including only construction and labor costs.

The analysis had three steps:

Step 1 – Conduct literature review. The first step was to look through the literature to see if this kind of analysis had been done before. Three relevant studies were identified that summarized the results of these and applied several of the methods and data sources in the analysis.

Step 2 – Estimate embedded energy and associated GHG emissions. In the analysis, the GHG emissions associated with a range of material components used in two stormwater management projects were examined, the Genesee CSO Project and the Pinehurst Natural Drainage Project. The available data did not allow for quantifying GHG emissions for all materials used in each project. Rather, the GHG emissions associated with those materials with lifecycle emission factors available in the literature were quantified.

Step 3 – Apply the value of carbon. As previously described, a range of per-unit values representing the potential costs associated with atmospheric GHG concentrations were used. This range of values includes estimates of the social cost of carbon, as well as market prices for carbon emissions from efforts to trade and tax emissions across the world. A range of $15–$60 per ton of CO_2e was applied to the volumes quantified in Step 2.

5.10.2 Review and Analysis

Literature review. Three previous studies are particularly relevant to this analysis: (1) Wegst (2010) conducted an eco-audit of seven different GSI BMPs to estimate the lifecycle GHG emissions tied to materials and construction efforts, (2) Spatari (2011) examined the avoided energy and GHG emissions of implementing GSI BMPs versus more traditional BMPs to manage stormwater on a one-block area in New York City using the International Organization for Standardization (ISO) guidelines for lifecycle assessment, and (3) DeSousa (2012) conducted a lifecycle assessment to compare the environmental efficiency of three approaches to reducing CSOs to the Bronx River in New York City.[83]

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[82] Tackett, T. No Date. *Making the Invisible Visible: Seattle's Green Stormwater Infrastructure. Retrieved on June 12, 2013 from https://www.seattle.gov/Documents/Departments/UrbanForestryCommission/2010/2010docs/StormwaterPresentation030310.pdf*;
Seattle Public Utilities. 2013. *Pinehurst Green Grid*. Retrieved on June 12, 2013 from *http://www.seattle.gov/util/EnvironmentConservation/Projects/GreenStormwaterInfrastructure/CompletedGSIProjects/PinehurstGreenGrid/index.htm*.

[83] Wegst, U., C. Barr, and F. Montalto. 2010. "Eco-audit of Seven Green Infrastructure Practices." *Bridge Maintenance, Safety, and Management.* July: 264-272; Spatari, S., Z. Yu, and F. Montalto. 2011. "Life Cycle Implications of Urban Green Infrastructure." *Environmental Pollution*. 154: 2174-2179; Wegst, U., C. Barr, and F. Montalto. 2010. "Eco-audit of Seven Green Infrastructure Practices." *Bridge Maintenance, Safety, and Management.* July: 264-272; DeSousa, M.R., F.A. Montalto, and S. Spatari. 2012. "Using Life Cycle Assessment to Evaluate Green and Grey Combined Sewer Overflow Control Strategies." *Journal of Industrial Ecology*. 16(6): 901-913.

Wegst (2010) used a wide range of material-specific sources to identify their embedded energy and lifecycle GHG emissions. The study considered eight scenarios in total (six using GSI BMPs and two using gray infrastructure), and calculated the embedded energy and associated GHG emissions in the materials of each. The study's findings show that GSI doesn't always offer lower emissions than gray alternatives.

Spatari (2011) analyzed two approaches to stormwater management on a one-block study site in New York City. The study applied ISO's guidelines for assessing embedded energy of materials and used emissions data from Wegst (2010) and emissions data for transportation from Wang (2009).[84] The study found that the GSI scenario had lower lifecycle GHG emissions than the gray scenario and also concluded that nonlinear relationships likely exist between lifecycle GHG emissions and stormwater volumes.

DeSousa (2012) quantified lifecycle GHG emissions associated with three different options for reducing CSOs in the Bronx River in New York City. DeSousa quantified the metric tons of CO_2e over the construction, operation, and maintenance phases of each project. The three projects included: (1) a combination of GSI BMPs including porous pavement, bioretention, infiltration planters, rain gardens, and cisterns, (2) an end-of-pipe detention facility sized to achieve a similar reduction of CSO events and volumes, and (3) an end-of-pipe detention facility that would physically and chemically treat stormwater at the tank location. The decentralized GSI strategy outperformed the two gray strategies in terms of GHG emissions, at all phases of the projects.

Results. In the analysis, the embedded GHG emissions associated with the construction materials used for the Genesee CSO Project (a gray infrastructure project) and the Pinehurst Natural Drainage Project, which uses a variety of GSI BMPs, were estimated. For each project, bid sheets from Seattle Public Utilities were used, which provide line-item descriptions of the types of materials used in the projects and their quantities. Using these line-item material data, the GHG emissions (in terms of tons of CO_2e) were quantified using emissions factors from Wegst (2011) and Hammond and Jones (2008).[85]Table 16 summarizes the results of the analysis. The available emissions factors from the literature were not sufficient to quantify the GHG emissions stemming from each line-item in the construction bid sheets. For the Pinehurst Project, lifecycle GHG emissions were quantified for a subset of the materials accounting for 83% of total materials costs (about 435 tons of CO_2e). For the Genesee Project, the materials included represent 40% of total materials costs (about 2,514 tons of CO_2e). Even with this limitation, the Genesee Project's GHG emissions are about five times larger than those of the Pinehurst Project. To quantify the total lifecycle GHG emissions associated with the Pinehurst Project, it was assumed that the remaining materials (those for which the literature did not provide emissions factors) had the same emissions-to-cost ratio as those materials for which the literature provided emissions factors. Using this approach, the materials used in the construction of the Pinehurst Project had a total lifecycle GHG emissions volume of about 524 tons of CO_2e. Given the tighter data limitations associated with the Genesee Project, a similar figure for the gray infrastructure project was not estimated. Using the range of the social cost of carbon indicated above, a range of values for lifecycle GHG emissions for each line-item included in the analysis was estimated.

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[84] Wang, M. 2009. *GREET 1.8c Spreadsheet Model*. Center for Transportation Research, ESD, Argonne National Laboratory.

[85] Wegst, U., C. Barr, and F. Montalto. 2010. "Eco-audit of seven green infrastructure practices." *Bridge Maintenance, Safety, Management and Life-Cycle Optimization*. Taylor Francis Group: London. 264-272.; Hammond, G. and C. Jones. 2008. *Inventory of Carbon and Energy (ICE): Version 1.6a.* Sustainable Energy Research Team, Department of Mechanical Engineering, University of Bath, UK.

Table 16. Lifecycle GHG Emissions of Two Projects

	Lifecycle GHG Emissions (tons of CO_2e)		Value of Lifecycle GHG Emissions	
	Pinehurst	Genesee	Pinehurst	Genesee
Asphalt Materials	111	488	$1,665–$6,659	$7,334–$29,337
Concrete Materials	112	2,277	$1,682–$6,727	$34,155–$136,619
Filter Fabric	1	-	$14–$58	-
Granular Fill	35	-	$523–$2,091	-
Jute Matting	0.1	-	$1–$6	-
Mulch, Compost, and Soil	211	-	$3,166–$12,091	-
Pipes	9	-	$136–$545	-
Metal Fabrication Materials	-	5	-	$77–$310
Materials Costs Calculated (percent of total costs)	**83%**	**40%**	**83%**	**40%**
Total Calculated GHG Emissions from Construction Materials	**479**	**2,771**	**$7,187–$28,749**	**$41,567–$166,267**
Total Approximated GHG Emissions from Construction Materials	**577**	**N/A**	**$8,659–$9,236**	**N/A**

The summary in the table shows lifecycle GHG emissions in gross terms. As described above, however, the Pinehurst Project was designed to manage about 9.7 million gallons of stormwater each year while the Genesee Project was designed to manage only 0.6 million gallons. At a per-unit level, the Pinehurst Project's lifecycle GHG emissions totaled about 49 tons of CO_2e per million gallons of stormwater managed each year. Total lifecycle GHG emissions for all materials used in the Genesee Project was not estimated. Using only the partial estimate (representing 40% of the Genesee Project's materials costs), its per-unit emissions total about 4,600 tons of CO_2e per million gallons of stormwater managed each year.

5.10.3 Summary and Distribution

The results show that, for both projects, lifecycle emissions are generally highest for materials such as asphalt, concrete, and soil. These results generally agree with Wegst (2010), who also found that these categories have relatively large volumes of lifecycle GHG emissions. Most of the concrete used in the Genesee Project went toward the storage tank and facility vault. Together, these two components of the project accounted for nearly 224 tons of CO_2e. Regardless of approach (green or gray), stormwater management efforts can reduce their overall impact on atmospheric GHG concentrations by decreasing the amount of concrete and asphalt used.

As with other climate change-related benefits, the benefits of pursuing development options with lower lifecycle GHG volumes accrue to society as a whole. While individuals in Seattle and across Washington will certainly benefit from reducing the magnitude of climate change impacts, so too will individuals globally.

5.11 Case Study: Economic Impacts of GSI

Up to this point, this report has focused on economic values and economic benefits related to GSI. In this section, it will focus on economic impacts. The term *economic impacts* has a very specific definition to economists. Economic impacts represent the number of jobs and the amount of income and tax revenue generated by a particular economic activity. These impacts are not additive to other economic benefits, but rather a separate prism or metric for evaluating the same activity. An investment that generates a benefit must do so through expenditures, but under benefit-cost analysis, such expenditures fall as costs. Economic impact analysis provides useful information for understanding the distribution and nature of the effects, and this information is particularly relevant to communities seeking to promote local jobs and local demand for market goods and services.

Insofar as infrastructure projects require spending on labor, materials, and other goods and services, they support economic activity. Stormwater infrastructure projects are no different. The tools economists typically use to estimate economic impacts provide gross results. In other words, these results do not necessarily reflect the share of new jobs or new earnings that would be possible from considering how the money would have been spent and the workers employed otherwise. After all, resources used to fund GSI could have been used to fund other infrastructure projects. Similarly, some of the individuals employed by GSI-related spending could have worked on some other project, or may have left an existing occupation to pursue GSI-related work. Comparing multiple scenarios though can shed light on the net impacts.

In general, to the extent that investments can use local materials and local labor, the investments can have greater local economic impacts than they would otherwise have. To further extend this reasoning, if investments use emergent industries and generate effects that attract other business and highly skilled workforces, they can further contribute to economic impact and development. GSI investments can take on a wide array of investment plans, but they are often seen as offering more potential for such local economic impacts than large-scale conventional projects that require large built capital and highly specialized labor imported from elsewhere.

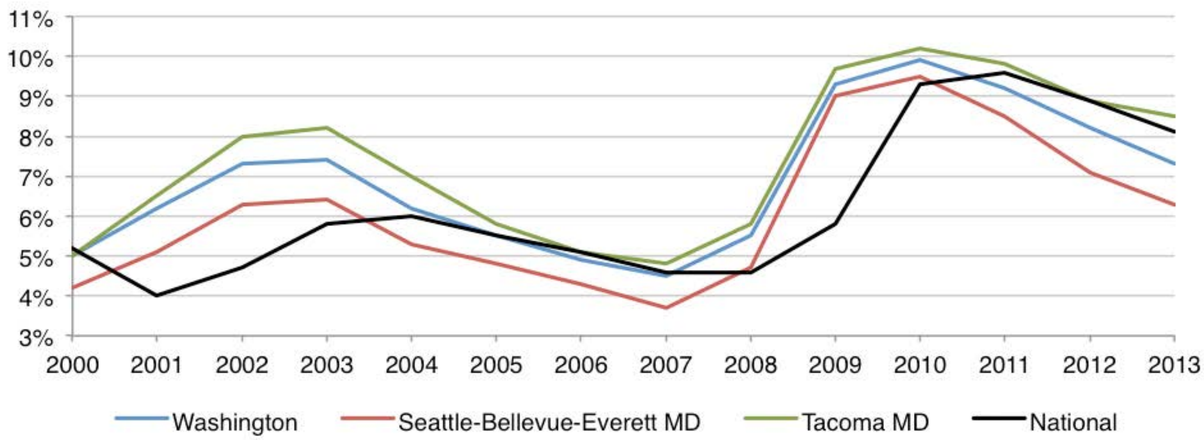
Regardless of these details, economic impacts have become important to decision makers while justifying and choosing between public spending options. Despite declining unemployment rates (see Figure 7 below), improving economic conditions remains a large concern for decision makers in the Seattle area and across the country.

5.11.1 Economic Impacts of Large GSI and Gray Infrastructure Projects

In this section, the results of an economic impact analysis of three of SPU's recent stormwater projects are described. Two of these projects represent large-scale GSI efforts in Seattle, while the third represents an even larger gray infrastructure effort. To some extent, comparing the economic activity each of these efforts supports is like comparing apples and oranges. The specific design parameters for each of these efforts were largely influenced by several feasibility factors such as spatial, technological, legal, and cost feasibility (e.g., in some cases, GSI simply is not feasible due to existing land use, topography, or a number of other factors).[86] Rather than serving as a decision criterion, this analysis helps demonstrate some of the similarities and differences in components of economic activity between the three efforts, and can help guide future efforts to meet specific economic objectives (e.g., local employment vs. nonlocal employment).

[86] For additional information regarding the consideration of these feasibility factors, see Seattle Public Utilities. 2010. *2010 CSO Reduction Plan* Amendment. May.

Figure 7. Average Annual Unemployment Rate



Source: Washington Employment Security Department. 2013. *Local Unemployment Statistics: Current Estimates*. Retrieved on June 13, 2013 from https://fortress.wa.gov/esd/employmentdata/reports-publications/regional-reports/local-unemployment-statistics; U.S. Bureau of Labor Statistics. 2013. *Unadjusted Unemployment Rate*. Retrieved on June 6, 2013 from http://data.bls.gov/timeseries/LNU04000000?years_option=all_years&periods_option=specific_periods&periods=Annual+Data.

Projects included in the analysis. For this analysis, bid sheets for three stormwater infrastructure projects were used. Two of these projects were large GSI projects, and the third was a large gray infrastructure project. The three projects are described below:

- **Ballard Roadside Rain Gardens Phase 1 Project** was funded by the American Reinvestment and Recovery Act, and included roadside rain gardens along eight blocks in the Ballard neighborhood. The project relies on bioretention cells in the right-of-way to reduce the volume of stormwater entering the combined sewer system, and to reduce the frequency and magnitude of CSO events. The initial design for the project was intended to manage a total of 38,000 gallons of stormwater each year.[87] The total cost for all three projects used in this analysis (about $0.8 million) includes only construction costs, and does not include additional costs, such as community engagement, design, and future maintenance.
- **Pinehurst Natural Drainage Solutions Project** was completed in 2006. The project provides enhanced drainage in the Pinehurst neighborhood and improves the quality of runoff into Thornton Creek. The project includes new sidewalks, roadways, and landscaping in addition to bioretention cells that are designed to manage a total of 9.7 million gallons of stormwater.[88] The total cost used in this analysis was $2.2 million.

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[87] Colwell, S. and T. Tackett. No Date. *Ballard Roadside Raingardens, Phase 1 – Lessons Learned*. Retrieved on June 12, 2013 from http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_ballardproject.pdf.

[88] Tackett, T. No Date. *Making the Invisible Visible: Seattle's Green Stormwater Infrastructure*. Retrieved on June 12, 2013 from https://www.seattle.gov/Documents/Departments/UrbanForestryCommission/2010/2010docs/StormwaterPresentation030310.pdf; Seattle Public Utilities. 2013. *Pinehurst Green Grid*. Retrieved on June 12, 2013 from http://www.seattle.gov/util/EnvironmentConservation/Projects/GreenStormwaterInfrastructure/CompletedGSIProjects/PinehurstGreenGrid/index.htm.

- **Genesee Area CSO Reduction Project** combines additional storage and transmission pipeline intended to manage a total of about 0.6 million gallons of stormwater each year. The ability to install GSI BMPs in the area was limited due to geographic constraints.[89] The total cost used in this analysis (about $19.7 million) includes only construction costs, and does not include additional costs, such as community engagement, design, and future maintenance.

Approach to conducting an economic impact analysis. SPU provided detailed bid sheets for each of the three infrastructure projects included in the economic impact analysis. Each bid sheet included line-item descriptions and costs for materials and labor activities required for the project. IMPLAN (Impact Analysis for PLANning) modeling software, with 2011 data, was used to examine the economic impacts of spending related to each of these projects. IMPLAN is an input-output model that works by tracing how spending associated with a specific project circulates through the defined impact area. For this impact analysis, the study area is defined as King County.

The results of this impact analysis are grouped into two economic impacts attributable to the infrastructure projects:

- **Direct Impacts** describe the economic activity directly tied to spending associated with each infrastructure project (e.g., wages paid to local construction workers).
- **Secondary Impacts** include indirect impacts and induced impacts. Indirect impacts occur as businesses buy from other businesses. They begin with changes in economic activity for businesses that supply directly affected businesses (e.g., the welding supply business that supplies or rents equipment to construction contractors), and continue as those businesses purchase the goods and services they need to operate. Induced impacts represent the economic activity supported by changes in household incomes generated by direct and indirect impacts.

Each type of impact (direct and secondary) is described in terms of several different variables that measure economic activity:

- **Output** is the broadest measure of economic activity and represents the value of production. Output includes intermediate goods plus the components of value added (including personal income), so the two measures (output and personal income) are not additive.
- **Personal Income** consists of wages and business income. Wages represent wages and salaries, as well as other payroll benefits such as health and life insurance, retirement payments, and non-cash compensation. Business income (also called proprietor's income) represents the payments received by small-business owners or self-employed workers (doctors, accountants, lawyers, etc.). Personal income is a subset of output.
- **Employment** represents full-and part-time jobs. In some instances, this analysis refers to "job years," which represents the equivalent of one full-time job for a year. Ten job years, for example, could refer to one job for 10 years, five jobs for 2 years, 10 jobs for 1 year, etc. The direct employment figure includes all work conducted in King County. Some of these workers, however, may live outside King County.

Results of the economic impact analysis. Table 17 summarizes the direct impacts and secondary impacts associated with each of the three projects within King County's boundaries. For each project and impact category, the table shows total output, total personal income, and total employment. These

[89] Seattle Public Utilities. 2013. *Genesee Basins*. Retrieved on June 12, 2013 from http://www.seattle.gov/util/EnvironmentConservation/Projects/DrainageSystem/SewageOverflowPrevention/CSOReductionProjects/GeneseeBasin/index.htm.

impacts are not normalized in any way, and since the impacts are directly linked to project-specific spending, the results are not surprising. The Genesee project is the most costly of the three (about $19.7 million), and as such, supports more economic activity than the other two projects.

Table 17. Summary of Economic Impacts in King County

Ballard Project	**GSI**	**Gallons Managed: 38,000/year**	**Total Cost: $0.8 million**
Impact Measure	**Direct**	**Secondary**	**Total**
Output	$0.8 million	$0.4 million	$1.2 million
Personal Income	$0.4 million	$0.1 million	$0.5 million
Employment	5.3	3.2	8.5
Pinehurst Project	**GSI**	**Gallons Managed: 9.7 million/year**	**Total Cost: $2.2 million**
Impact Measure	**Direct**	**Secondary**	**Total**
Output	$1.7 million	$1.0 million	$2.7 million
Personal Income	$1.1 million	$0.3 million	$0.3 million
Employment	11.6	7.6	19.2
Genesee Project	**Gray**	**Gallons Managed: 0.6 million gallons/year**	**Total Cost: $19.7 million**
Impact Measure	**Direct**	**Secondary**	**Total**
Output	$16.3 million	$10.6 million	$26.9 million
Personal Income	$12.0 million	$3.8 million	$3.8 million
Employment	108.2	76.6	184.8

Given the large difference in scale across the three projects, a per-unit comparison offers more helpful conclusions. Table 18 focuses on the direct economic impacts of the three projects within King County's boundaries, and summarizes these impacts in per-unit terms. As the data indicate, the Genesee project has larger impacts than the two GSI projects in absolute terms. Relative to total construction costs, however, the three projects have similar economic impacts. Relative to the volume of stormwater managed, the Genesee project has higher total construction costs and larger economic impacts than the two GSI projects.

Table 18. Direct Impacts of Construction Costs in King County

Impact Measure	**Ballard Project**	**Pinehurst Project**	**Genesee Project**
Total Construction Cost	$0.8 million	$2.2 million	$19.7 million
Total construction cost per gallon managed	$21	< $1	$33
Output	$0.8 million	$1.7 million	$16.3 million
Output per million dollars in cost	$1.0	$0.8	$0.8
Output per gallon managed	$21	< $1	$27
Personal Income	$0.4 million	$1.1 million	$12.0 million
Personal income per dollar in cost	$0.5	$0.5	$0.6
Personal income per gallon managed	$10	< $1	$20
Employment	5.3	11.6	108.2
Employment per million dollars in cost	6.7	5.2	5.5
Employment per million gallons managed	139	1	180

The results summarized above are not very helpful to decision makers looking to select one approach over another based purely on economic activity. In general, the economic activity supported by the construction of large stormwater projects is closely tied to overall construction costs, not the type of infrastructure (e.g., GSI vs. gray infrastructure). Furthermore, since the model uses multipliers to estimate economic activity, several small projects may support the same activity as one large project. If decision makers select an approach with the objective of supporting local economic activity, there are several means by which a project's local economic impacts can be strengthened:

- **Purchase local supplies.** The economic impact analysis used a regional purchasing coefficient specific to King County to estimate the percentage of supplies purchased within the county. Increasing the percentage of supplies purchased in the local area increases local economic activity because it increases the opportunity for project expenditure to circulate through secondary impacts within the area.
- **Use the local labor force.** Some projects require specialized labor from other parts of the country. These nonlocal workers spend some of their earnings in the local area, but they send most of their earnings back home. Local workers, on the other hand, spend a larger percentage of their earnings in the local community. Increasing the use of local labor increases the opportunity for project expenditures to circulate through secondary impacts within the area. In addition, planners can attempt to utilize projects that have relative high labor-to-capital ratios for overall costs.
- **Hire local firms.** The economic impact analysis assumes that all profits accruing to nonlocal firms leave the local area. All three stormwater infrastructure projects relied on nonlocal construction firms. Had they used local construction firms, these projects would have had larger local economic impacts.

As previously discussed, the analysis looked only at the economic impacts associated with construction spending. All three projects, however, also had non-construction costs (e.g., planning, design, and O&M costs). In terms of O&M, green and gray approaches differ. Insofar as GSI relies more heavily on labor-related O&M costs, and if that labor comes from local sources, it has the potential to support more economic activity than gray infrastructure efforts. For example, as workers spend their earnings in King County, they will support additional secondary impacts within the county. According to data from the IMPLAN model, every million dollars in personal income helps support an additional $550,000 in output, $180,000 in personal income, and four jobs.

5.11.2 Economic Impacts of SPU's RainWise Program

The previous section discussed the economic impacts of three large GSI and gray infrastructure projects. In this section, the small-scale GSI projects implemented through SPU's RainWise Program are examined. SPU's RainWise Program encourages residents to install rain gardens and cisterns to reduce stormwater runoff from their properties in target CSO basins. Since it began, the program has offered free training to contractors interested in becoming eligible to install facilities under the program. Over 400 contractors have gone through the training program.[90] This section summarizes some data describing the facilities installed through the RainWise Program, summarizes the results of a short survey sent to RainWise contractors, and discusses the impacts of the RainWise Program on Seattle's economy.

[90] Personal Communication. Spencer, Bob. Seattle Public Utilities. Telephone. June 3, 2013.

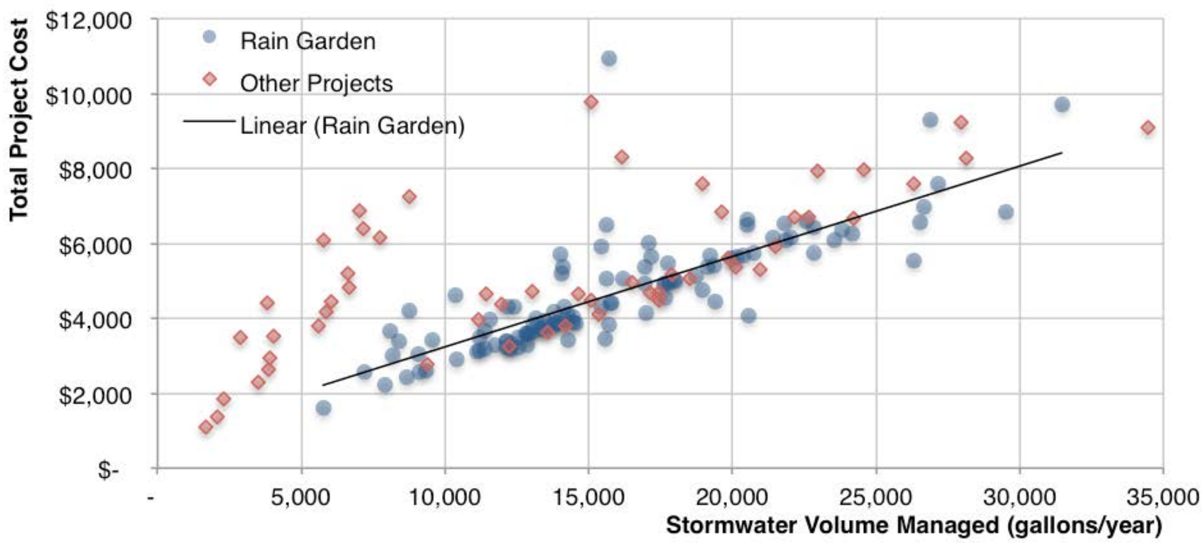
Summary of existing RainWise facilities. As of September 2012, a total of 162 facilities have been installed through the RainWise Program. Table 19 summarizes the types of projects installed through the program, the number of facilities, the volume of stormwater managed, and the total cost. Rain gardens account for the majority of the GSI facilities installed through the program. Figure 8 summarizes costs and management volumes for all facilities installed through the RainWise Program. The blue circles represent facilities labeled as rain gardens and the red diamonds represent all other facilities (see Table 19 for full list of types of RainWise facilities). The data suggest a linear relationship between project costs and volume management. At the per-gallon level, project costs decline slightly as the total volume of stormwater management increases.[91] Figure 8 also suggests that rain gardens are generally more efficient for large volumes of stormwater than other RainWise projects.

Table 19. Summary of RainWise Projects (as of September 2012)

Project Description	Number of Facilities	Volume Managed (gallons/year)	Total Cost
Rain Garden	108	1,712,869	$502,904
Rain Garden and Cistern	18	345,601	$114,305
Cistern Overflowing to Conveyance Furrow	3	15,458	$12,496
Cistern Overflowing to Sewer	8	40,800	$31,164
Cistern	8	39,116	$35,134
Cistern Overflowing to Rain Garden	17	312,590	$99,533
Total	**162**	**2,466,433**	**$795,536**

Source: Personal Communication. Emerson, Pam. Seattle Public Utilities. E-mail. October 3, 2012.

Figure 8. Project Costs and Management Volume for RainWise Facilities



Source: Personal Communication. Emerson, Pam. Seattle Public Utilities. E-mail. October 3, 2012.

[91] Minimum = $0.20/gallon; Maximum = $1.21/gallon; Average = $0.37/gallon; Median = $0.28

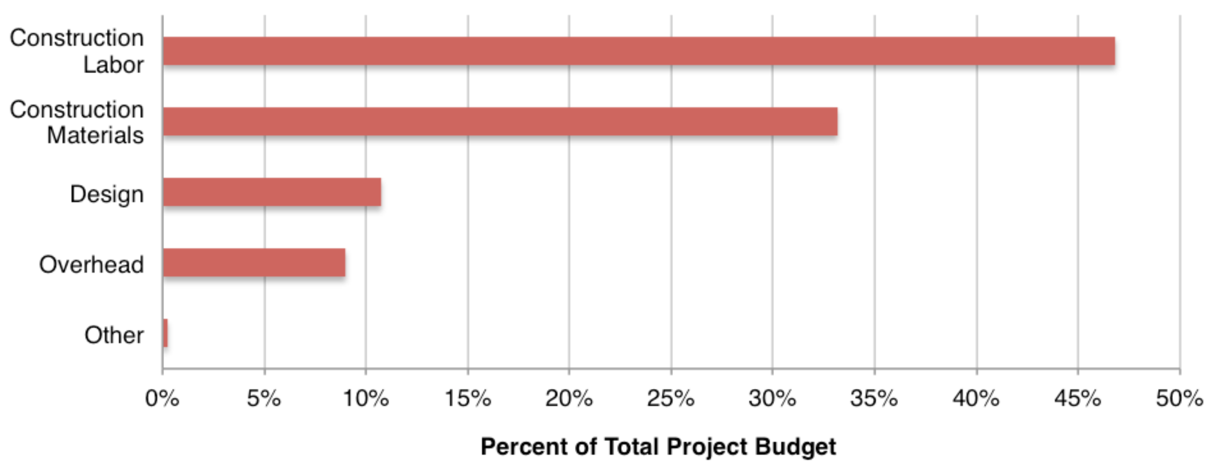
Contractor survey. To date, a total of 24 contractors have completed work on at least one RainWise facility. To better understand who these contractors are, and their potential contributions to the Seattle area's economy, each of them received a brief survey with nine questions asking them about their business and about their labor/material spending on RainWise projects. A total of 17 contractors completed at least a portion of the survey. Table 20 describes the firms that responded to the survey. Many of the contractors provide both design and construction services. Most of the firms are small (1–3 employees) and located in King County.

Table 20. Summary of Contractor Characteristics

Type of firm	Design: 18% Construction: 0% Design and Construction: 82% Other: 0%
Size of firm	1–3 employees: 56% 4–6 employees: 31% 7–10 employees: 13% More than 10 employees: 0%
Firm location	In Seattle: 65% Outside Seattle, but in King County: 12% Outside King County: 23%

One of the main objectives of the survey was to identify how RainWise-related spending is allocated to different components of the installation process. In the survey, contractors were presented with a hypothetical RainWise project and were asked to allocate spending across five categories: construction labor, construction materials, design, overhead, and other. Figure 9 summarizes the results of the contractors' responses. Construction labor accounted for the majority of costs (about 47%), followed by construction materials (about 33%). When asked where they purchase materials, respondents stated that they purchase most (if not all) of their materials from local vendors. In some instances, however, they stated that they rely on major retail chains for their supplies, which may skew the extent to which this local spending stays in the Seattle area.

Figure 9. RainWise Project Spending



Economic impacts of RainWise Program. As stated above, a total of about $0.8 million has been spent across 162 RainWise projects. These projects manage a total of about 2.5 million gallons of stormwater each year. For this analysis, a number of assumptions are made regarding project spending to describe these economic impacts:

- Data from Figure 9 are used to distribute spending across spending categories. It is assumed that design costs all go toward labor. No overhead costs and other costs are included.
- It is assumed that all construction labor occurs in King County (because all RainWise facilities are in the county) and that 77% of design labor occurs in King County (based on the locations of the firms surveyed).
- It is assumed that 90% of all materials are purchased in King County.

Table 21 summarizes some of the direct economic impacts associated with the existing inventory of RainWise facilities. Overall, about 55% of all RainWise expenditures ($438,000) were spent on labor that took place in King County. Using average income figures for construction and design labor, it is noted these labor expenditures helped support about 6 direct jobs in King County (or about 2.5 jobs per million gallons managed). Furthermore, about 30% of all expenditures ($237,000) were spent on materials purchased in King County.

These figures reflect only direct impacts associated with design and construction. They do not include secondary impacts (i.e., indirect impacts and induced impacts) associated with supplier expenditures and the circulation of personal income through the economy, nor do they include period maintenance costs.

Table 21. Summary of Direct Economic Impacts of RainWise

	King County	Outside of King County
Labor Spending	$438,000	$20,000
Materials Spending	$237,000	$26,000
Direct Employment	6.3	< 1

6 Climate Change Resilience

In previous sections, climate change has been discussed primarily in terms of the avoided costs associated with reducing atmospheric concentrations of GHGs. This section discusses how GSI at a landscape scale can help support Puget Sound area's resilience to the potential effects of climate change.

The effects of climate change on the Puget Sound region are becoming increasingly well understood, and the direct importance of attempting to mitigate or adapt to these effects is gaining increasing political and social support. In general, the changes in climate in terms of averages, extremes, and patterns of variability, are all expected to contribute to increased scarcity of natural resources in the region. The University of Washington's Climate Impacts Group identified 10 specific changes attributable to climate change that likely will affect the Puget Sound area.[92]

[92] The Climate Impacts Group, University of Washington. 2005. *Uncertain Future: Climate Change and its Effects on Puget Sound*. October.

1. Continued increases in temperature
2. Continued increases in water temperature
3. Continued alteration of river and stream flows
4. Increased flooding
5. Accelerated rates of sea level rise
6. Loss of nearshore habitat
7. Salt marshes at risk
8. Further pressures on salmon
9. Warmer water temperatures
10. Increased likelihood of algal blooms and low oxygen concentrations in bottom waters

As described throughout this report, GSI does, and increasingly has the potential to contribute directly to mitigating these effects of climate change in the Seattle area through improvements to water quality and habitat. One of GSI's greatest potential capacities to provide resilience to climate change comes in the form of improved flood management. GSI can also mitigate climate change by helping reduce the urban heat island effect and enhance groundwater recharge. The Climate Impacts Group states that "with more of the region's winter precipitation falling as rain rather than snow, flooding in Puget Sound watersheds likely would increase [and] if winter precipitation increases . . . the risk of flooding would be compounded."[93] In 2009, the Climate Impacts Group produced a statewide assessment of climate change impacts. According to the report, "drainage infrastructure designed using mid-20th century rainfall records may be subject to a future rainfall regime that differs from current design standards."[94] Implicit in this statement is the need for municipalities to expect to manage more rainfall either from more precipitation or more intense events in the future, and to implement plans and projects that could curb the potential increase in frequency and magnitude of flood events. By capturing and slowing stormwater, GSI reduces the extremes or flashiness of flood events.

GSI can provide climate change adaptation benefits to the extent that it can provide services that are increasing demand under future climate conditions. The above list of identified effects of climate change in Puget Sound represent areas of adaptation need and increasing scarcity of countervailing services. Several of the benefits of GSI identified in this report can contribute to directly mitigating these expected climate change effects, thereby likely increasing the value of these GSI services in the future as they become more scarce (increasing demand relative to existing supply). For example, increasing severity of storms and temperature extremes will also increase demand for services to buffer these extremes.

At times, GSI also can be sited in locations that would not work for conventional stormwater systems, in part because of the size scaling flexibility or willingness of private households or businesses to host such facilities because of the co-benefits. In this way, it can provide localized benefits that might not be available otherwise in the face of climate change, and it provides important diversification to Seattle's overall climate strategy.

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[93] The Climate Impacts Group, University of Washington. 2005. *Uncertain Future: Climate Change and its Effects on Puget Sound*. October. Pg. 7.

[94] The Climate Impacts Group, University of Washington. 2009. *The Washington Climate Change Impacts Assessment*. June. Pg. 340.

6.1 Sanitary Sewer Overflows

The potential benefits of GSI within the context of climate change are not limited by the range of benefits described in this report. In particular, GSI can be used to help curb the frequency of sanitary sewer overflows (SSOs) that likely would increase in the face of climate change. Appendix E contains a brief memo describing the extent to which GSI can help curb SSOs as the effects of climate change materialize. Table 22 summarizes the results. Under future conditions with climate change, including GSI in Seattle's approach to stormwater management has the capacity to reduce the number of SSOs per year by 1.5 in the Ballard CSO Basin.

Table 22. Summary of Simulation Scenarios and Estimated Number of SSOs per Year

Scenario	Conditions	Includes Climate Change	Includes GSI	Estimated Number of SSOs per Year
Scenario 1	Current	No	No	4.9
Scenario 2	Current	No	Yes	3.6
Scenario 3	Future	Yes	No	5.8
Scenario 4	Future	Yes	Yes	4.3

SSO events cause damages that require financial compensation by the City of Seattle. Based on damage claims filed with Seattle, over 1000 claims were filed for sewer backup and surface water flooding from late 2003 through mid 2013. Nearly $9 million was paid in total to these claimants, and litigation and consulting costs were nearly $2 million. The City of Seattle paid on 620 of these claims, and the average payment was $14,334. Each avoided SSO event would avoid at least tens of thousands of dollars in damages, and likely tens of thousands of dollars in compensation payments from the city.

7 Discussion and Summary

Just as Seattle's GSI efforts employ a diverse set of technologies at a range of scales and locations, so do they provide an array of benefits to residents, businesses, and agencies in Seattle and beyond. Local, state, and federal agencies are increasingly considering GSI in their approaches to stormwater management because it offers a wide range of benefits beyond those related to stormwater, as well as offering, in certain contexts, stormwater treatment benefits not provided by conventional approaches. At the same time, GSI in Seattle and elsewhere is best thought of as part of a portfolio of approaches rather than a single superior approach under all circumstances. GSI benefits accrue to government agencies, utilities, businesses, communities, and individuals across scales within and beyond Seattle.

Table 23 summarizes the results reported in this analysis. The results demonstrate a number of different ways in which GSI provides benefits to a number of different beneficiaries. In some instances, these additional benefits may sway decisions regarding a general approach to stormwater management. Decision makers should consider the extent to which these benefits apply to their own objectives when developing stormwater policy and when funding stormwater management efforts. While these results are specific to GSI efforts in Seattle, many of them also apply to stormwater management efforts elsewhere in the country. GSI efforts outside Seattle might support only a subset of these benefits or a broader range of benefits. Nonetheless, understanding and considering these additional benefits remains an important component to thorough assessment of stormwater management opportunities.

Table 23. Summary of Results

Benefit Category	Inventory	Low Build-Out Scenario	Medium Build-Out Scenario	High Build-Out Scenario
Stormwater Treatment	$66,000–$88,000	$1.8–$2.5 million	$3.3–$4.4 million	$5.5–$7.4 million
Water – Potable Water Conservation	$5,000-$14,000 for 1000 square feet, and $50-$3000 per acre-foot (one-time value).			
Energy – Household Use	$0.2–$0.5 million	$15–$37 million	$17–$43 million	$20–$49 million
Greenhouse Gas Emissions	$0.3–$3.3 million	$25–$284 million	$29–$331 million	$34–$379 million
Air Quality	< $0.3 million	$2.1–$21 million	$2.4–$24 million	$2.8–$27 million
Small-scale Habitat	$0.72 million	$30 million	$34 million	$39 million
Hydrologic Function	Improved hydrology of Seattle's waterways and promote wildlife populations that rely on those waterways. Potential for annual benefits to nearby households, and lesser benefits to regional residents.			
Mental Health	Improved mental health of residents interacting with GSI facilities and improve community cohesion throughout Seattle. Reduced healthcare costs and improved happiness.			
Ecological Literacy and Behavioral Change	Improved environmental awareness and likely some improved environmental behavior.			
Embedded Energy	Reduced lifecycle greenhouse gas emissions of GSI relative to gray stormwater infrastructure.			
Economic Impacts	Increased local job and income creation from local GSI construction and operation.			

Another way to consider these results is in per-unit terms (e.g., per gallon managed or per tree planted). Table 24 summarizes the 100-year NPV of each economic benefit in the relevant units. The right side of the table identifies instances in which each benefit is realized in terms of basin and GSI BMP. For example, the 100-year NPV of benefits related to household energy use is about $130–$321 per tree. This benefit is associated with all trees regardless of basin. It is not, however, applicable to non-tree GSI BMPs.

Table 24. Summary of Results (100-year NPV of benefits per unit)

			Creek Basin					CSO Basin					Direct Discharge				
Benefit Category	**Units**	**Per-unit 100-year NPV**	**Bioretention**	**Permeable Pavement**	**Green Roof**	**Rainwater Harvesting**	**Trees**	**Bioretention**	**Permeable Pavement**	**Green Roof**	**Rainwater Harvesting**	**Trees**	**Bioretention**	**Permeable Pavement**	**Green Roof**	**Rainwater Harvesting**	**Trees**
Stormwater Treatment	per million gallons	$4,945–$6,594						X	X	X	X	X					
Household Energy Use (tree-related energy reduction)	per tree	$130 –$321					X					X					X
GHG Emissions (home cooling and heating)	per tree	$84–$324					X					X					X
GHG Emissions (stormwater treatment)	per million gallons	$1,842–7,123						X	X	X	X	X					
GHG Emissions (Tree sequestration)	per tree	$84–$1,656					X					X					X
Air Quality (tree filtration)	per tree	$13–$169					X					X					X
Air Quality (home cooling and heating)	per tree	$4					X					X					X
Air Quality (stormwater treatment)	per million gallons	$175						X	X	X	X	X					
Small-scale Habitat	N/A	Qualitative	X		X		X	X		X		X	X		X		X
CSO Costs	N/A	Qualitative						X	X	X	X	X					
Potable Water	N/A	Qualitative				X					X					X	
Hydrologic Function	N/A	Qualitative	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mental Health	N/A	Qualitative	X		X	X	X	X		X	X	X	X		X	X	X
Behavioral Change	N/A	Qualitative	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Climate Change	N/A	Qualitative	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Challenges still exist for quantifying the full range of benefits of GSI. Collection of GSI design, monitoring, and implementation data will need to be pursued with intentions to better understand the types of benefits, the level of benefits, and the contexts that generate these benefits. This continued investigation is necessary for communities to choose the right types, quantities, and contexts for GSI in their overall water quality management portfolio. While there is a growing body of evidence for a wide range of benefits, the benefits are determined by biophysical conditions, such as soil, precipitation, and hydrology, as well as socioeconomic conditions, such as land use patterns and economic sectors. Community scarcities such as open space or street trees can contribute to the values of these benefits.

Another way to consider these benefits is in terms of the groups that receive them. Table 25 provides a high-level overview of the distribution of the benefits considered in this analysis. Many of these benefits accrue directly to Seattle residents. Often residents with GSI facilities on their property are not the only ones to benefit. Nearby residents and others in Seattle can benefit from GSI efforts even if the facilities are not on their property and even if they do not directly interact with the facilities. Many of the benefits permeate through the city by contributing to overall improvements in water quality in the region, overall improvements in air quality, and rate changes from local utilities. Some of the benefits accrue to individuals beyond the city's limits. This broad distribution of benefits reveals the importance of community-level planning and implementation, in that individual benefits and incentives likely are insufficient to generate efficient levels of GSI investment.

Table 25. Distribution of Benefits across Beneficiaries

	Beneficiaries					
	Seattle			Outside Seattle		
Benefit Category	GSI Property Owners	Residents near GSI	Other Residents and Businesses	Utilities / Agencies	Washington	National / Global
Stormwater Treatment	X	X	X	X		
Combined Sewer Overflow Costs	X	X	X	X	X	
Potable Water	X			X		
Energy – Household Use	X	X				
Energy – Stormwater Treatment	X	X	X	X		
Greenhouse Gas Emissions	X	X	X	X	X	X
Air Quality	X	X	X			
Small-Scale Habitat	X	X	X			
Hydrologic Function	X	X	X	X	X	X
Mental Health	X	X	X			
Behavioral Change	X	X	X	X	X	X
Lifecycle Greenhouse Gas Emissions	X	X	X	X	X	X
Economic Impacts			X			

Appendix A. GSI Inventory

This appendix summarizes the approach to compiling data describing the inventory of GSI facilities in Seattle and outlines how the volume of stormwater these facilities manage was quantified. The first section of this appendix is organized by the six data sources relied on for describing the existing inventory. Within that section, a series of conversion factors are applied to quantify the volume of stormwater the inventory of GSI facilities manages. The second section summarizes the inventory in geographic terms. The third section describes the distribution of the inventory within the socioeconomic and demographic context. At the end of this appendix, a brief memo is provided specifying the assumptions used to convert GSI footprints to stormwater volumes as well as a series of maps referred to throughout the appendix. Table A-1 identifies all of the maps included at the end of this appendix.

Table A-1. Maps in this Appendix

Map Title	Map Description
Map A-1. RainWise Facilities	This map shows all GSI facilities associated with the RainWise Program.
Map A-2. RainWise Facilities	This map focuses in on the neighborhoods the RainWise Program Targets
Map A-3. Rainwater Harvest Facilities	This map shows all GSI facilities from the rain harvesting dataset.
Map A-4. Green Roofs and Rooftop Gardens	This map shows all GSI facilities from the green roofs and rooftop gardens datasets.
Map A-5. Code-triggered GSI Facilities	This map shows all GSI facilities from the private GSI audit dataset. These facilities were constructed prior to 5/4/2011. The facilities in the map do not incorporate the facilities projected through the end of 2012.
Map A-6. Right-of-way GSI Facilities	This map shows all GSI facilities in the City's right-of-way.
Map A-7. Large Public Facilities	This map shows the one additional GSI facility included in the analysis that did not fit within the other categories.
Map A-8. All GSI Facilities	This map shows all GSI facilities built in Seattle area to date. They are categorized by facility type. These data do not include projected facilities extrapolated from the GSI audit dataset.
Map A-9. Volume Managed by GSI Facilities	This map shows the per-acre volume of stormwater managed by GSI facilities each year, by US Census Tract.
Map A-10. Property Value per Acre	This map shows the distribution of per-acre property values across the City of Seattle, by property parcel.
Map A-11. Race and Ethnicity	This map shows the distribution of Seattle's racial and ethnic minority populations, by US Census Block.

1. GSI Facilities by Category

The data describing Seattle's GSI facilities came from six distinct data sources: (1) those installed through the RainWise Program, (2) rainwater harvest systems, (3) green roofs and roof gardens, (4) those installed through code-triggered mechanisms, (5) private and public right-of-way GSI facilities, and (6) one stand-alone GSI facility in a public park. Each category is described in this section. The number of GSI facilities installed, by category, and the total volume of stormwater they manage is summarized. Six best management practices (BMPs) are itemized these categories: (1) bioretention, (2) permeable paving, (3) trees, (4) green roofs, (5) rainwater harvesting systems, and (6) biofiltration. At the end of this appendix is a detailed table and memo describing the assumptions used to quantify stormwater volumes.

1.1 RainWise Program

SPU's RainWise Program encourages residents to reduce stormwater runoff from their properties in target combined sewer basins. The program encourages the use of two BMPs (rain gardens and rainwater harvesting systems). To comply with program guidelines, these facilities must mitigate at least 400 square feet of impervious roof area.[95] The program provides rebates to eligible facilities based on construction costs and the size of the facility (in terms of roof area mitigated). In some instances, these rebates cover 100 percent of installation costs. To qualify for the rebate, a licensed contractor must perform the installation and an SPU inspector must perform an infiltration test of the facility.[96]

A total of 162 facilities were installed under the RainWise Program as of September 2012 (see Map A-1 and Map A-2).[97] As shown in Map A-2, most of these facilities are located between NW Market Street and NW 85th Street, and 15th Avenue NW and 32nd Avenue NW in northwest Seattle. Nearly all of these facilities are located in the combined sewer basin. Of these facilities, 143 are classified as bioretention, and are responsible for managing an estimated 2.4 million gallons of stormwater per year from 164,000 square feet (about 3.8 acres) of impervious area. The remaining 19 facilities are classified as rainwater harvesting, and are responsible for managing an estimated 95,000 gallons of stormwater per year from 24,000 square feet (about 0.6 acres) of impervious area.

1.2 Rainwater Harvest Systems

Through the end of 2012, a total of 22 facilities that were not included in any other GSI programs were classified as rainwater harvesting systems (see Map A-3).[98] These facilities are scattered across the City. Many of them, however are located in or near downtown Seattle. Nearly all of these rainwater harvest systems are located in the combined and partially separated sewer basins. Data are not sufficient to estimate the annual volume of stormwater runoff these facilities manage.

1.3 Green Roofs

Through the end of 2012, a total of 90 facilities that were not included in any other GSI programs were classified as green roofs or roof gardens (see Map A-4).[99] For the purposes of this analysis, both BMP types are classified as green roofs. As with the rainwater harvesting systems, these facilities are scattered across the City, although there is a concentration of green roofs in or near downtown Seattle. In total, these facilities are responsible for managing an estimated 8.4 million gallons of stormwater per year from 1.8 million square feet (about 42.2 acres) of impervious area.

1.4 Code-triggered Projects - Private Property GSI Audit

To comply with Seattle's stormwater code, some types of new developments are required to incorporate GSI BMPs to the maximum extent feasible (limited by engineering and design feasibility, physical limitations of the site, and economic feasibility).[100] In general, there are three types of new developments that trigger Seattle's stormwater code: (1) new developments disturbing more than 7,000

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[95] Seattle Public Utilities. 2012. *RainWise Detail Sheet 1: Facility Sizing Tables*. Retrieved on January 18, 2012 from *http://www.seattle.gov/util/groups/public/@spu/@usm/documents/webcontent/02_008087.pdf*.

[96] Seattle Public Utilities. 2011. *Rainwise Tools*. Retrieved on January 18, 2013 from *https://rainwise.seattle.gov/city/seattle/rainwise_rebates*.

[97] Three BMPs were not mapped due to insufficient data describing their locations.

[98] Three BMPs were not mapped due to insufficient data describing their locations.

[99] Ten BMPs were not mapped due to insufficient data describing their locations.

[100] City of Seattle. Seattle Municipal Code (SMC) 22.800-22.808.

square feet, (2) new developments that generate new/replace over 2,000 square feet of impervious area, and (3) new single-family residential dwellings.[101]

From November 30, 2009 to May 4, 2011, a total of 206 developments triggered Seattle's stormwater code. Of these, 122 developments went on to install GSI facilities (see Map A-5). Table A-2 summarizes these facilities. Data describing code-triggered facilities since May 4, 2011 are not available. Existing data were used to extrapolate the likely contributions of these additional facilities. In total, code-triggered facilities installed through the end of 2012 manage an estimated 8.7 million gallons of stormwater per year, mitigating stormwater from about 0.7 million square feet (about 15.0 acres) of impervious area.

Table A-2. Summary of Code-Triggered Facilities (through May 4, 2011)

BMP	Number of Installations	Total Stormwater Managed (gallons per year)
Bioretention	30	1,988,000
Green Roofs	5	23,000
Permeable Pavement	25	805,000
Multiple BMPs (1)	21	705,000
Trees	114	495,000
Total	**N/A**	**4.0 million**

(1) A total of 114 sites installed trees. Most sites installed trees as well as other BMPs. In order to make the discussion more useful, trees were considered alone followed by other BMPs installed at these sites. This row represents sites that had multiple BMPs in addition to trees potentially planted on the site.

Tree-specific data are important to economic analyses described in this report. Table A-3 summarizes the approach to quantifying the number of trees associated with code-triggered facilities. In total, 759 trees contributed to code-triggered GSI facilities from November 30, 2009 to May 4, 2011. Assuming a linear increase in trees over time, there likely were a total of about 1,640 trees associated with code-triggered GSI facilities through the end of 2012.

Table A-3. Summary of Tree-related Data from Code-Triggered GSI Facilities

	Number of Trees	Total Canopy Area (square feet)	Area Mitigated (square feet)
Existing Evergreen (9/30/09–5/4/11)	98	9,933	10,756
Projected total through 2012	212	21,509	23,291
Existing Deciduous (9/30/09–5/4/11)	115	10,931	6,721
Projected total through 2012	249	23,670	14,554
New Evergreen (9/30/09–5/4/11)	104	N/A	5,200
Projected total through 2012	225	N/A	11,260
New Deciduous (9/30/09–5/4/11)	442	N/A	8,840
Projected total through 2012	957	N/A	19,142
Total (9/30/09–5/4/11)	**759**	**N/A**	**31,517**
Projected total through 2012	**1,644**	**N/A**	**68,246**

Source: Data from SPU
Notes: Data describe trees associated with code-triggered projects from November 30, 2009 to May 4, 2011.

[101] Seattle Public Utilities. 2013. *City Policies Requiring and Related to Using GSI*. Retrieved on May 3, 2013 from http://www.seattle.gov/util/EnvironmentConservation/Projects/GreenStormwaterInfrastructure/StormwaterCode/CityPoliciesRequiringRelatedtousingGSI/index.htm.

1.5 Right-of-way GSI Facilities

Data from SPU identified a total of 666 additional right-of-way GSI facilities not included in any of the other datasets.[102] Of these facilities SPU owns and operates 562 of them. The other 104 are privately owned. As shown in Map A-6, these facilities are distributed across the City, but two areas in particular contain many of the facilities (one in the northwest part of the City and one in the southwest part of the City). Each of these is discussed in turn.[103]

- **High Point.** This cluster of facilities in southwest Seattle is in the High Point neighborhood. The cluster contains a total of 449 facilities, which manage a total of 36.0 million gallons of stormwater each year from about 58 acres of impervious area. Nearly all of these facilities, however, are connected to an underdrain, which is primarily tasked with water quality treatment. These facilities also provide stormwater flow management by reducing the intensity and duration of peak flows through the bioretention system, before stormwater reached the detention pond downstream. These underdrain facilities manage a total of 34.3 million gallons of stormwater each year.
- **The Cascades.** This cluster of facilities is in northwest Seattle. The Cascades contains a total of 121 GSI facilities, which manage a total of 10.0 million gallons of stormwater each year from about 15.4 acres of impervious area. Some of these facilities also incorporate surface storage detention elements which manage additional stormwater volumes. A total of 44 facilities within the Cascades have these detention elements. In total, these facilities manage an additional 6.2 million gallons of stormwater each year from about 9.3 acres of impervious area.
- **Swale on Yale (aka Capitol Hill Water Quality Improvement Project).** This project, when completed, will treat an average of 190 million gallons of stormwater annually flowing from Capitol Hill into Lake Union, greatly reducing the amount of pollution flowing into the lake. It does this by diverting the stormwater into a series of extra-wide biofiltration swales between the sidewalk and the roadway. These naturalistic, biofiltration "swales" are designed to slow the stormwater flow and remove pollutants before they reach the lake. The first phase of the project was completed in 2013, and the portion of the runoff managed by infiltration through the bioretention soils or evaporation are included within this analysis.

In total, these right-of-way GSI facilities manage an estimated 85million gallons of stormwater per year from over 240 acres of impervious area. Table A-4 summarizes the distribution of these GSI facilities by BMP.

Table A-4. Summary of Right-of-way GSI Facilities

BMP	Number of Installations	Total Impervious Area Managed (acres)	Total Stormwater Managed (gallons per year)
Bioretention	501	94.3	59.8 million
Biofiltration	48	10.3	5.3 million
Biofiltration - Swale on Yale Phase 1	2	Appx. 140	18 million
Permeable Pavement	117	3.7	2.0 million
Total	**666**	**248**	**85.0 million**

[102] The number of facilities includes only facilities with a BMP footprint greater than 200 square feet. Smaller facilities are assumed to be components of larger efforts. The total impervious area and stormwater volume managed includes all facilities regardless of size.

[103] More information on projects available at *http://www.seattle.gov/util/MyServices/DrainageSewer/Projects/GreenStormwaterInfrastructure/CurrentGSIProjects/index.htm*

1.6 Additional GSI Facilities

SPU identified one additional public project that does not fit into any of the categories discussed thus far (see Map A-7). The **Thornton Creek Water Quality Channel** is located in the Northgate neighborhood. The facility is designed to improve water quality by slowing the flow of stormwater runoff, allowing sediments and pollutants to settle out of the flowing stormwater.[104] This project manages an estimated 14,000 gallons of stormwater per year through infiltration and evaporation.

2. Geographic Summary of Stormwater Treatment

Map A-8 shows all GSI facilities currently constructed in Seattle. The facilities are distributed by facility type. This summary of GSI facilities shows that, by and large, the distribution of facilities is dictated by type of facility and program type. The RainWise Program, for example, supports the large cluster of bioretention facilities in northwest Seattle. Green roofs account for most of the GSI facilities in downtown Seattle. The two large right-of-way GSI efforts in northwest and southwest Seattle represent the remaining clusters of GSI facilities in the City. The remaining GSI facilities are distributed across Seattle. Areas north of downtown Seattle have relatively more GSI facilities than areas south of downtown Seattle, but there does not appear to be a general relationship describing the distribution aside from the clustering already identified.

Table A-5 summarizes the GSI facilities considered in this analysis. The right-of-way GSI facilities manage the most water, followed by code-triggered GSI facilities on private property, green roofs, and facilities installed through the RainWise program. In total, these facilities manage a total of 86.6 million gallons of stormwater each year.

Table A-5. Summary of Existing GSI Facilities in Seattle, by Data Source

	Impervious Area Mitigated (acres)	Total Stormwater Managed (gallons per year)
RainWise Program	4.3	2.5 million
Rainwater Harvest Systems	N/A	N/A
Green Roofs and Roof Gardens	42.2	8.4 million
Private Property GSI Audit*	15.0	8.7 million
Right-of-way GSI Facilities	248	85 million
Additional GSI Facilities	0.2	< 0.1 million
Total	**309**	**104.6 million**

* The values in this table for the private property GSI audit project stormwater volumes through the end of 2012 based on historical data of implementation rates. These projected volumes are not, however, reflected in Map A-8 due to uncertainty regarding their specific spatial distribution across the City.

Table A-6 summarizes the GSI facilities by facility type. The table shows the number of facilities and the volume of stormwater the facilities manage each year. For reasons described earlier, the number of GSI facilities cannot be summed due to complexities involved in the code-triggered GSI projects. The volume of stormwater managed, however, can be summed without concerns of double-counting.

[104] SvR Design Company. 2009. *Thornton Creek Water Quality Channel*. October 28. Retrieved on May 24, 2013 from http://www.seattle.gov/util/cs/groups/public/documents/webcontent/spu01_006146.pdf.

Table A-6. Summary of GSI Facilities in Seattle, by Facility Type*

	Number of Facilities	Total Stormwater Managed (gallons per year)
Bioretention	674	64.1 million
Biofiltration	52	23.3 million
Green Roof	95	8.4 million
Permeable Paving	142	2.8 million
Rainwater Harvesting	31	0.1 million
Trees	114	0.5 million
Multiple BMPs	21	0.7 million
Total	**N/A**	**99.9 million**

* The number of facilities and the volumes presented in the table do not incorporate the projections of code-triggered facilities through the end of 2012.

The volumes presented in the table do not incorporate the projected volume of stormwater managed at private, code-triggered facilities. Table A-7 summarizes the distribution of the existing inventory's stormwater management by basin and implementation mechanism.

Table A-7. Summary of GSI Facilities in Seattle, by Basin (gallons managed per year)

Basin	Right-of-way	Code-triggered	RainWise	Other	Total
Combined Sewer Basin	4.4 million	3.3 million	2.3 million	3.4 million	13.4 million
Creek Basin	62.1 million	0.8 million	--	< 0.1 million	63.0 million
Direct Discharge Basin	18.3 million	4.6 million	0.2 million	4.9 million	28.0 million
Total	66.9 million	8.7 million	2.4 million	8.4 million	104.4 million

Notes: Values elsewhere in this report may differ slightly from other values in this appendix due to rounding. Code-triggered values include projections from mid-2011 to the end of 2012 as described assuming a weighted distribution across the three basins based on the distribution of facilities installed prior to mid-2011.

Another way to think about the distribution of these GSI facilities is to look at the average volume of stormwater they manage in per-acre terms, by census tract. Map A-9 shows this distribution. GSI facilities in the dark blue census tracts manage the most stormwater in per-acre terms (over 10,000 gallons per acre per year). Yellow census tracts have no GSI facilities. As the map shows, while there are several census tracts north of downtown Seattle with no GSI facilities, the census tracts with GSI facilities generally manage more stormwater than census tracts south of downtown.

3. Seattle's GSI Projects in a Socioeconomic Context

The final two maps in Appendix A reflect Seattle's socioeconomic profile. The first map shows per-acre property values across the City. As expected, property values are highest in downtown Seattle and in the more affluent areas on the north side of the City. The second map shows the distribution of the City's population in terms of race and ethnicity. Areas in south and southeast Seattle have the largest minority populations, while areas in north and west Seattle tend to have smaller minority populations. Aligning these data with data describing stormwater facilities suggest that, in general, areas with high property values and small minority populations tend to have more GSI facilities and more stormwater managed by GSI facilities than areas with lower property values and larger minority populations.

4. Conversion Factors

The table below summarizes the data used and the assumptions applied to calculate the annual volume of stormwater that GSI facilities in Seattle manage each year. A copy of the memo SPU staff provided is at the end of this appendix.

RainWise Program			
GSI BMP from File	**Impervious Footprint Factor (square feet)**	**Annual Volume Factor (cubic feet)**	**Final GSI BMP used on Maps**
Cistern	20.83	0.53	Rainwater Harvesting
Cistern Overflowing to Back to Sewer	20.83	0.53	Rainwater Harvesting
Cistern Overflowing to Conveyance Furrow	20.83	0.53	Rainwater Harvesting
Cistern Overflowing to Rain Garden	35.71	2.00	Bioretention
Rain Garden	10.75	1.91	Bioretention
Rain Garden & Cistern	35.71	2.00	Bioretention
Green Roofs and Roof Gardens			
GSI BMP from File	**Impervious Footprint Factor (square feet)**	**Annual Volume Factor (cubic feet)**	**Final GSI BMP used on Maps**
Green Roof	1.00	0.61	Green Roof
Roof Garden	1.00	0.61	Green Roof
Private Property GSI Audit			
GSI BMP from File	**Impervious Footprint Factor (square feet)***	**Annual Volume Factor (cubic feet)**	**Final GSI BMP used on Maps**
Trees	N/A	2.10	Trees
Downspout	N/A	1.91	Bioretention
Bioretention Cell	N/A	1.91	Bioretention
Permeable Pavement	N/A	1.63	Porous Pavement
Green Roof	N/A	0.61	Green Roof
Bioretention Planter	N/A	1.91	Bioretention
Roadside GSI Facilities			
GSI BMP from File	**Impervious Footprint Factor (square feet)**	**Annual Volume Factor (cubic feet)**	**Final GSI BMP used on Maps**
BIO	SPU: 21.74 | Other: 10.75	SPU: 2.00 | Other: 1.91	Bioretention**
BSB	SPU: 21.74 | Other: 10.75	SPU: 2.00 | Other: 1.91	Bioretention**
BSW	1.00	0.21	Biofiltration
PP	1.00	1.63	Porous Pavement
BIO in High Point	38.46	1.91	Bioretention**
BSB /BSW in Cascades (additive)	26.20	2.06	Bioretention** and Biofiltration
Additional GSI Facilities			
GSI BMP from File	**Impervious Footprint Factor (square feet)**	**Annual Volume Factor (cubic feet)**	**Final GSI BMP used on Maps**
Biofiltration	1.00	0.21	Biofiltration

* There is no impervious footprint factor for facilities associated with the private property GSI audit because the stormwater code database includes the specific impervious area each facility manages.
**BMP square footage was divided by 1.8 to convert from top of BMP area to bottom of BMP area.

City of Seattle
Seattle Publiic Utilities

April 23, 21013

MEMORANDUM

To: Mark Buckley and Tom Souhlas, ECONorthwest
Fr: Tracy Tackett, PE, GSI Program Manager
Re: Valuing the stormwater benefit for GSI technologies within Seattle study

This memo is to provide guidance on the following question: "Given X square feet of a GSI best management practice, what is the average annual volume of stormwater runoff managed in the Seattle area?"

Seattle has three types of drainage systems, Creeks, non-creek separated systems, and combined sewer systems. Each system has different stormwater management objectives, including reducing stormwater rates and volumes for creek biota protection, deductions of peak intensities and durations for pipe capacity preservation and/or reducing combined or sanitary sewer backups, and removing pollutants prior to discharge to our waterbodies. As a way of providing Citywide evaluation as well as tracking Citywide implementation of GSI, Seattle has begun to quantify the average annual volume managed by GSI approaches. "Managed" flow equates to the volume of stormwater runoff that is reused (in the case of rainwater harvesting), removed by evaporation or infiltrating into native soils, or slowed through engineered soil media. The methodology for quantifying these different management approaches are provided below.

Two primary data sources provide the technical basis of the recommendations. These sources were generated during the development of Seattle's stormwater manual, which requires GSI to the Maximum Extent Feasible. To facilitate installation of GSI practices, we had technologies presized, thereby reducing the need for complicated stormwater modeling for project with less than 10,000 square feet impervious surfaces. When a stormwater code applicant is using these presizing factors to manage runoff from impervious surfaces, we do not require additional management for pervious areas discharging to the BMP. This is because the stormwater code also requires landscaped areas to be amended with compost. For simplicity I recommend we use the same approaches for this economic valuing exercise. Although there is some runoff from pervious areas, it is small relative to the contribution from impervious surfaces. Also through detailed SWMM v5.022 modeling within the Ballard CSO basin, we have found the sizing factors developed for the small projects (<10,000SF) to be representative of larger projects where both impervious and pervious surfaces are managed. Note that the calculations provided for impervious area managed assume runoff from an equivalent or larger drainage area is contributing to the facility; if less area is contributing calculations would need to be modified accordingly. If further information is desired, the data sources are as follows:

- "SPU 201.1 / DPD 15-2012 Requirements for Green Stormwater Infrastructure to the Maximum Extent Feasible for Single-Family Residential and Parcel-Based Projects " (available at seattle.gov/util/greeninfrastructure see "stormwater Code" then "City Policies Requiring and Related to using GSI. The majority of GSI to MEF Credits are based on infiltrating 91%-95% of the total runoff volume produced by the runoff file (per Section 6.5.4.6 of the Stormwater Manual Volume 3). For non-infiltrating technologies, the GSI to MEF Credits for impervious surface reduction methods are based on achieving a 91% reduction of the 1-year recurrence interval flow.
- 2009, Herrera. Memorandum "Average Annual Runoff Volume from Impervious Surface in the City of Seattle". This was subsequently validated through evaluation of calibrated models in our Long Term Control Plan. Provides basis for this calculation. Average annual volume runoff generated from the impervious surface can be calculated by multiplying the impervious surface are (square feet) by 2.1 (cubic feet/square foot), resulting in cubic feet of stormwater runoff managed.

Table 1: BMPS managing runoff through volume reduction

GSI Technology/ BMP	Flow management approach	Impervious area managed (SF)	Average annual runoff volume managed (CF)
Bioretention, infiltrating. Facilities installed by SPU (1)	Removed by infiltrating into native soils	BMP bottom area ÷ 4.6%	Impervious area managed 2.1 x 95%
Bioretention, infiltrating. Facilities installed by others (1)	Removed by infiltrating into native soils	BMP bottom area ÷ 9.3%	Impervious area managed x 2.1 x 91%
Permeable paving surface (2)	Removed by infiltrating into native soils	BMP area x 1	Impervious area managed x 2.1 x ((100% + 55%)/2)
Permeable pavement facility	Removed by infiltrating into native soils	BMP area x 2.5 (3)	Impervious area managed x 2.1 91%
Trees, deciduous, newly planted or retained (4)	Removed by evaporation, evapotranspiration or infiltrating into native soils	Canopy area x 11%	Impervious area managed x 2.1
Trees, evergreen, newly planted or retained (4)	Removed by evaporation or infiltrating into native soils	Canopy area x 22.5%	Impervious area managed x 2.1

Rain water harvesting	Reused	Facility not presized	Project specific, refer to project data
Biofiltration swale without underdrain	Credit for portion removed by infiltrating into native soils	Facility not presized	Impervious area managed x 2.1 x 10%
Greenroofs (5)	Evapotransporation component	Green roof area x 1	Impervious area managed x 2.1 x 29%
Cisterns (6)	Reuse component	Cistern area ÷ 4.8%	Impervious area managed x 2.1 x 25%
Cistern to raingarden (7)	Removed by infiltrating into native soils	Cistern area ÷ 2.8%	Impervious area managed x 2.1 x 95%

(1) SPU installed facilities are assumed to be typical NDS systems designed to infiltrate 95% runoff. The sizing factor used is 4.6% based on the majority of City retrofit project conditions with design infiltration rates between 0.5 and 0.9in/hr, and ponding depths between 9-inches and 12-inches.
For facilities installed by private entities or other agencies, the data based provide by the City already included impervious area managed for all installations except those in the right-of-way For right-of-way installations, a sizing factor of 9.3% is used because the projects were predominantly bioretention cells with 2-inches of ponding and 0.25inch/hr infiltration rates, designed to infiltrate 91% runoff.

(2) Average of flow control credits for low slope and high slope installations.

(3) This assumes 150% run-on to the facility (i.e., run-on area is 1 and ½ times the facility area)

(4) Source: 2008, Herrera. "The Effects of Trees on Stormwater Runoff". Assumed half canopy within 10-feet of impervious and half greater than 10-feet from ground level impervious. These credits are more generous than those adopted in the City of Seattle Stormwater Manual.

(5) 2012, She. Memorandum "Seattle Green Roof Modeling Results for Emergency Operation Center and Fire Station 10". Based on the volume delayed for larger storms in Table 2

(6) Assuming average contributing roof size 1,200 square feet and 25% reuse of stored volume.

(7) Assuming average contributing roof size 1,200 square feet, 1 cistern, and a bioretention cell with 6-inch ponding and 0.25in/hr native soil infiltration rate. Sizing is based on temporary storage in the cistern, which is then metered into the raingarden; use of the cistern for delaying stormwater peaks allows a smaller rain garden footprint than a system without a cistern. For this table, the focus is the volume infiltrated; the calculation is representative of the total volume infiltrated by the cistern/raingarden combination.

Some GSI practices do not remove significant stormwater volumes, but provide stormwater management through either water quality treatment or flow delay. Note that these practices should not be included in the valuation calculations for categories such as reduced energy use as these volumes do enter the downstream piping system.

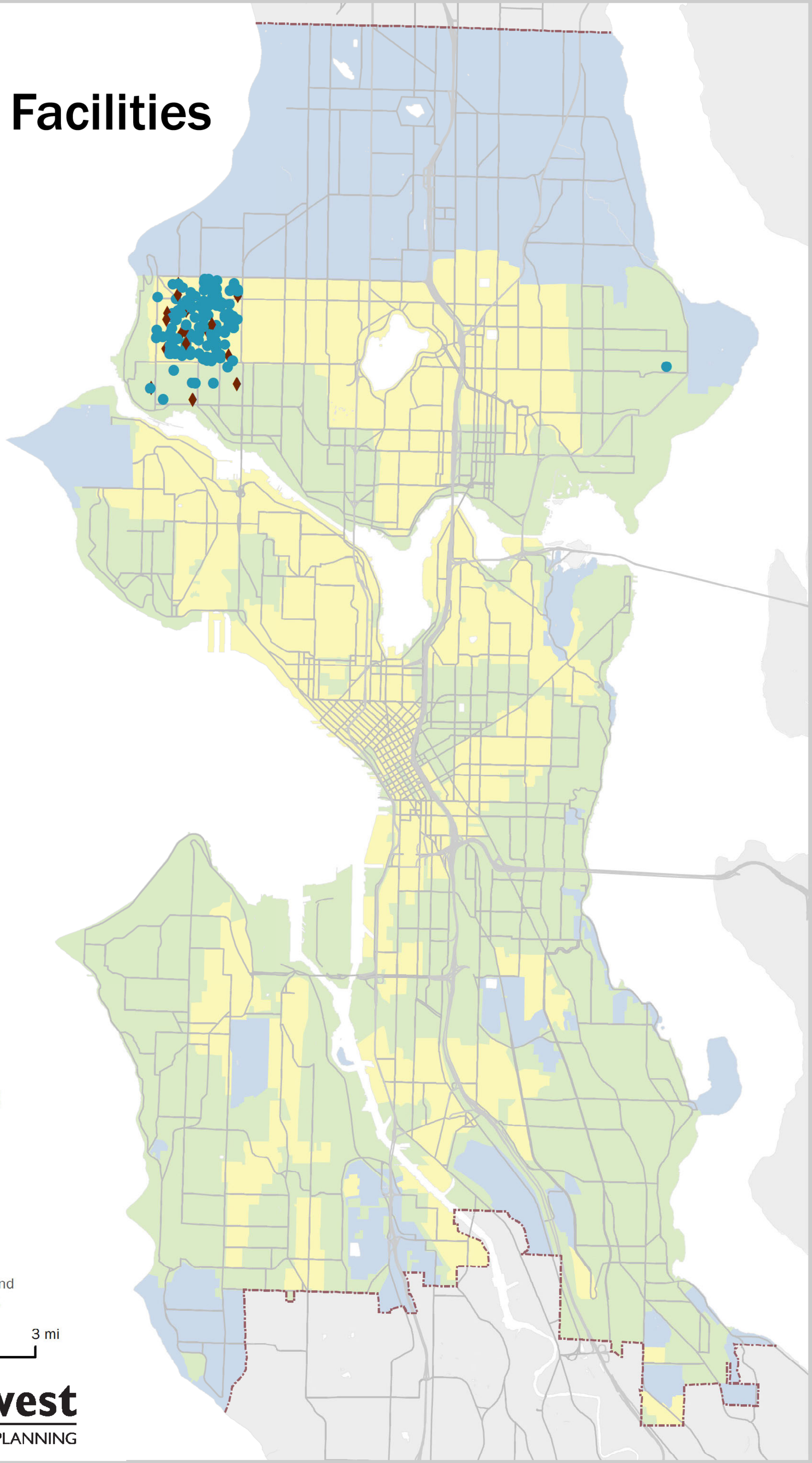
Table 2: BMPS managing runoff without volume reduction

GSI Technology/ BMP	Flow management approach	Impervious area managed (SF)	Average annual runoff volume managed (CF)
Bioretention with underdrain, non-CSO basin (8)	Water quality treatment	BMP bottom area ÷ 2.6%	Impervious area managed x 2.1 x 91%
Bioretention with underdrain, CSO basin (8)	Slowed through engineered soil media	BMP bottom area ÷ 2.6%	Impervious area managed x 2.1 x 46%
Greenroofs	Slowed through engineered soil media	Green roof area x 1	Impervious area managed x 2.1 x 55%
Cisterns o single family properties	Reused	Cistern area 4.8%	Impervious area managed x 2.1x 95%
Biofiltration swale with underdrain (9)	Credit for portion slowed through engineered soil media	Swale bottom area ÷ 0.5%	Impervious area managed x 2.1 x 19%

(8) Facilities assumed to have 6-inch ponding depth. (Note, High Point is predominantly bioretention with underdrain, non-CSO basin)

(9) Biofiltration sizing factor of 0.5% is size estimated to conform to Department of Ecology criteria for biofiltration (per communication with Jason Sharpley – SPU based on modification of Swale on Yale project calculations). Flow treated through soil and drained through underdrains or infiltration into native soil is therefore estimated to be equal to the proportional sizing factor relative to an equivalent bioretention facility, i.e. 0.5%/2.6% = 19%.

Map A-1.
RainWise Facilities



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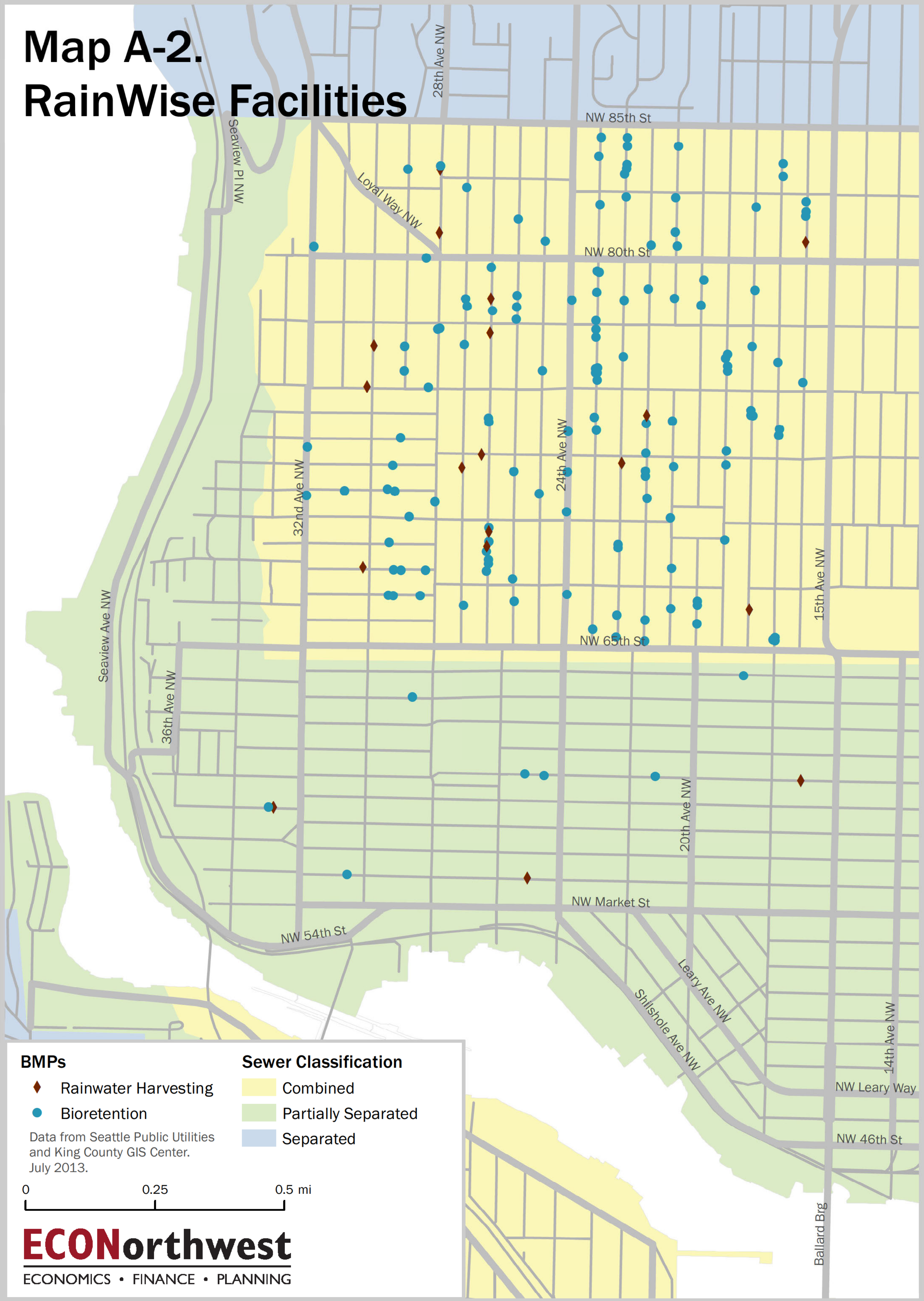
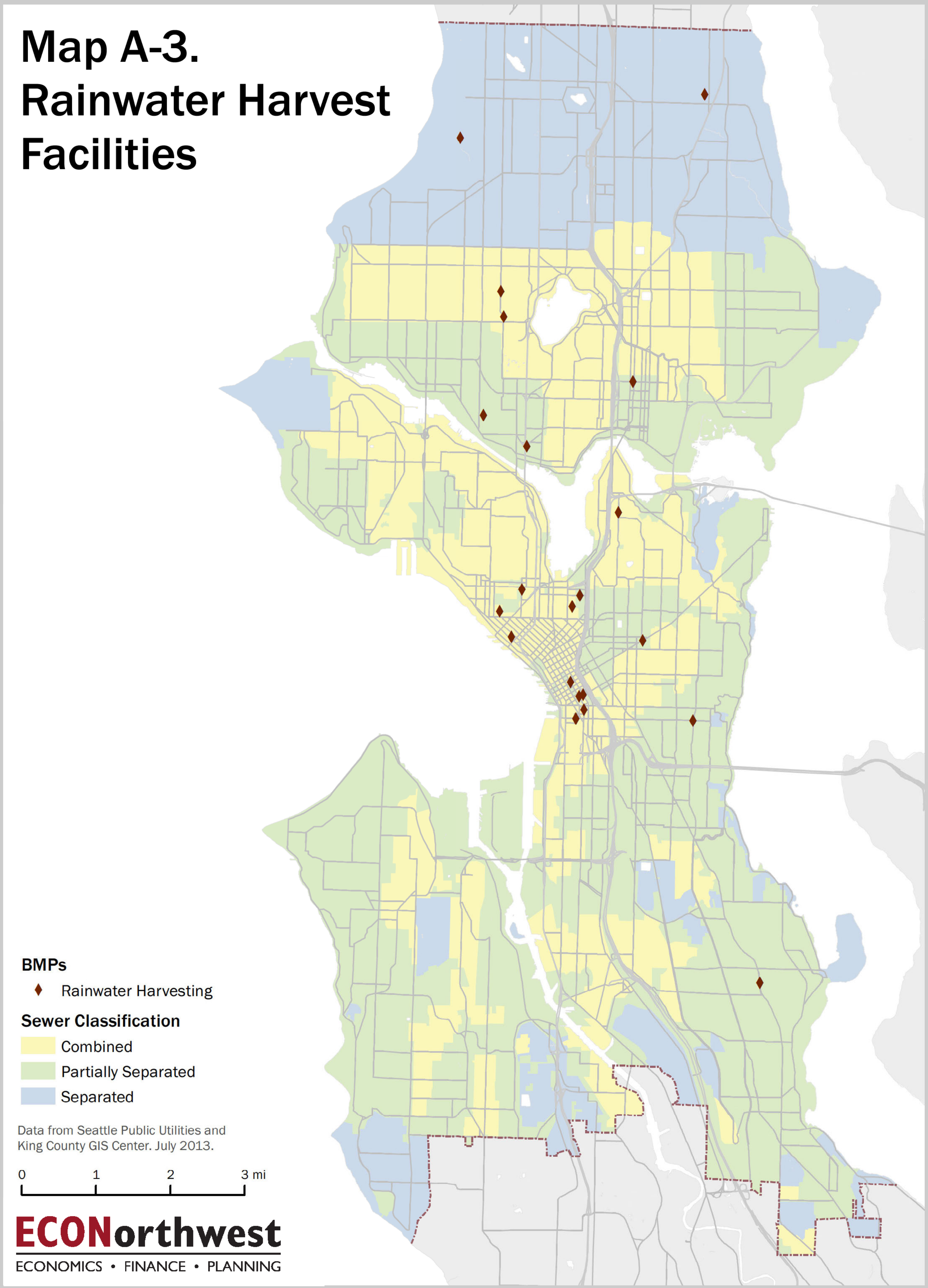
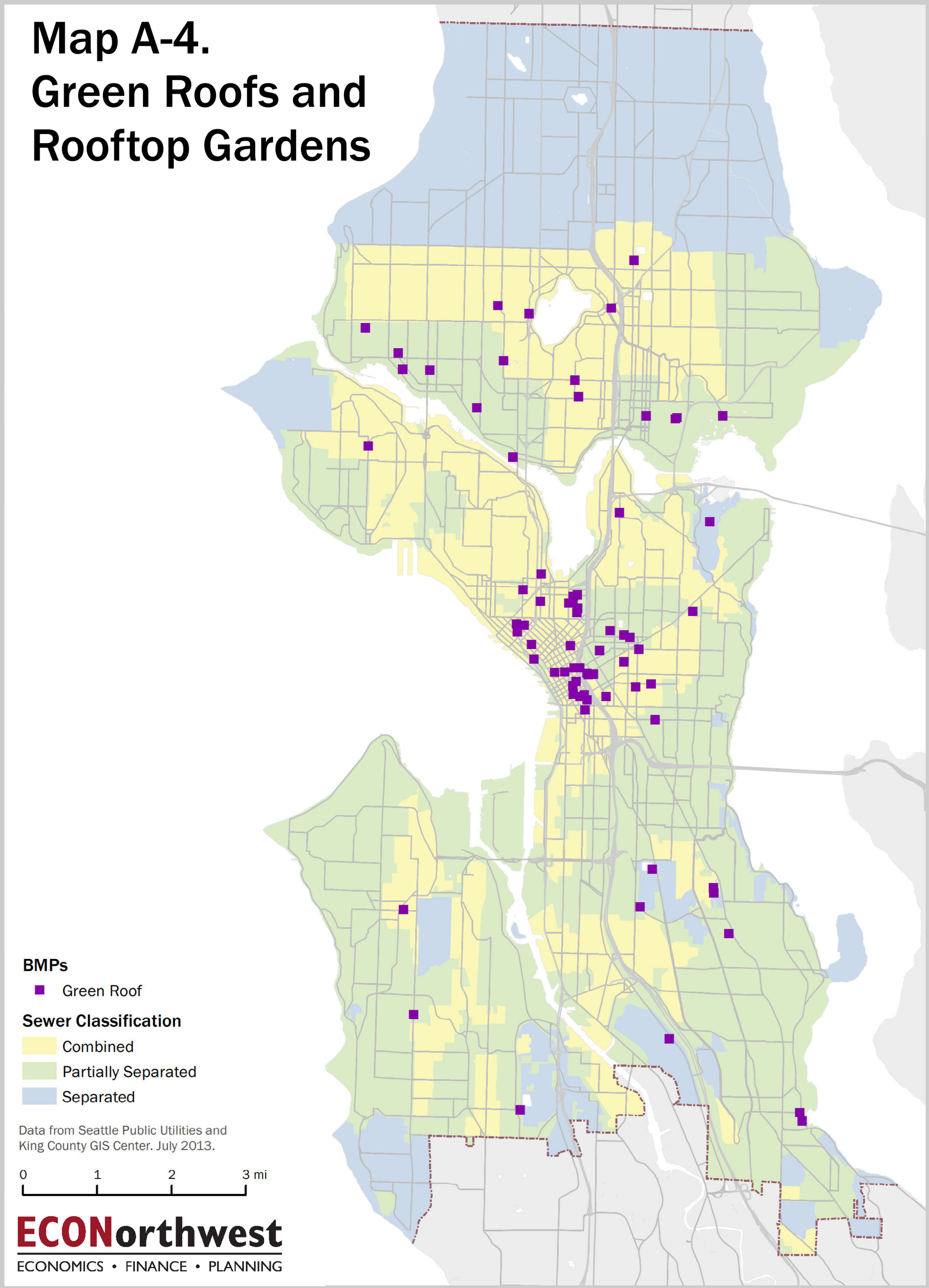
Map A-2. RainWise Facilities



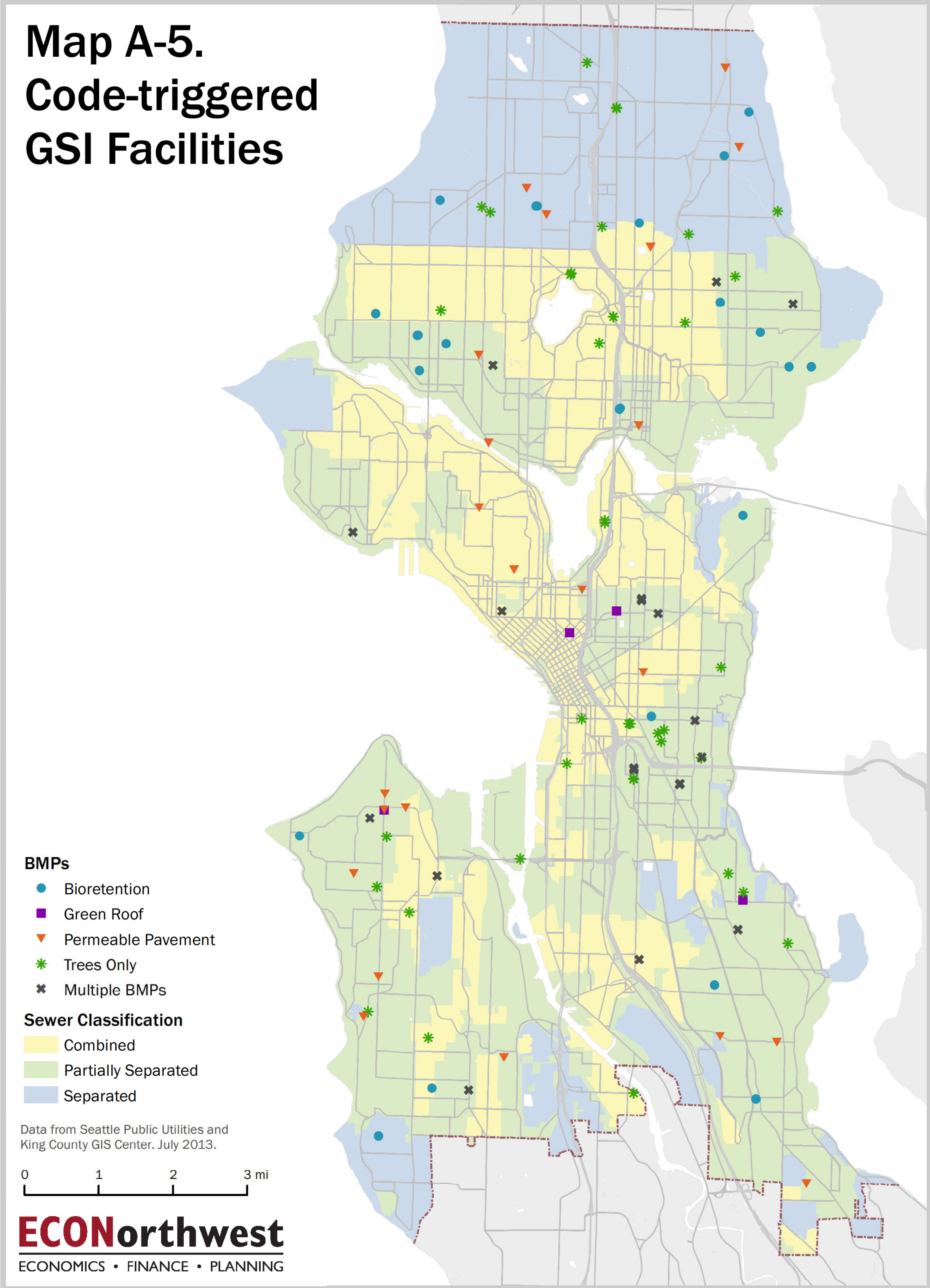
Map A-3. Rainwater Harvest Facilities



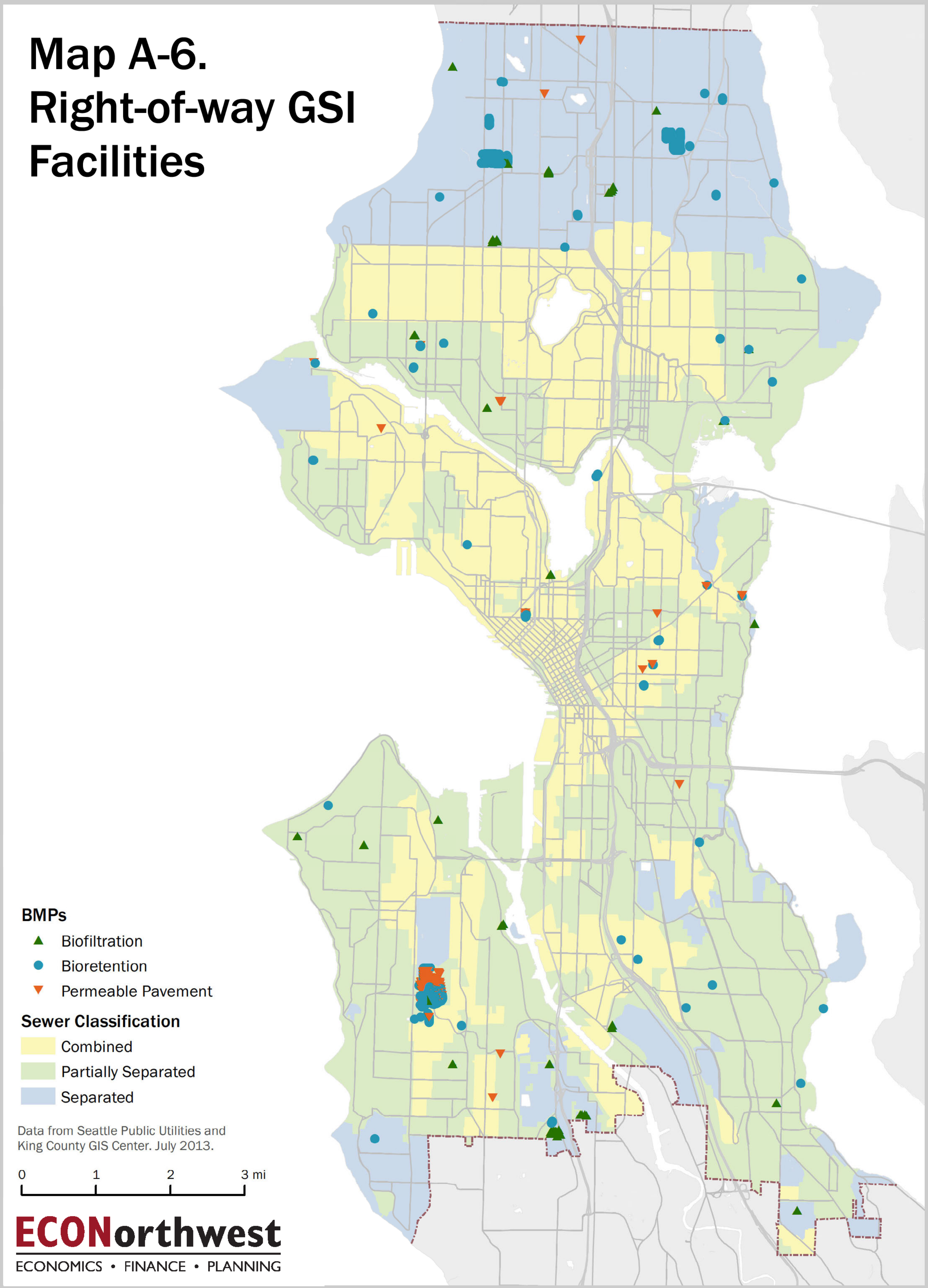
Map A-4. Green Roofs and Rooftop Gardens



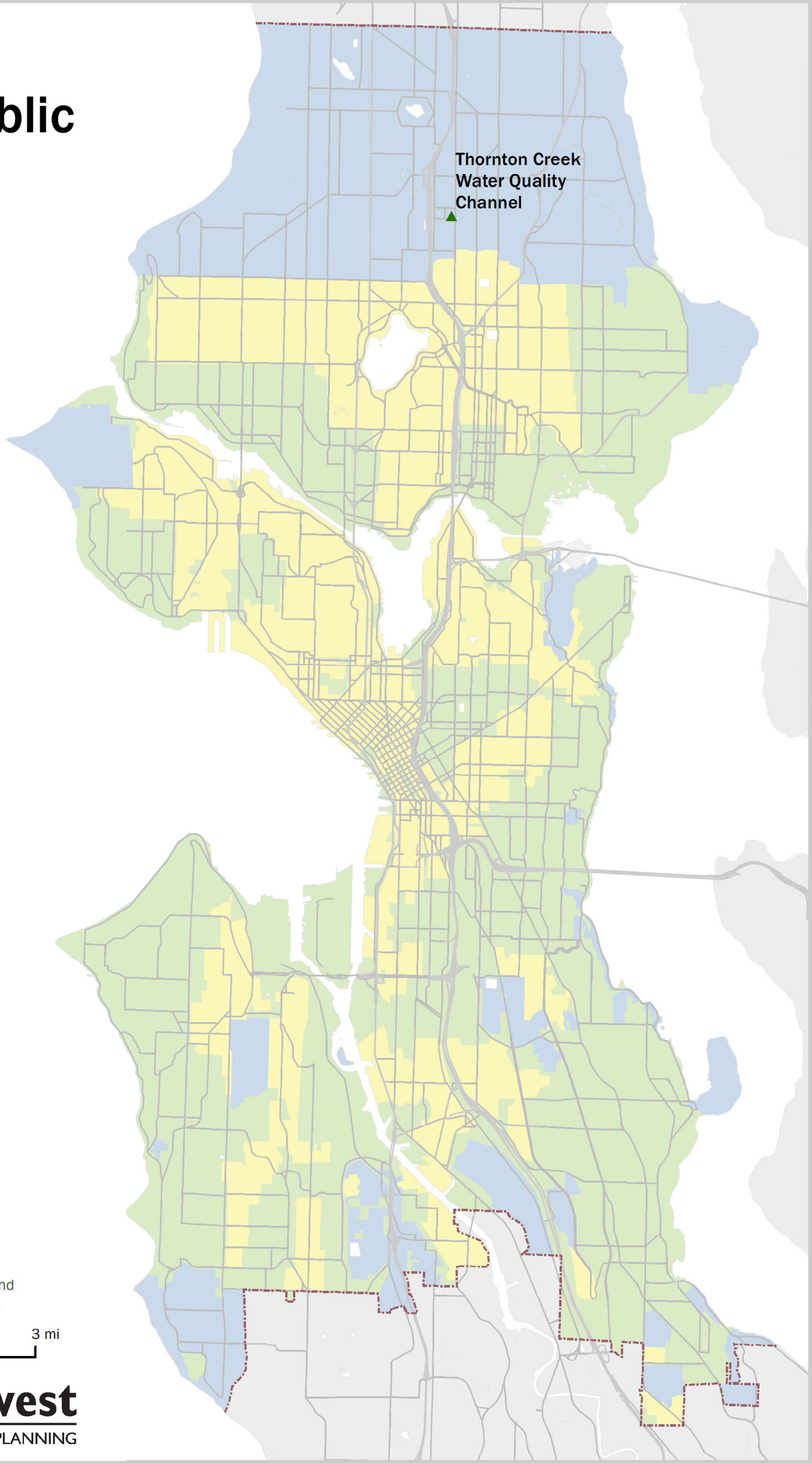
Map A-5. Code-triggered GSI Facilities



Map A-6. Right-of-way GSI Facilities



Map A-7. Large Public Facilities



BMPs

▲ Biofiltration

Sewer Classification

- Combined
- Partially Separated
- Separated

Data from Seattle Public Utilities and King County GIS Center. July 2013.

0 1 2 3 mi

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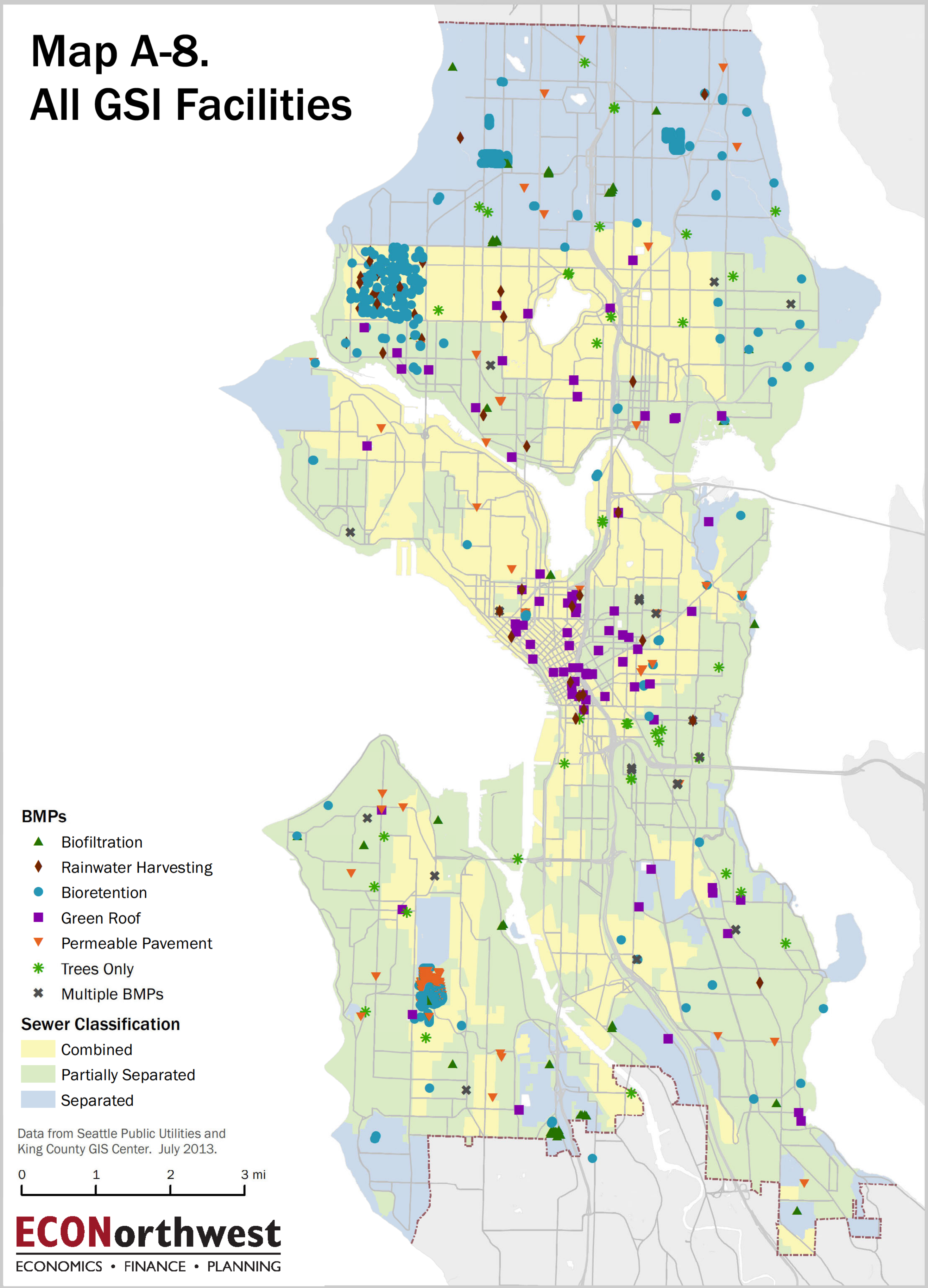
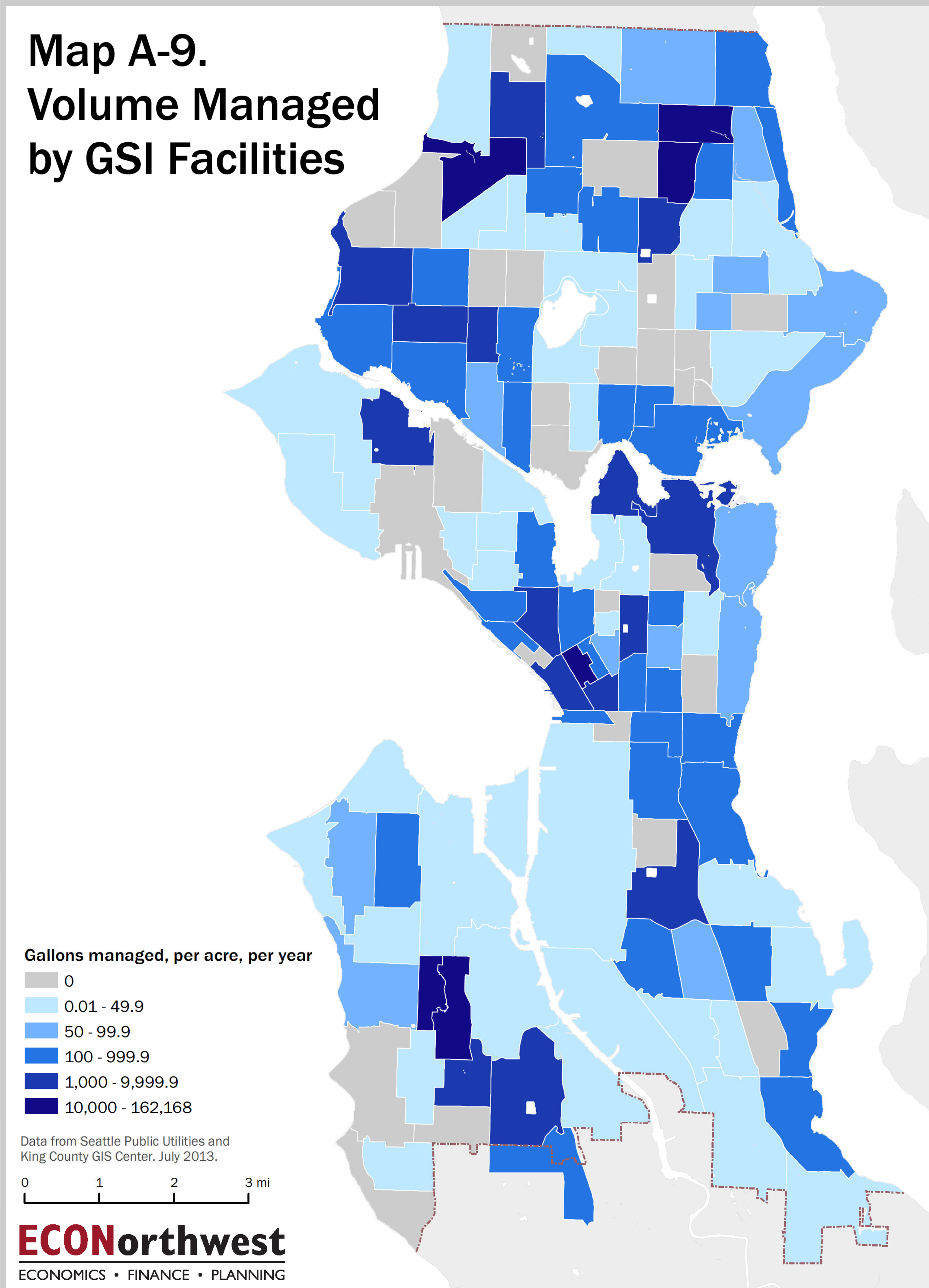
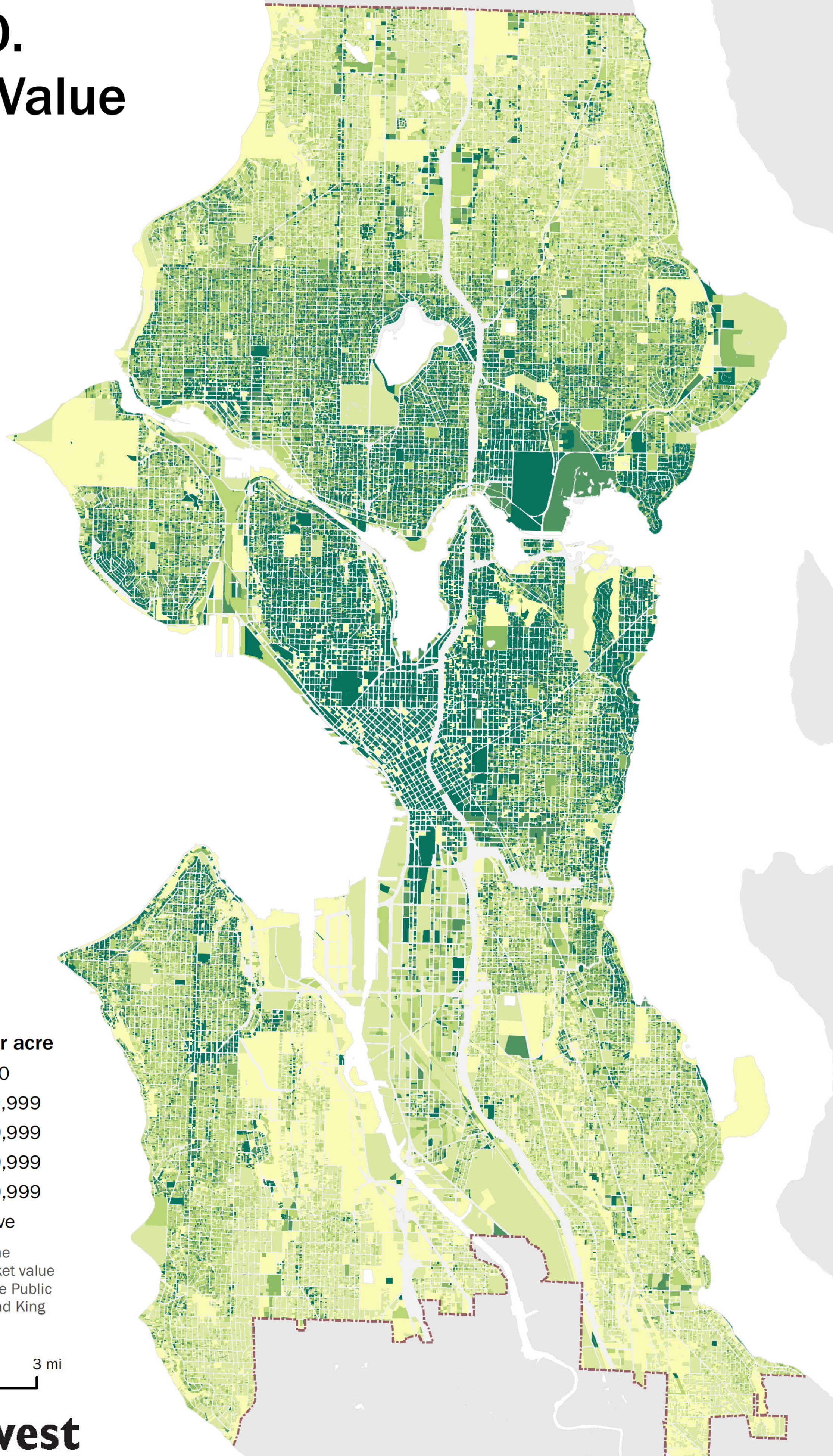
Map A-8.
All GSI Facilities



Map A-9. Volume Managed by GSI Facilities



Map A-10. Property Value per Acre



Total appraised value per acre

- Less than $1,000,000
- $1,000,000 - $1,999,999
- $2,000,000 - $2,999,999
- $3,000,000 - $3,999,999
- $4,000,000 - $4,999,999
- $5,000,000 and above

Total appraised value is equal to the market value of the land plus market value of improvements. Data from Seattle Public Utilities, King County Assessors, and King County GIS Center. July 2013.

0 1 2 3 mi

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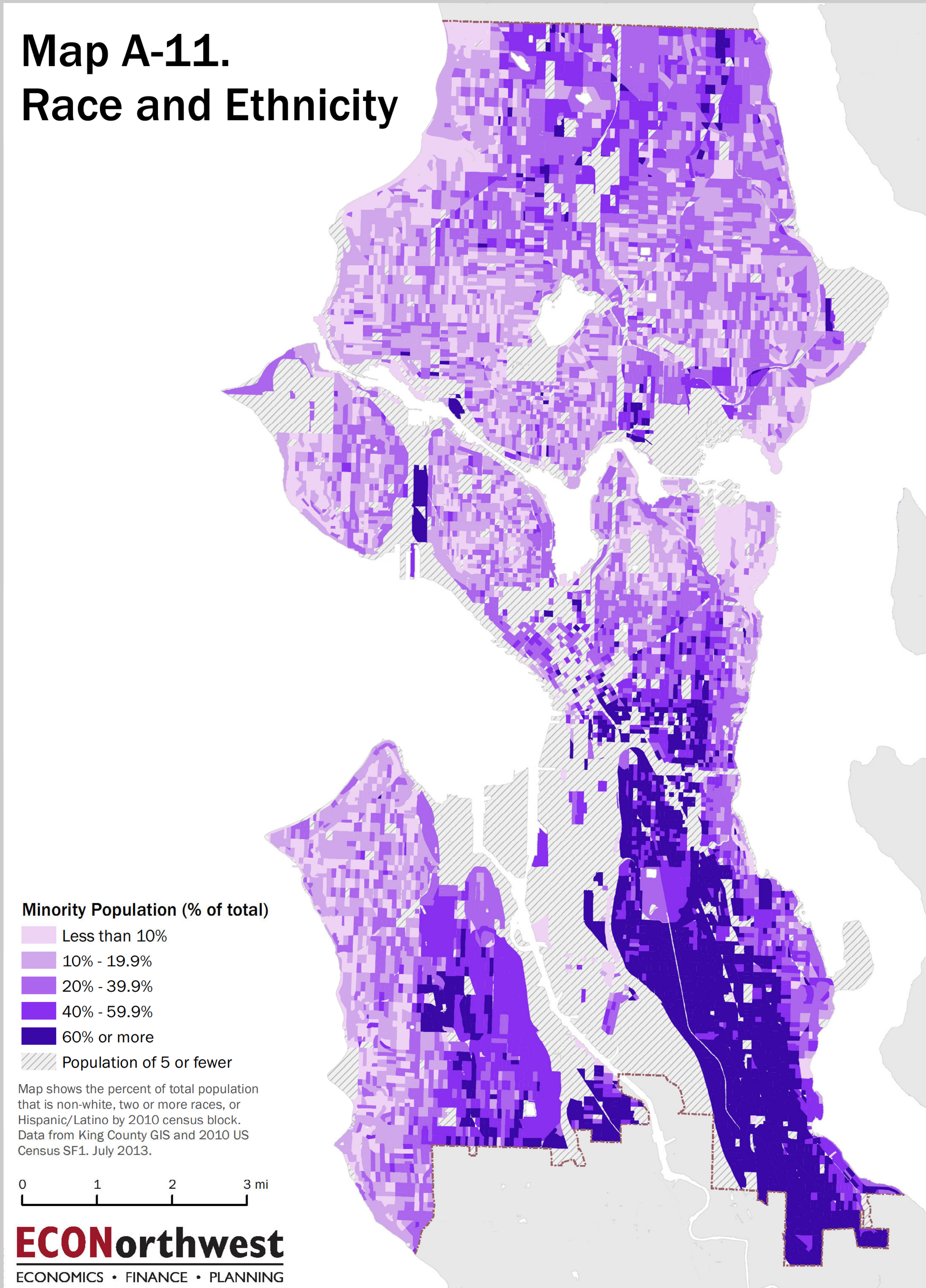
Map A-11.
Race and Ethnicity



Appendix B. Developing Build-Out Scenarios

In this analysis, three build-out scenarios (low, medium, and high) were considered, which represent different rates of future expansions of GSI facilities in Seattle. SPU staff provided all assumptions used to develop the build-out scenarios. These assumptions are basin-specific (three basins), mechanism-specific (three mechanisms), and BMP-specific (five BMPs). In all cases, a linear increase in GSI installation from 2014 to 2050 was assumed.

The three basins used to project future GSI efforts are the combined sewer basin, the creek basin, and the direct discharge basin. By using these three basins, future GSI efforts are projected based on the system through which stormwater is conveyed as well as the end location of that stormwater. The three mechanisms used to project future GSI efforts are right-of-way projects, code-triggered projects, and RainWise projects. The five BMPs used to project future GSI efforts are trees, porous pavement, bioretention, green roofs, and rainwater harvesting.

1. Summary of Build-Out Assumptions

Table B-1 summarizes the build-out assumptions used for right-of-way projects. Tree projections are based on GIS data that SPU provided that indicate all areas in the City with the potential to support trees. Bioretention projections are based on GIS data that SPU provided that indicate all portions of the right-of-way with the capacity to support bioretention. Porous pavement projections are based on GIS data that SPU provided showing all the alleys in the City. There are no green roofs or stormwater harvesting facilities associated with right-of-way projects.

Table B-1. Build-Out Assumptions for Right-of-Way Projects

Trees	Low	Medium	High
Combined Sewer Basin	10% of planting potential	20% of planting potential	30% of planting potential
Creek Basin	10% of planting potential	20% of planting potential	30% of planting potential
Direct Discharge Basin	10% of planting potential	20% of planting potential	30% of planting potential
Porous Pavement	**Low**	**Medium**	**High**
Combined Sewer Basin	None	None	None
Creek Basin	None	None	10% of alleys
Direct Discharge Basin	None	None	None
Bioretention	**Low**	**Medium**	**High**
Combined Sewer Basin	10% of technically feasible blocks	25% of technically feasible blocks	50% of technically feasible blocks
Creek Basin	10% of technically feasible blocks	25% of technically feasible blocks and	50% of technically feasible blocks and
Direct Discharge Basin	5% of technically feasible blocks	10% of technically feasible blocks	10% of technically feasible blocks

Table B-2 summarizes build-out assumptions for code-triggered projects. For these projects, there are no basin-specific assumptions or scenario-specific assumptions. These build-out scenarios are based on the assumption that 1% of impervious area in Seattle is redeveloped each year, and that this area must comply with GSI-related redevelopment codes. For the area facing redevelopment each year, it was assumed that GSI would manage stormwater from 19% of the impervious parcel area.[105]

Table B-2. Build-Out Assumptions for Code-triggered Projects

Trees – 10% of area managed	Bioretention – 50% of area managed
Porous Pavement – 27% of area managed	Green Roof – 3% of area managed
Downspout Disconnects – 7% of area managed	Rainwater Harvesting – 3% of area managed

Table B-3 summarizes build-out assumptions for RainWise projects. RainWise projections are based on GIS data that SPU provided that indicates all parcels in the City with the potential to support RainWise Projects. In terms of BMP distribution, it is assumed that 88% of all future facilities installed through the RainWise Program provide bioretention, while the remaining 12% provide rainwater harvesting. These percentages are based on the distribution of existing RainWise facilities across the two BMPs from the inventory data.

Table B-3. Build-Out Assumptions for RainWise Projects

Parcel Selection	Low	Medium	High
Combined Sewer Basin	10% of feasible single family parcels, commercial parcels, and schools.	20% of feasible single family parcels, commercial parcels, and schools.	30% of feasible single family parcels, commercial parcels, and schools.
Creek Basin	10% of feasible single family parcels, commercial parcels, and schools.	20% of feasible single family parcels, commercial parcels, and schools.	30% of feasible single family parcels, commercial parcels, and schools.
Direct Discharge Basin	None	None	None

2. Build-Out Scenarios for Right-of-Way Projects

Trees, porous pavement, and bioretention are the three GSI BMPs installed through the right-of-way mechanism. In this section, the assumptions (described above) are applied to quantify the amount of each BMP installed through this mechanism.

Trees. SPU staff provided data showing all the existing trees in the City of Seattle. These data also show all the places trees could potentially be planted in the future. Table B-4 summarizes the number of trees that can be planted within the right-of-way in Seattle, by zone and sewer basin. Across all zones and sewer basin, data suggest a total of 277,533 additional trees can be planted in Seattle.

For this analysis, the following is assumed (1) under the Low Build-Out Scenario, 10% of all potential trees, in each of the three basins, are planted, (2) under the Medium Build-Out Scenario, 20% of all potential trees, in each of the three basins, are planted, and (3) under the High Build-Out Scenario, 30% of all potential trees, in each of the three basins, are planted. Table B-5 summarizes the total number of trees planted under each build-out scenario, by basin. It also summarizes the number of trees planted each year, assuming a linear distribution of planting from 2013 to 2050.

[105] Data from SPU show that, on average, parcels that have already installed code-triggered GSI facilities are managing stormwater from about 19% of the total parcel impervious area with GSI.

Table B-4. Total Tree Potential in the Right-of-Way (number of trees)

Zoning	Combined	Creek	Direct Discharge	Total
Commercial/Mixed Use	2,511	1,843	4,613	**8,967**
Developed Park or Boulevard	1,851	211	4,762	**6,824**
Downtown	213		200	**413**
Major Institutions	375	369	1,257	**2,001**
Manufacturing/Industrial	2,156	15	8,843	**11,014**
Multi-Family	9,384	2,805	15,259	**27,448**
Parks Natural Area	431	86	755	**1,272**
Single Family	70,375	37,501	111,718	**219,594**
Total	**87,296**	**42,830**	**147,407**	**277,533**

Table B-5. Number of Trees Planted in the Right-of-Way (through 2050 | each year)

Scenario	Combined	Creek	Direct Discharge	Total
Low Build-Out Scenario	8,730 | 236/year	4,283 | 116/year	14,741 | 398/year	**27,753 | 750/year**
Medium Build-Out Scenario	17,459 | 472/year	8,566 | 232/year	29,481 | 797/year	**55,507 | 1,500/year**
High Build-Out Scenario	26,189 | 708/year	12,849 | 347/year	44,222 | 1,195/year	**83,260 | 2,250/year**

On average, trees used to manage stormwater on existing code-triggered parcels manage about 652 gallons of water per year per tree.[106] This conversion factor is used to quantify the volume of stormwater trees planted through the right-of-way mechanism manage each year. Table B-6 summarizes the volume of stormwater these trees manage each year through 2050, as well as each year from 2013–2050.

Table B-6. Tree-related Stormwater Management in the Right-of-Way (millions of gallons through 2050 | each year)

Scenario	Combined	Creek	Direct Discharge	Total
Low Build-Out Scenario	5.7 | 0.2/year	2.8 | 0.1/year	9.6 | 0.3/year	**18.1 | 0.5 /year**
Medium Build-Out Scenario	11.4 | 0.3/year	5.6 | 0.2/year	19.2 | 0.5/year	**36.2 | 1.0 /year**
High Build-Out Scenario	17.1 | 0.5/year	8.4 | 0.2/year	28.8 | 0.8/year	**54.3 | 1.5 /year**

Porous pavement. For this analysis, it is assumed that no porous pavement is installed in the combined basin or the direct discharge basin right-of-ways under any of the build-out scenarios, or in the creek basin right-of-way under the Low and Medium Build-Out Scenarios. For the creek basin's High Build-Out Scenario, it is assumed that porous pavement is installed on 10% of the alleys in the creek basin by 2050. Data from SPU show that there are a total of 64.56 acres of alleys in Seattle's creek basin. About 0.17 acres of porous pavement will be installed each year, for a total of 6.46 acres by 2050 in the creek basin under the High Build-Out Scenario. According to data used for the inventory, each acre of porous pavement manages a total of 0.53 million gallons of stormwater each year. This conversion factor is used to quantify the volume of stormwater porous pavement installed through the right-of-way

[106] Data from the analysis of the existing inventory show that 759 trees on code-triggered parcels manage a total of 495,000 gallons of stormwater each year, which is used to calculate an average per tree.

mechanism manage each year. Table B-6 summarizes the volume of stormwater these areas manage each year through 2050, as well as each year from 2013–2050.

Table B-7. Porous Pavement-related Stormwater Management in the Right-of-Way (millions of gallons through 2050 | each year)

Scenario	Combined	Creek	Direct Discharge	Total
Low Build-Out Scenario	—	—	—	—
Medium Build-Out Scenario	—	—	—	—
High Build-Out Scenario	—	3.4 | 0.1 /year	—	**3.4 | 0.1 /year**

Bioretention. SPU staff provided data showing all of the City's right-of-way areas, as well as all technically feasible areas for bioretention efforts. The two datasets were aligned to identify technically feasible portions of the City's right-of-way system available for bioretention efforts. In total, there are about 2,260 acres of right-of-way technically feasible for bioretention in the combined sewer basin, about 940 acres in the creek basin, and about 3,060 acres in the direct discharge basin. For each basin and each scenario, the total right-of-way area was multiplied by 1.83 to quantify the total impervious area managed. In order to convert the impervious area managed into stormwater volume, it is assumed that each acre of impervious area managed by bioretention equates to 0.62 million gallons of stormwater each year. Table B-8 summarizes the volume of stormwater these bioretention facilities manage per year in 2050 as well as the volume they manage per year in annual increments building up to 2050.

Table B-8. Bioretention-related Stormwater Management in the Right-of-Way (millions of gallons through 2050 | each year)

Scenario	Combined	Creek	Direct Discharge	Total
Low Build-Out Scenario	258 | 7.0/year	107 | 2.9/year	175 | 4.7/year	**539 | 14.6/year**
Medium Build-Out Scenario	644 | 17.4/year	267 | 7.2/year	349 | 9.4/year	**1,260 | 34.0/year**
High Build-Out Scenario	1,287 | 34.8/year	534 | 14.4/year	349 | 9.4/year	**2,170 | 58.7/year**

3. Build-Out Scenarios for Code-triggered Projects

Trees, porous pavement, bioretention, green roofs, downspout disconnects, and rainwater harvesting are the six GSI BMPs installed through the code-triggered mechanism.[107] In this section, the assumptions (described above) are applied to quantify the amount of each BMP installed through this mechanism.

Projecting code-triggered projects. In total, there are about 38,500 acres of parcel land in Seattle, and an estimated 20,700 acres of which are impervious.[108] As stated in the assumptions, 1% of all impervious area is redeveloped each year under each of the build-out scenarios. Using this assumption, it is assumed that a total of about 207 acres of impervious area is redeveloped each year. Data from SPU show that, on average, parcels that have already installed GSI facilities through this mechanism are managing stormwater from about 19% of the total impervious area. Combining the total amount of impervious redeveloped each year with the average mitigation factor suggests that, each year, code-

[107] This is based on the data generated by the audit of code-triggered projects. Bioretention cells and bioretention planters are group together here based on common performance assumptions.

[108] Impervious calculation is based on typical percent impervious by zoning category.

triggered GSI facilities will manage stormwater from about 38.7 acres of impervious surface area). The current breakdown by BMP type summarized in Table B-2 for the code-triggered build-out is assumed (see Table B-9.)[109]

Table B-9. Quantifying Annual Distribution of New Code-triggered Projects

Category/BMP	Area Managed
Total Parcel Area	**38,508 acres**
Total Impervious Area	**20,680 acres**
Annual Redevelopment	**207 acres**
Annual Impervious Area Mitigated	**38.7 acres**
Trees	**3.9 acres**
Bioretention	**19.3 acres**
Porous Pavement	**10.4 acres**
Green Roofs	**1.2 acres**
Downspout Disconnects	**2.7 acres**
Rainwater Harvesting	**1.2 acres**

Notes: The conversion factors are based on the factors presented in Appendix A.
They have been converted from square feet to cubic feet terms to acres to gallons terms.
Totals may not sum due to rounding.

Trees. The number of trees is based on the share of managed area managed by trees in the existing inventory, and the proportion of number of trees to area in this inventory. Based on assumed conditions described above, the build-out scenarios include enough tree plantings to manage a total of an additional 1.9 million gallons of stormwater each year from a total of about 2.8 acres of impervious area mitigated each year. To determine the associated number of trees planted, it is assumed that each tree manages about 652 gallons of water per year.[110] Using this conversion factor (from gallons managed per year to number of trees per year), the build-out scenarios include a total of 2,908 trees per year (about 2,046 in the combined sewer basin, 485 in the creek basin, and 378 in the direct discharge basin).

Bioretention. As described above, the build-out scenarios include enough bioretention facilities to manage a total of about 8.6 million gallons of stormwater each year from a total of about 13.9 acres of impervious area mitigated each year.

Table B-10 summarizes the volume of stormwater managed, each year, by GSI facilities installed through the code-triggered mechanism. The table distinguishes between different GSI BMPs and the three basins. The first number indicated the total volume managed per year in 2050 and the second number indicates the annual increase in volume managed from 2013–2050.

---

[109] Approximately 33 percent of the area is in the combined basins, 24 percent in the creek basin, and 43 percent in the direct discharge basin.

[110] Data from the analysis of the existing inventory show that 759 trees on code-triggered parcels manage a total of 495,000 gallons of stormwater each year, which is used to calculate an average per tree.

Table B-10. Stormwater Management by Code-triggered Projects (millions of gallons through 2050 | each year)

BMP	Volume Managed
Trees	98 | 2.6/year
Bioretention	445 | 12/year
Porous Pavement	205 | 5.5/year
Green Roofs	8.5 | 0.2/year
Downspout Disconnects	62 | 1.7/year
Rainwater Harvesting	14 | 0.4/year

4. Build-Out Scenarios for RainWise Projects

Bioretention and rainwater harvesting are the two GSI BMPs installed through the RainWise Program. In this section, the assumptions (described above) are applied to quantify the amount of each BMP installed through this mechanism. Bioretention accounts for about 88% of the RainWise projects in the existing inventory; rainwater harvesting accounts for the other 12%.

Projecting RainWise projects. In total, there are 25,599 parcels that align with the Seattle or King County RainWise Basins as well as the area identified as suitable for infiltration.[111] Table B- 11 distributes these parcels across the basins, and identifies the type of parcel, according to data from the Urban Forest Management Plan. According to the build-out assumptions described earlier, 10% of the parcels in the combined sewer basin and the creek basin (a total of 2,560 parcels) would join the RainWise Program under the Low Build-Out Scenario, 20% (a total of 5,120 parcels) would join the RainWise Program under the Medium Build-Out Scenario, and 30% (a total of 7,680 parcels) would join under the High Build-Out Scenario.

Table B- 11. Number of Parcels Aligning with RainWise Requirements

Basin	Single Family	Commercial	Other	Total
Combined Sewer Basin	23,903	1,326	10	**25,239**
Creek Basin	355	5	—	**360**
Direct Discharge Basin	—	—	—	—
Total	**25,136**	**1,381**	**10**	**25,599**

Bioretention. Of all the RainWise projects in the inventory, about 88% of them use bioretention to manage stormwater. The average parcel using bioretention in the inventory collects stormwater from about 1,150 square feet of impervious surface, and manages a total of 16,580 gallons of stormwater per year. For each build-out scenario, the annual and cumulative additions of bioretention facilities through the RainWise program are described below. Table B-12 summarizes the volume these facilities manage each year in 2050 and each year from 2013–2050.

[111] SPU does not offer RainWise in direct discharge basins.

- The Low Build-Out Scenario would add bioretention facilities to a total of 61 parcels per year (60 in the combined sewer basin and one more in the creek basin). These facilities would manage a total of 1.6 acres of impermeable surface and about 1.0 million gallons of stormwater each year. By 2050, the Low Build-Out Scenario would add bioretention to a total of about 2,250 parcels, managing a total of about 59.5 acres of impermeable surface and about 37.3 million gallons of stormwater each year.
- The Medium Build-Out Scenario would add bioretention facilities to a total of 122 parcels per year (120 in the combined sewer basin and two more in the creek basin). These facilities would manage a total of 3.2 acres of impermeable surface and about 2.0 million gallons of stormwater each year. By 2050, the Medium Build-Out Scenario would add bioretention to a total of about 4,500 parcels, managing a total of about 118.9 acres of impermeable surface and about 74.7 million gallons of stormwater each year.
- The High Build-Out Scenario would add bioretention facilities to a total of 183 parcels per year (180 in the combined sewer basin and three more in the creek basin). These facilities would manage a total of 4.8 acres of impermeable surface and about 3.0 million gallons of stormwater each year. By 2050, the High Build-Out Scenario would add bioretention to a total of about 6,760 parcels, managing a total of about 178.4 acres of impermeable surface and about 112.0 million gallons of stormwater each year.

Table B-12. Bioretention-related Stormwater Management from RainWise Projects (millions of gallons through 2050 | each year)

Scenario	Combined	Creek	Direct Discharge	Total
Low Build-Out Scenario	36.8 | 1.0/year	0.5 | < 0.1/year	—	**37.3 | 1.0/year**
Medium Build-Out Scenario	73.6 | 2.0/year	1.0 | < 0.1/year	—	**74.7 | 2.0/year**
High Build-Out Scenario	110.5 | 3.0/year	1.5 | < 0.1/year	—	**112.0 | 3.0/year**

Rainwater harvesting. Of all the RainWise projects in the inventory, about 12% of them use rainwater harvesting to manage stormwater. The average parcel using rainwater harvesting in the inventory collects stormwater from about 1,280 square feet of impervious surface, and manages a total of 5,020 gallons of stormwater per year. For each build-out scenario, the annual and cumulative additions of rainwater harvesting facilities through the RainWise program are described below. Table B-13 summarizes the volume these facilities manage each year in 2050 and each year from 2013–2050.

- The Low Build-Out Scenario would add rainwater harvesting facilities to a total of 8 parcels per year (only a fraction of the annual build-out would occur in the creek basin). These facilities would manage a total of 0.2 acres of impermeable surface and about 42,000 gallons of stormwater each year. By 2050, the Low Build-Out Scenario would add rainwater harvesting facilities to a total of about 310 parcels, managing a total of about 9.0 acres of impermeable surface and about 1.5 million gallons of stormwater each year.
- The Medium Build-Out Scenario would add rainwater harvesting facilities to a total of 17 parcels per year (only a fraction of the annual build-out would occur in the creek basin). These facilities would manage a total of 0.5 acres of impermeable surface and about 83,000 gallons of stormwater each year. By 2050, the Medium Build-Out Scenario would add rainwater harvesting facilities to a total of about 614 parcels, managing a total of about 18.1 acres of impermeable surface and about 3.1 million gallons of stormwater each year.

- The High Build-Out Scenario would add rainwater harvesting facilities to a total of 25 parcels per year (only a fraction of the annual build-out would occur in the creek basin). These facilities would manage a total of 0.7 acres of impermeable surface and about 0.1 million gallons of stormwater each year. By 2050, the High Build-Out Scenario would add rainwater harvesting facilities to a total of about 920 parcels, managing a total of about 27.1 acres of impermeable surface and about 4.6 million gallons of stormwater each year.

Table B-13. Rainwater Harvest-related Stormwater Management from RainWise Projects (millions of gallons through 2050 | each year)

Scenario	Combined	Creek	Direct Discharge	Total
Low Build-Out Scenario	1.5 | < 0.1/year	< 0.1| < 0.1/year	—	**1.5 | < 0.1/year**
Medium Build-Out Scenario	3.0 | < 0.1/year	< 0.1 | < 0.1/year	—	**3.1 | < 0.1/year**
High Build-Out Scenario	4.6 | 0.1/year	< 0.1 | < 0.1/year	—	**4.6 | 0.1/year**

5. Summary of Build-Out Scenarios

This section summarizes each of the three build-out scenarios in terms of the quantify of GSI facilities installed each year, the volume of stormwater they manage each year in 2050, and the incremental increase in volume from 2013–2050. At the end of the section, a series of maps demonstrates some of the spatial assumptions used in developing the build-out scenarios.

The following three figures summarize some of the quantified GSI efforts used in the analysis of the build-out scenarios.

- Figure B-1 summarizes the amount of each GSI BMP installed, annually, under each build-out scenario (Low, Medium, and High) and within each of the three basins (combined, creek, and direct discharge).
- Figure B-2 summarizes the volume of stormwater managed, per year, for the GSI BMPs installed each year, under each build-out scenario (Low, Medium, and High) and within each of the three basins (combined, creek, and direct discharge).Figure B-3 summarizes the volume of stormwater managed, per year, in 2050, after all build-out scenarios have been fully implemented, under each build-out scenario (Low, Medium, and High) and within each of the three basins (combined, creek, and direct discharge).

Figure B-1. GSI BMPs installed, per year, for each build-out scenario, in each basin

		GSI Installed each year 2013-2050											
		Low				Medium				High			
		ROW	Code	RainWise	Subtotal	ROW	Code	RainWise	Subtotal	ROW	Code	RainWise	Subtotal
Trees (Number of Trees)	Combined	235.9	1,338.6	-	*1,574.6*	471.9	1,338.6	-	*1,810.5*	707.8	1,338.6	-	*2,046.4*
	Creek	115.8	973.6	-	*1,089.3*	231.5	973.6	-	*1,205.1*	347.3	973.6	-	*1,320.8*
	Direct Discharge	398.4	1,744.3	-	*2,142.7*	796.8	1,744.3	-	*2,541.1*	1,195.2	1,744.3	-	*2,939.5*
	Subtotal	*750.1*	*4,056.5*	*-*	***4,806.6***	*1,500.2*	*4,056.5*	*-*	***5,556.7***	*2,250.3*	*4,056.5*	*-*	***6,306.7***
Porous Pavement (Acres of Impervious Surface Managed	Combined	-	3.4	-	*3.4*	-	3.4	-	*3.4*	-	3.4	-	*3.4*
	Creek	-	2.5	-	*2.5*	-	2.5	-	*2.5*	0.2	2.5	-	*2.7*
	Direct Discharge	-	4.5	-	*4.5*	-	4.5	-	*4.5*	-	4.5	-	*4.5*
	Subtotal	*-*	*10.4*	*-*	***10.4***	*-*	*10.4*	*-*	***10.4***	*0.2*	*10.4*	*-*	***10.6***
Bioretention (Acres of Impervious Surface Managed)	Combined	11.2	6.4	1.6	*19.1*	28.0	6.4	3.2	*37.5*	55.9	6.4	4.8	*67.0*
	Creek	4.6	4.6	0.0	*9.3*	11.6	4.6	0.0	*16.3*	23.2	4.6	0.1	*27.9*
	Direct Discharge	7.6	8.3	-	*15.9*	15.2	8.3	-	*23.5*	15.2	8.3	-	*23.5*
	Subtotal	*23.4*	*19.3*	*1.6*	***44.3***	*54.7*	*19.3*	*3.2*	***77.3***	*94.3*	*19.3*	*4.8*	***118.4***
Green Roof (Acres of Impervious Surface Managed)	Combined	-	0.4	-	*0.4*	-	0.4	-	*0.4*	-	0.4	-	*0.4*
	Creek	-	0.3	-	*0.3*	-	0.3	-	*0.3*	-	0.3	-	*0.3*
	Direct Discharge	-	0.5	-	*0.5*	-	0.5	-	*0.5*	-	0.5	-	*0.5*
	Subtotal	*-*	*1.2*	*-*	***1.2***	*-*	*1.2*	*-*	***1.2***	*-*	*1.2*	*-*	***1.2***
Downspout Disconnects (Acres of Impervious Surface Managed)	Combined	-	10.3	-	*10.3*	-	10.3	-	*10.3*	-	10.3	-	*10.3*
	Creek	-	18.5	-	*18.5*	-	18.5	-	*18.5*	-	18.5	-	*18.5*
	Direct Discharge	-	42.9	-	*42.9*	-	42.9	-	*42.9*	-	42.9	-	*42.9*
	Subtotal	*-*	*71.7*	*-*	***71.7***	*-*	*71.7*	*-*	***71.7***	*-*	*71.7*	*-*	***71.7***
Rainwater Harvesting (Acres of Impervious Surface Managed)	Combined	-	0.4	0.2	*0.6*	-	0.4	0.5	*0.9*	-	0.4	0.7	*1.1*
	Creek	-	0.3	0.0	*0.3*	-	0.3	0.0	*0.3*	-	0.3	0.0	*0.3*
	Direct Discharge	-	0.5	-	*0.5*	-	0.5	-	*0.5*	-	0.5	-	*0.5*
	Subtotal	*-*	*1.2*	*0.2*	***1.4***	*-*	*1.2*	*0.5*	***1.6***	*-*	*1.2*	*0.7*	***1.9***

Figure B-2. Volume of Stormwater Managed (per year) for Annual Increases in GSI (through 2050) for Each Build-Out Scenario, in Each Basin

		Millions of Gallons Managed per Year by Build-out GSI 2013-2050											
		Low				Medium				High			
		ROW	Code	RainWise	Subtotal	ROW	Code	RainWise	Subtotal	ROW	Code	RainWise	Subtotal
Trees	Combined	0.2	0.9	-	*1.0*	0.3	0.9	-	*1.2*	0.5	0.9	-	*1.3*
	Creek	0.1	0.6	-	*0.7*	0.2	0.6	-	*0.8*	0.2	0.6	-	*0.9*
	Direct Discharge	0.3	1.1	-	*1.4*	0.5	1.1	-	*1.7*	0.8	1.1	-	*1.9*
	Subtotal	*0.5*	*2.6*	*-*	***3.1***	*1.0*	*2.6*	*-*	***3.6***	*1.5*	*2.6*	*-*	***4.1***
Porous Pavement	Combined	-	1.8	-	*1.8*	-	1.8	-	*1.8*	-	1.8	-	*1.8*
	Creek	-	1.3	-	*1.3*	-	1.3	-	*1.3*	0.1	1.3	-	*1.4*
	Direct Discharge	-	2.4	-	*2.4*	-	2.4	-	*2.4*	-	2.4	-	*2.4*
	Subtotal	*-*	*5.5*	*-*	***5.5***	*-*	*5.5*	*-*	***5.5***	*0.1*	*5.5*	*-*	***5.6***
Bioretention	Combined	7.0	4.0	1.0	*11.9*	17.4	4.0	2.0	*23.4*	34.8	4.0	3.0	*41.8*
	Creek	2.9	2.9	0.0	*5.8*	7.2	2.9	0.0	*10.1*	14.4	2.9	0.0	*17.4*
	Direct Discharge	4.7	5.2	-	*9.9*	9.4	5.2	-	*14.6*	9.4	5.2	-	*14.6*
	Subtotal	*14.6*	*12.0*	*1.0*	***27.6***	*34.0*	*12.0*	*2.0*	***48.1***	*58.7*	*12.0*	*3.0*	***73.7***
Green Roof	Combined	-	0.1	-	*0.1*	-	0.1	-	*0.1*	-	0.1	-	*0.1*
	Creek	-	0.1	-	*0.1*	-	0.1	-	*0.1*	-	0.1	-	*0.1*
	Direct Discharge	-	0.1	-	*0.1*	-	0.1	-	*0.1*	-	0.1	-	*0.1*
	Subtotal	*-*	*0.2*	*-*	***0.2***	*-*	*0.2*	*-*	***0.2***	*-*	*0.2*	*-*	***0.2***
Downspout Disconnects	Combined	-	0.6	-	*0.6*	-	0.6	-	*0.6*	-	0.6	-	*0.6*
	Creek	-	0.4	-	*0.4*	-	0.4	-	*0.4*	-	0.4	-	*0.4*
	Direct Discharge	-	0.7	-	*0.7*	-	0.7	-	*0.7*	-	0.7	-	*0.7*
	Subtotal	*-*	*1.7*	*-*	***1.7***	*-*	*1.7*	*-*	***1.7***	*-*	*1.7*	*-*	***1.7***
Rainwater Harvesting	Combined	-	0.1	0.0	*0.2*	-	0.1	0.1	*0.2*	-	0.1	0.1	*0.2*
	Creek	-	0.1	0.0	*0.1*	-	0.1	0.0	*0.1*	-	0.1	0.0	*0.1*
	Direct Discharge	-	0.2	-	*0.2*	-	0.2	-	*0.2*	-	0.2	-	*0.2*
	Subtotal	*-*	*0.4*	*0.0*	***0.4***	*-*	*0.4*	*0.1*	***0.5***	*-*	*0.4*	*0.1*	***0.5***
	Total	***15.0***	***20.8***	***1.1***	***36.9***	***35.0***	***20.8***	***2.1***	***58.0***	***60.2***	***20.8***	***3.2***	***84.2***

Figure B-3. Volume of Stormwater Managed (per year) in 2050 for Each Build-Out Scenario, in Each Basin

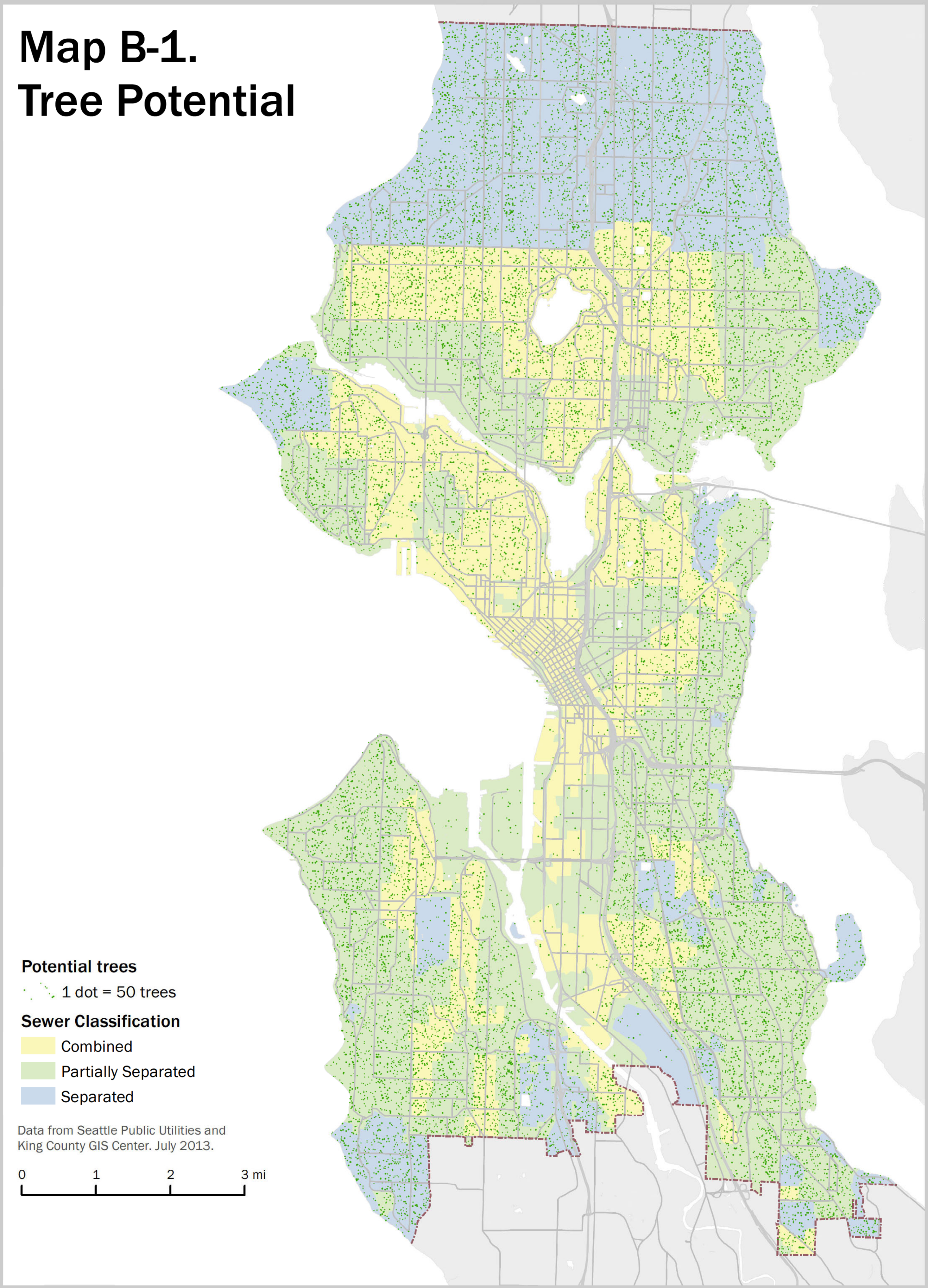
		Millions of Gallons Managed by Build-out GSI through 2050											
		Low				Medium				High			
		ROW	Code	RainWise	Subtotal	ROW	Code	RainWise	Subtotal	ROW	Code	RainWise	Subtotal
Trees	Combined	5.7	32.3	-	38.0	11.4	32.3	-	43.7	17.1	32.3	-	49.4
	Creek	2.8	23.5	-	26.3	5.6	23.5	-	29.1	8.4	23.5	-	31.9
	Direct Discharge	9.6	42.1	-	51.7	19.2	42.1	-	61.3	28.8	42.1	-	70.9
	Subtotal	*18.1*	*97.9*	-	***116.0***	*36.2*	*97.9*	-	***134.1***	*54.3*	*97.9*	-	***152.2***
Porous Pavement	Combined	-	67.7	-	67.7	-	67.7	-	67.7	-	67.7	-	67.7
	Creek	-	49.2	-	49.2	-	49.2	-	49.2	3.4	49.2	-	52.7
	Direct Discharge	-	88.2	-	88.2	-	88.2	-	88.2	-	88.2	-	88.2
	Subtotal	-	*205.2*	-	***205.2***	-	*205.2*	-	***205.2***	*3.4*	*205.2*	-	***208.6***
Bioretention	Combined	257.5	146.9	36.8	441.2	643.7	146.9	73.6	864.3	1,287.4	146.9	110.5	1,544.8
	Creek	106.8	106.9	0.5	214.2	267.0	106.9	1.1	374.9	534.0	106.9	1.6	642.4
	Direct Discharge	174.5	191.5	-	365.9	348.9	191.5	-	540.4	348.9	191.5	-	540.4
	Subtotal	*538.7*	*445.2*	*37.3*	***1,021.3***	*1,259.6*	*445.2*	*74.7*	***1,779.6***	*2,170.3*	*445.2*	*112.0*	***2,727.6***
Green Roof	Combined	-	2.8	-	2.8	-	2.8	-	2.8	-	2.8	-	2.8
	Creek	-	2.0	-	2.0	-	2.0	-	2.0	-	2.0	-	2.0
	Direct Discharge	-	3.7	-	3.7	-	3.7	-	3.7	-	3.7	-	3.7
	Subtotal	-	*8.5*	-	***8.5***	-	*8.5*	-	***8.5***	-	*8.5*	-	***8.5***
Downspout Disconnects	Combined	-	20.6	-	20.6	-	20.6	-	20.6	-	20.6	-	20.6
	Creek	-	15.0	-	15.0	-	15.0	-	15.0	-	15.0	-	15.0
	Direct Discharge	-	26.8	-	26.8	-	26.8	-	26.8	-	26.8	-	26.8
	Subtotal	-	*62.3*	-	***62.3***	-	*62.3*	-	***62.3***	-	*62.3*	-	***62.3***
Rainwater Harvesting	Combined	-	4.6	1.5	6.1	-	4.6	3.0	7.7	-	4.6	4.6	9.2
	Creek	-	3.4	0.0	3.4	-	3.4	0.0	3.4	-	3.4	0.1	3.4
	Direct Discharge	-	6.0	-	6.0	-	6.0	-	6.0	-	6.0	-	6.0
	Subtotal	-	*14.0*	*1.5*	***15.5***	-	*14.0*	*3.1*	***17.1***	-	*14.0*	*4.6*	***18.6***
	Total	***556.8***	***770.8***	***38.9***	***1,366.6***	***1,295.8***	***770.8***	***77.8***	***2,144.5***	***2,228.0***	***770.8***	***116.7***	***3,115.6***

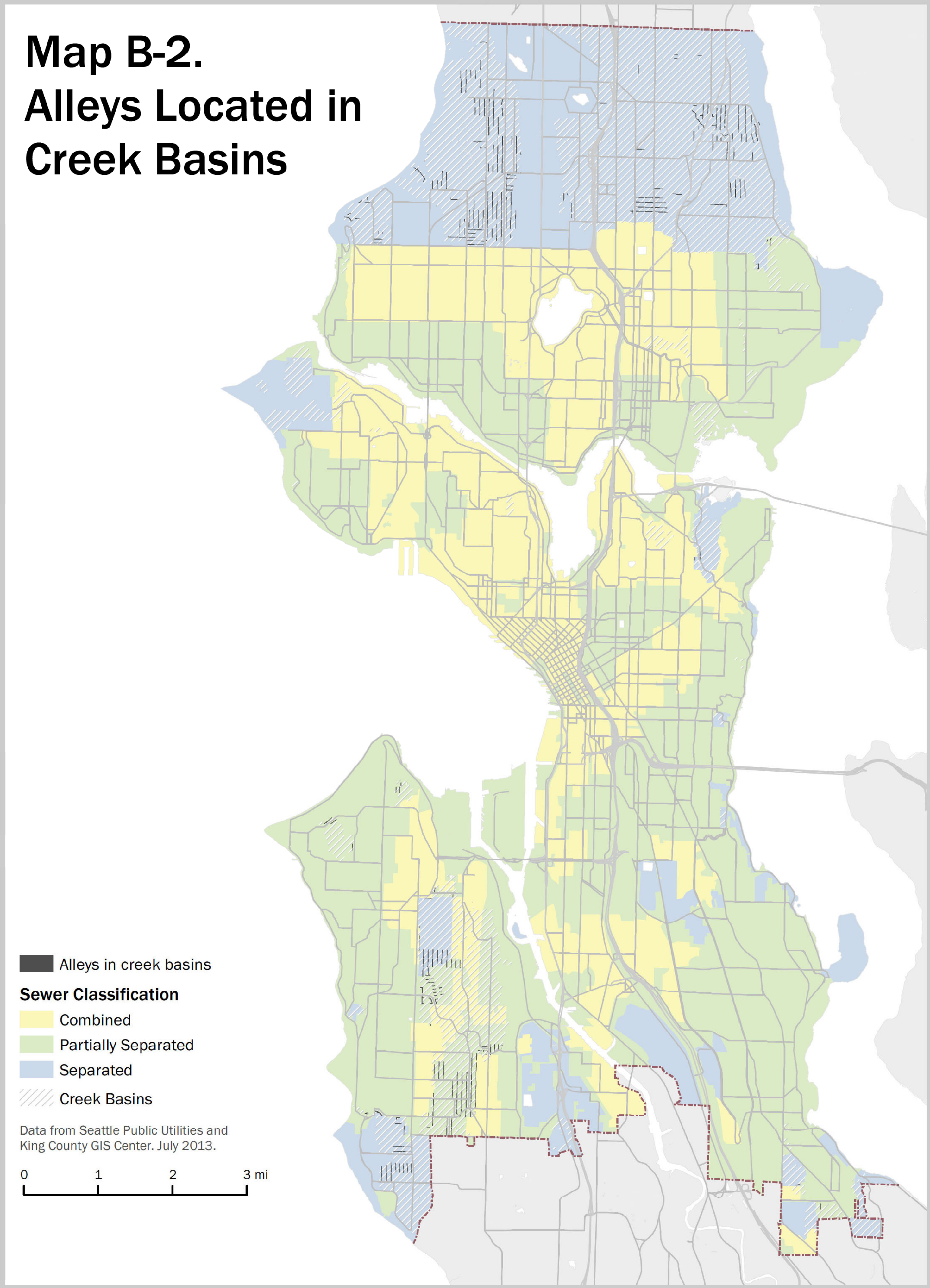
The following maps summarize some of the spatial components of the assumptions used to develop the three build-out scenarios. Table B-14 identifies all of the maps included at the end of this appendix.

Table B-14. Maps in this Appendix

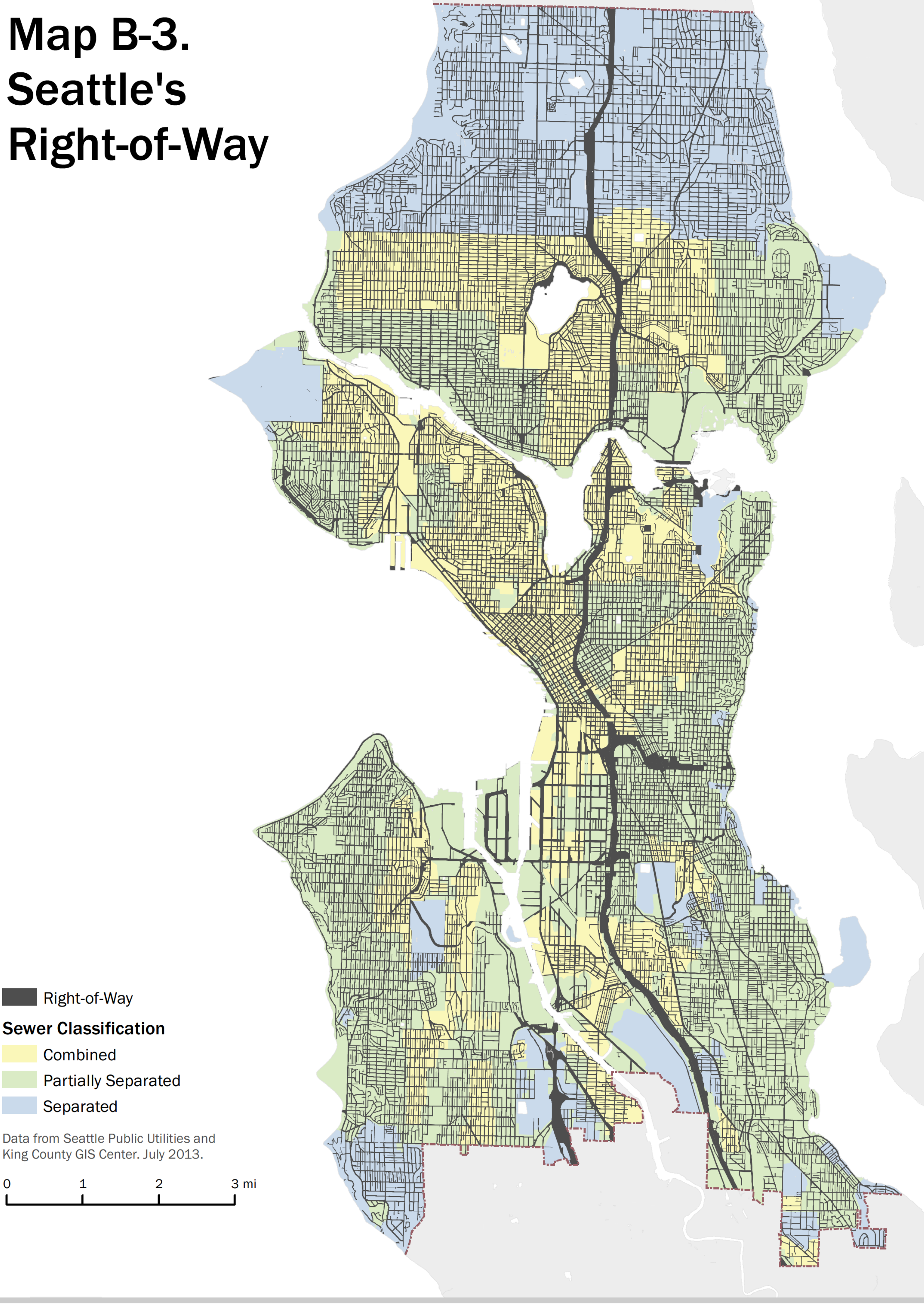
Map Title	Map Description
Map B-1. Tree Potential	This map shows all of the areas with the capacity to support new trees in the future.
Map B-2. Seattle's Alleys	This map shows all of the City's alleys. Some of the build-out scenarios rely on effort to install permeable pavement in some of these alleys.
Map B-3. Seattle's Right-of-way	This map shows all of the City's right-of-way areas.
Map B-4. Areas Suitable for Infiltration	This map shows all of the land in the City that is suitable for infiltration.
Map B-5. Development Rates	This map provides an illustrative example of redevelopment to shed light on the extent of the 1% redevelopment per year assumption used in the analysis. The map shows all parcels in Seattle. It also shows an area that represents 1% of those parcels (the amount assumed to be redeveloped each year), as well as an area that represents 37% of those parcels (the amount assumed to be redeveloped by 2050). This map is for illustrative purposes only and does not represent actual anticipated redevelopment in any specific areas within Seattle.
Map B-6. RainWise Basins	This map shows the RainWise Basins used in the analysis.

Map B-1. Tree Potential



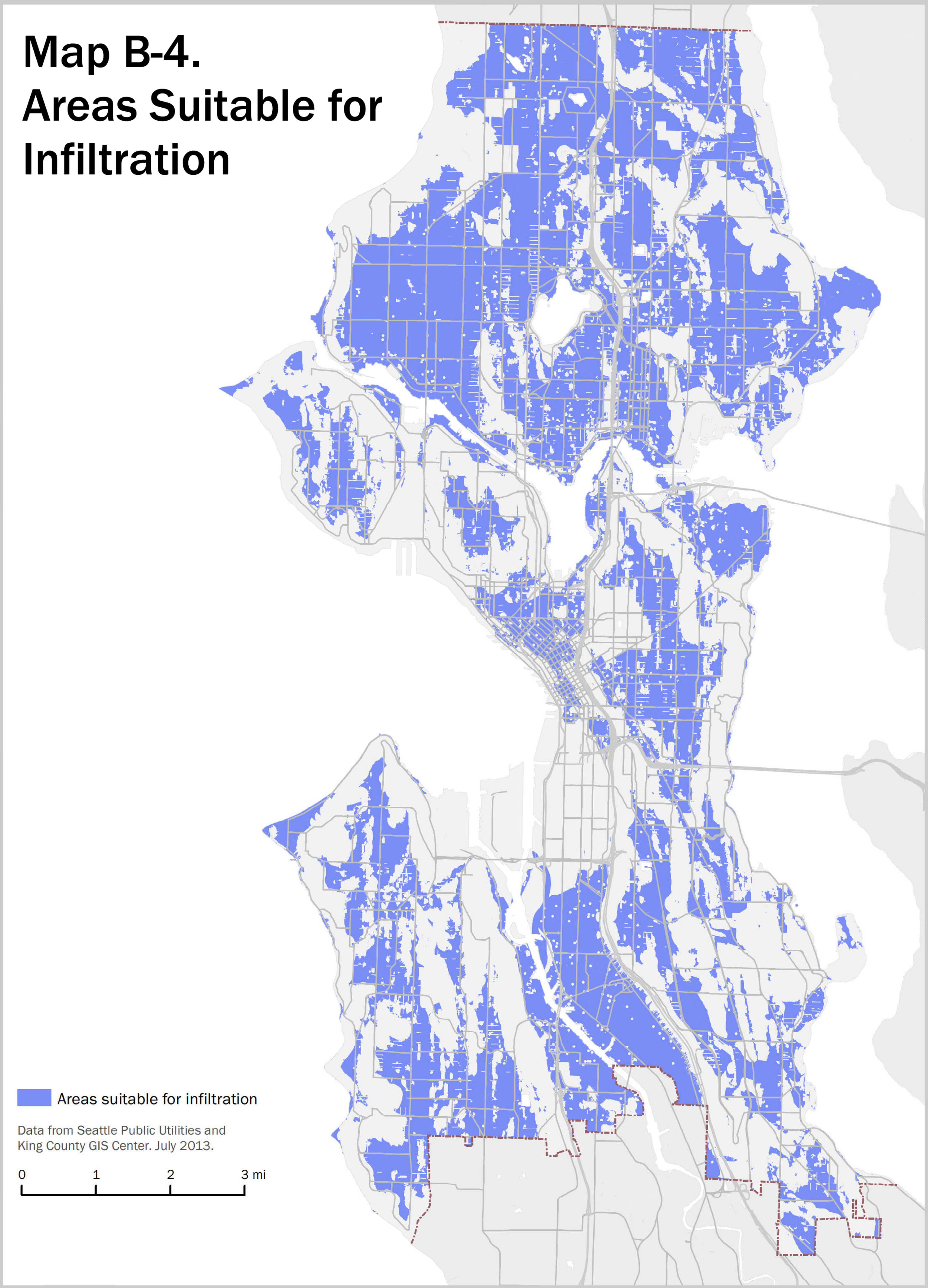

Map B-2.
Alleys Located in Creek Basins
Alleys in creek basins
Sewer Classification
Combined
Partially Separated
Separated
Creek Basins
Data from Seattle Public Utilities and King County GIS Center. July 2013.
0
1
2
3 mi

Map B-3. Seattle's Right-of-Way

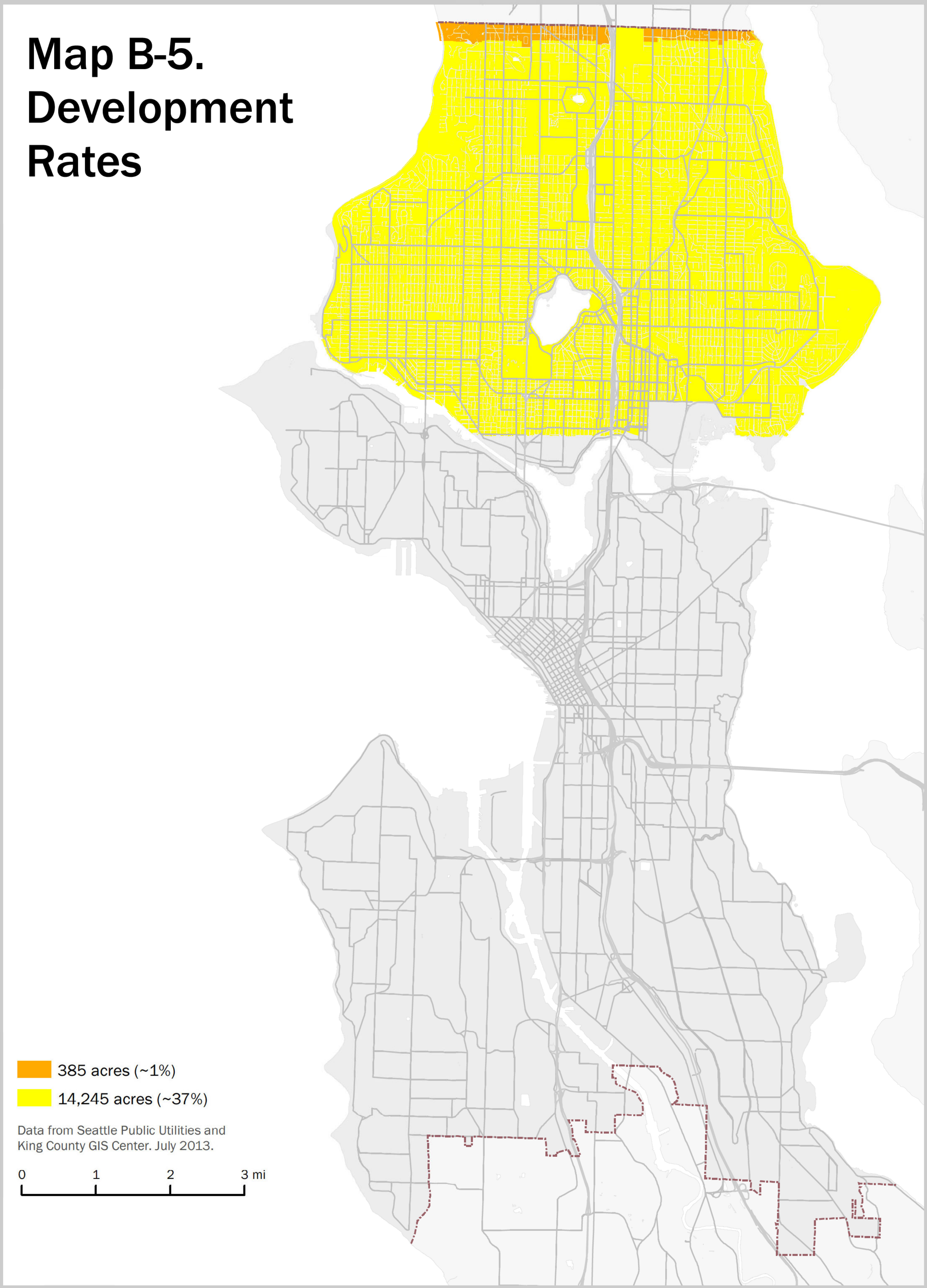


Data from Seattle Public Utilities and King County GIS Center. July 2013.

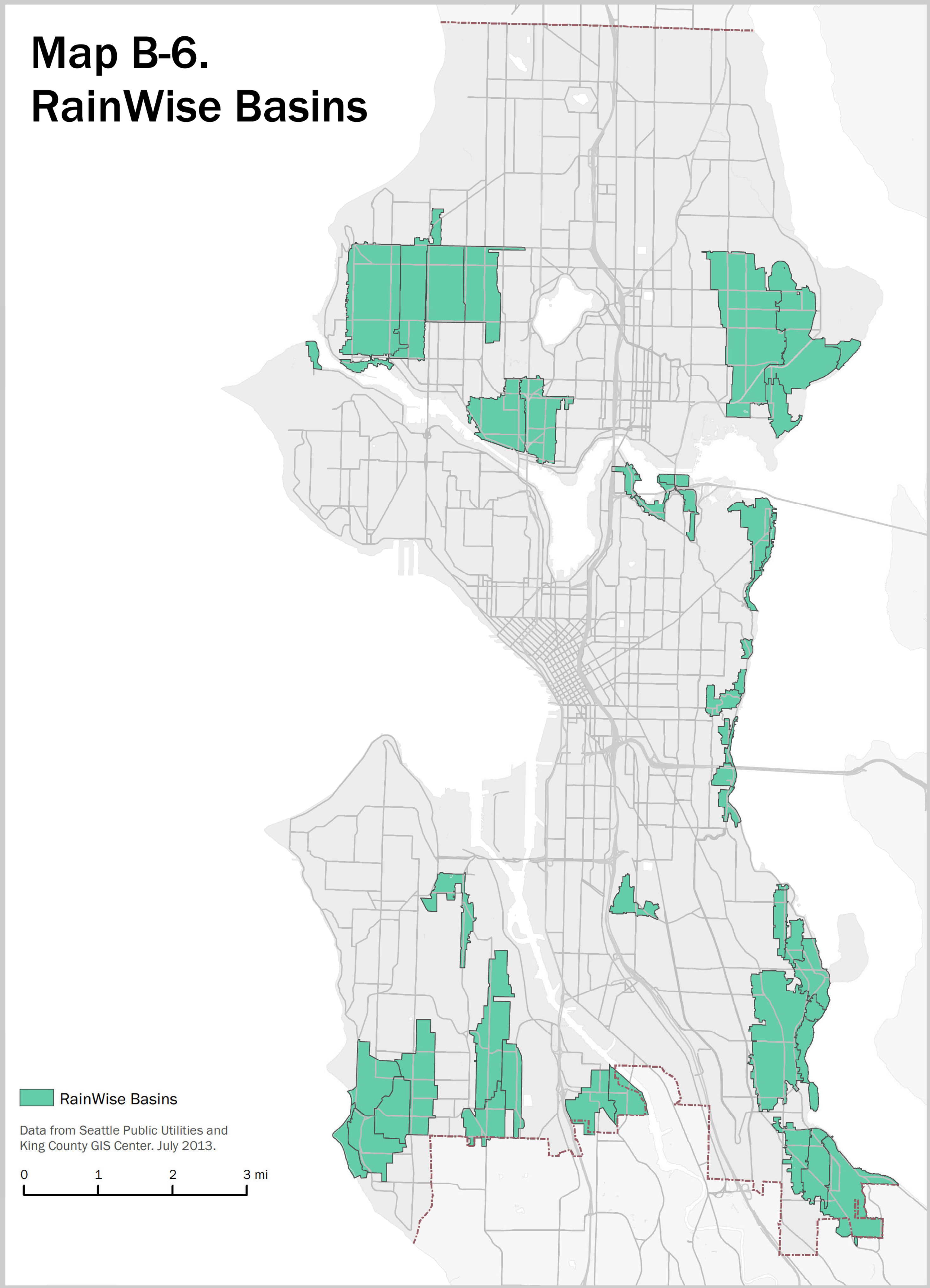
Map B-4. Areas Suitable for Infiltration



Map B-5. Development Rates



Map B-6. RainWise Basins



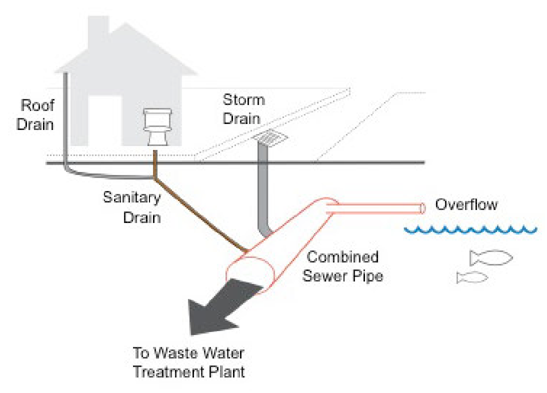
Appendix C. Seattle's Sewer System

This report refers to several different sewer basins, and the economic analysis relies heavily on tracking stormwater as it travels through Seattle's sewer system. In this appendix, Seattle's sewer system is described in order to provide a thorough context within which to consider the results and to interpret the analysis and methods. Figure C-1 describes the evolution of Seattle's sewer system. Put simply, the system evolved from a system relying on combined sewer pipes (which manage stormwater and wastewater) to a system relying on combined sewer pipes and stormwater pipes (which still combine stormwater and wastewater in some instances, but manage stormwater from certain locations separately).

Figure C-1. Evolution of Seattle's Sewer System

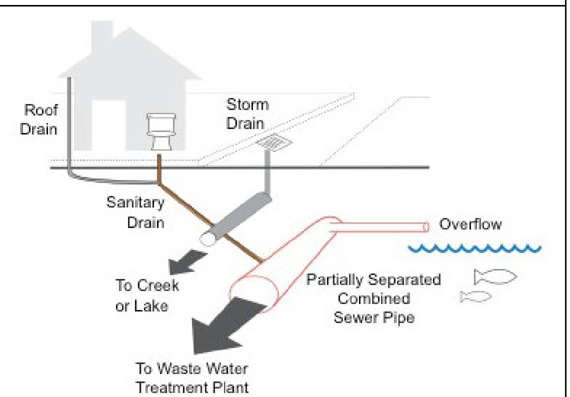
Combined Sewer System

Like most cities across the country, Seattle's original sewer system was a combined system in which stormwater and wastewater both flow to a combined sewer pipe. Currently several neighborhoods in Seattle rely on this combined sewer system for all their wastewater and stormwater management. After they combine in the combined sewer pipe, the system conveys this water to a wastewater treatment plant, where it is treated before entering nearby waterways. During large storm events, the system's capacity reaches its limits. In these instances, some of the untreated water in the combined sewer pipe is discharged directly into nearby waterways (these discharges are referred to as CSO events).



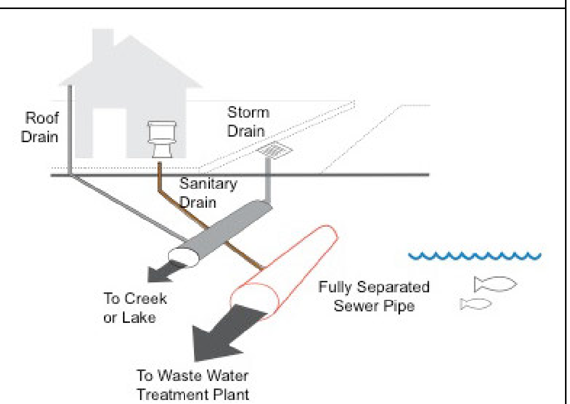
Partially Separated Sewer System

In the 1960s and 1970s, Seattle and other cities across the country became concerned with how their combined sewer systems were affecting water quality. In an attempt to reduce the stress on the combined sewer system, Seattle implemented efforts to divert stormwater flow from storm drains to a separate sewer system. This separate sewer system does not flow to the wastewater treatment plant, but rather flows directly into nearby waterways. Wastewater and stormwater from roof drains still flow to the combined sewer pipe, but all stormwater flowing into storm drains flows to stormwater pipes.



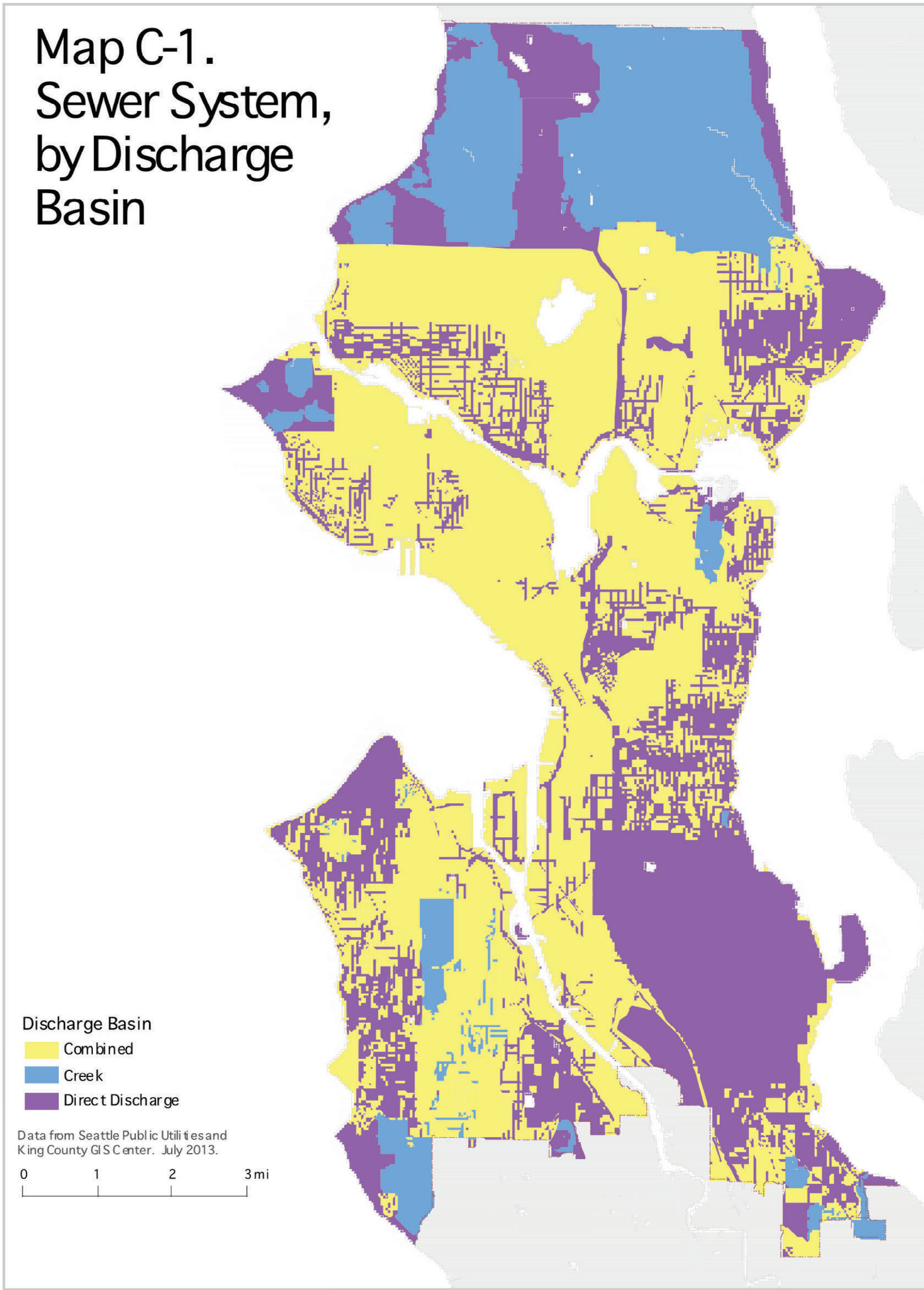
Fully Separated Sewer System

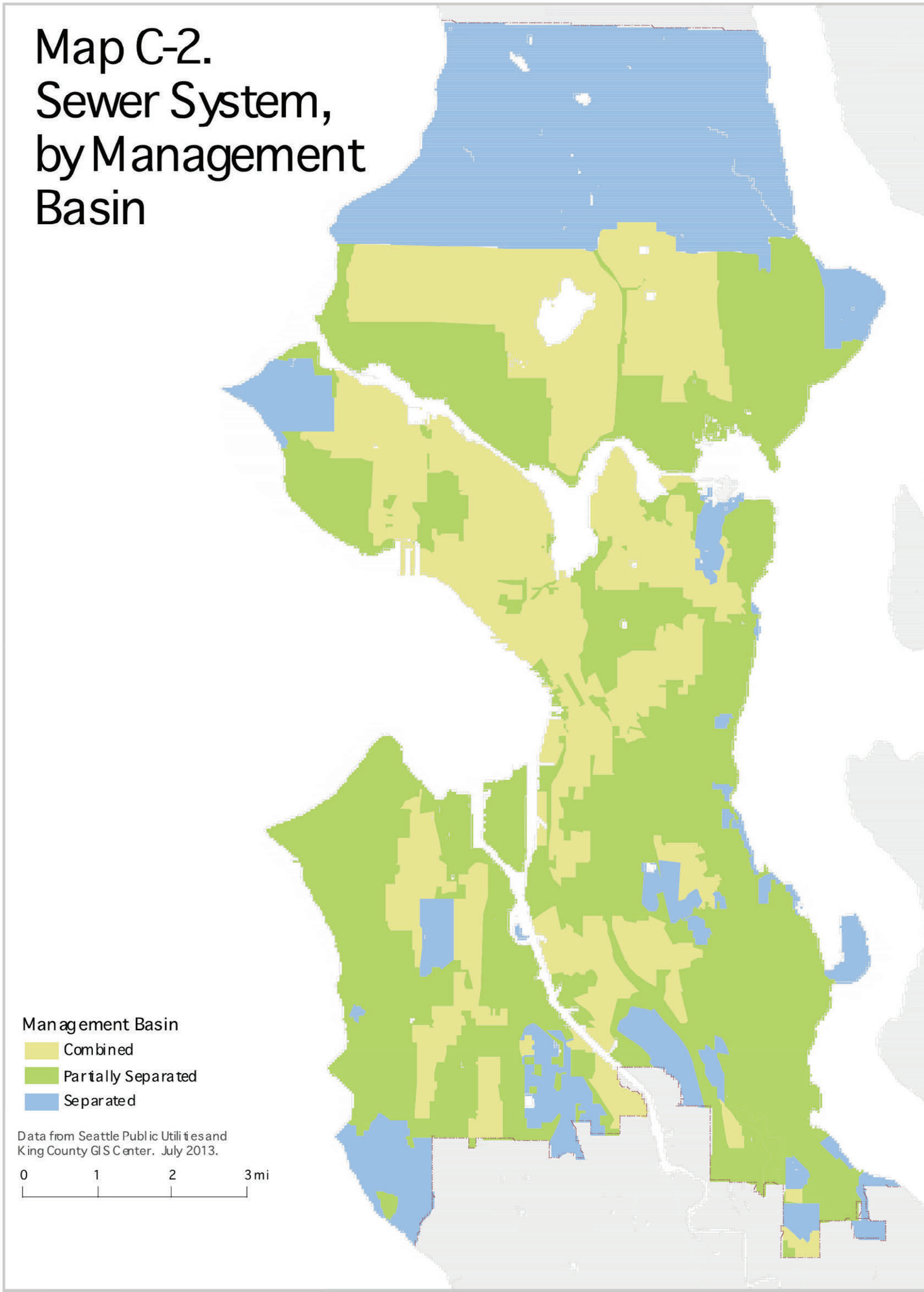
Recently, Seattle and other cities across the country have expanded the concept of the partially separated sewer system. In the fully separated sewer system, all stormwater (i.e., stormwater flowing into storm drains as well as stormwater flowing into roof drains) is directed toward stormwater pipes, and is completely diverted from the combined sewer system. This process further reduces stress on the combined sewer system, and helps reduce the frequency and magnitude of CSO events. By diverting this stormwater, however, the fully separated sewer system increases the volume of untreated stormwater runoff entering nearby waterways.



To demonstrate how these three approaches to stormwater management interact, it is useful to look at the system in spatial terms. Map C-1 shows the City's sewer system in terms of where stormwater flows. The solid yellow areas represent parts of the City that still rely entirely on the combined sewer system for their stormwater and wastewater management. The solid blue and purple areas represent parts of the City in which the fully separated approach has been implemented. Wastewater in these areas enters the combined sewer system, and stormwater enters the separate sewer pipes that discharge stormwater directly into nearby waterways. Some areas on the map have a yellow base along with a blue or purple grid. These areas represent parts of the City in which the partially separated approach has been implemented. Wastewater in these areas enters the combined sewer system. Stormwater falling on parcels (e.g., residential and commercial roofs) flows into the combined sewer system as well. Stormwater falling on the right-of-way (e.g., roads) flows into stormwater pipes and is discharged directly into nearby waterways. Map C-2 shows a higher-level representation of these three approaches to sewer system design.

Depending on where GSI facilities are located, they will have different effects on stormwater management. GSI facilities placed in the combined sewer basin will reduce stormwater flows into the combined system. GSI facilities placed in the fully separated sewer basin will reduce the volume of untreated stormwater flowing directly into nearby waterways through stormwater pipes. GSI facilities in the partially separated sewer basin will do one or the other depending on whether they are place on parcels or in the right-of-way.

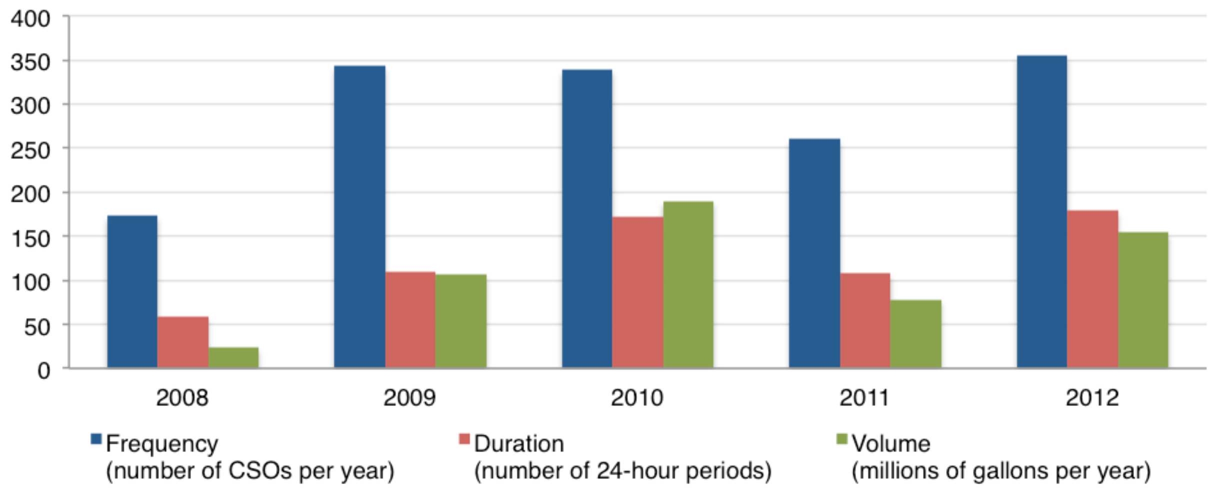

Map C-1.
Sewer System,
by Discharge
Basin
Discharge Basin
Combined
Creek
Direct Discharge
Data from Seattle Public Utilities and
King County GIS Center. July 2013.
0
1
2
3 mi


Map C-2.
Sewer System, by Management Basin
Management Basin
Combined
Partially Separated
Separated
Data from Seattle Public Utilities and King County GIS Center. July 2013.
0
1
2
3 mi

Appendix D. Combined Sewer Overflows

Combined sewer overflows (CSOs) occur when the volume of water entering the combined sewer system exceeds the system's capacity. When this happens, untreated water from the combined sewer system is removed from the system through one of 92 CSO outfalls. This untreated water then flows into nearby waterways. According to the 2010 CSO Reduction Plan, Seattle's CSO volumes have declined since the 1980s, when they averaged about 400 million gallons (and about 2,800 CSO events) per year.[112] The goal of the plan, however, is to achieve an average of no more than one CSO event per outfall per year.[113] Figure D-1 demonstrates the frequency, duration, and volume of Seattle's CSO events from 2008 to 2012. The figure does not reflect the decline in frequency, duration, and volume of CSO events since the 1980s. It does, however, show that more action is needed to meet SPU's goal of no more than one CSO event per outfall per year.

Figure D-1. Seattle's CSO Events (2008–2012)



Source: Seattle Public Utilities. 2013. *2012 Annual Report CSO Reduction Program*. March.

GSI can help reduce the frequency and volume of CSO events by managing some of the stormwater that would have entered the combined sewer system. Because it can reduce the frequency and volume of CSO events, GSI provides two types of benefits. One of these benefits represents the avoided costs of dealing with a CSO event once it has happened. The other benefit represents the avoided costs of relying solely on gray infrastructure techniques for managing stormwater.

Valuation Methodology

Data are not sufficient to quantify the extent to which the existing inventory or potential build-out of GSI facilities reduce the frequency and magnitude of CSO events. Furthermore, the potential costs of future CSOs (and the avoided costs of preventing those CSOs) are context specific, and are difficult to accurately quantify. The methodological approach to considering the benefits of GSI-related CSO reductions relies on an avoided cost approach. Several potential costs associated with CSO events in the

[112] Seattle Public Utilities. 2010. *2010 CSO Reduction Plan* Amendment. May. Pg. 3-2.

[113] Seattle Public Utilities. 2010. *2010 CSO Reduction Plan* Amendment. May. Pg. 1-1.

future are identified and used as a proxy to estimate the value of the benefits of reducing future CSO events.

Review and Analysis

This section presents a brief outline of how to consider two types of costs associated with reducing the frequency and magnitude of CSO events: (1) ex post costs of CSO events, and (2) costs of preventing CSOs.

Ex post costs of CSO events

The 2010 CSO Reduction Plan contains a goal of reducing the frequency of CSO events in Seattle to no more than one per CSO outfall per year. The reason that Seattle and other communities across the country are trying to reduce the frequency of CSO events is because of the costs that materialize in their aftermath. CSO events release untreated wastewater and stormwater into waterways. Described below are two mechanisms through which these biophysical effects turn into economic costs.

- Stormwater management agencies often face fines or penalties for allowing CSO events to occur or for failing to comply with the relevant permits and procedures. For example, the Washington Department of Ecology fined King County $46,000 in 2010 for failing to comply with CSO-related water quality permits. [114] Ecology also fined Seattle $12,000 in 2007 for a CSO event caused by a pump failure.[115]
- By diverting untreated wastewater and stormwater into nearby waterways, CSO events decrease water quality in those waterways. Decreasing water quality is costly for a number of reasons. Most directly, it can restrict access to certain uses (e.g., swimming or fishing). More indirectly, it can harm the aquatic ecosystem, from which people derive a number of valuable benefits.

Past penalties. Earlier in 2013, after settlement discussions with the U.S. Department of Justice and EPA, the city of Seattle and King County agreed to provide funding for major upgrades to their combined sewer system.[116] Between 2006 and 2010, King County discharged about 900 million gallons of raw sewage into nearby waterways, and between 2007 and 2010, the Seattle discharged another 200 million gallons of raw sewage into nearby waterways. These discharges violated section 301 of the Clean Water Act as well as other agreements and regulations. As a result, the county was fined a civil penalty of $400,000 and the city was fined a civil penalty of $350,000. The county and city also agreed to implement long-term control plans for controlling CSO discharges in the coming years.

Potential future penalties. The city of Seattle's Consent Decree also identifies a number of penalties it may face if it fails to meet all of its conditions. For example, the city is liable to pay a penalty of $7,500 per day for each dry-weather CSO event and a penalty of $2,500 per day for each sewer overflow. There are a number of other per-day and per-violation penalties the city faces if it fails to meet the requirements set forth in the Consent Decree.[117] To some extent, implementing GSI efforts will help

[114] Washington Department of Ecology. 2010. *King County Fined for Combined Sewer Overflow Violation.* Retrieved on June 5, 2013 from *http://www.ecy.wa.gov/news/2010news/2010-139.html*.

[115] Washington Department of Ecology. 2007. *Seattle Fined for Sewage Discharge*. Retrieved on June 5, 2013 from *http://www.ecy.wa.gov/news/2007news/2007-212.html*.

[116] U.S. Environmental Protection Agency. 2013. *Seattle, Washington and King County, Washington Settlement*. Retrieved on June 7, 2013 from *http://www.epa.gov/enforcement/water/cases/washington.html*.

[117] Consent Decree, United States of America and the State of Washington v. the City of Seattle, Washington. April 16, 2013. Civil Action No. 2:13-cv-678. Retrieved on June 7, 2013 from *http://www.epa.gov/enforcement/water/documents/decrees/cityofseattlewashington-cd.pdf*.

prevent the city and county from violating the requirements of the Consent Decree, and in doing so, will provide valuable benefit equal to the costs of the penalties avoided.

Total cost of potential future penalties. From 2008 to 2012, there was an average of 294 CSO events per year. Each CSO event lasted an average of 10 hours. Combined, these CSO events lasted a total of 125, 24-hour periods per year, and discharged an average of 111 million gallons of untreated water per year. As previously stated, the Consent Decree will institute a penalty of $2,500 per day for wet-weather CSO events and $7,500 per day for dry-weather CSO events. Assuming that these penalties can serve as a proxy for the costs (or forgone benefits) society incurs due to CSO events, they can be applied to average annual frequency of CSO events, and project those values into the future. The full range of these costs is about $0.3–$2.2 million per year.[118] Assuming no change in CSO frequency or duration, the 100-year NPV of these CSO costs, discounted at a rate of 2%, is about $13.8–$96.9 million. To the extent that GSI can be used to decrease the frequency and duration of these future CSO events, it can provide a valuable benefit equal to the value of the avoided penalty costs.

In reality, however, if SPU implements no additional stormwater management efforts, the frequency and duration of CSO events will increase in the future when faced with increased urbanization and increased precipitation related to climate change. This potential increase in frequency and duration of CSO events suggests that the 100-year NPVs presented above likely understate the total costs. Furthermore, since the estimates are based on penalty values, they likely understate the actual costs associated with CSO events. To the extent that GSI efforts undertaken under the build-out scenarios decrease the frequency and duration of CSO events in the future, they can reduce the total value of these costs.

Costs of preventing future CSOs

As mentioned above, the 2010 CSO Reduction Plan contains a goal of reducing the frequency of CSO events in Seattle to no more than one per CSO outfall per year. To meet that challenge, agencies will implement a broad range of BMPs (both GSI and gray infrastructure). The 2010 CSO Reduction Plan identified and described 16 CSO control projects that could support the objective of reducing CSO frequency. These projects are listed below.

- Windermere
- Genesee
- Henderson
- Ballard
- N. Union Bay
- Interbay
- Central Waterfront
- Fremont/Wallingford
- Duwamish
- Longfellow/Delridge
- West Seattle
- Montlake
- Leschi
- Union Bay
- East Waterway
- Lake Union/Portage Bay

These CSO control projects vary in terms of complexity, and many of them included multiple BMPs. Table D-1 summarizes these projects by the BMPs they implement. For each BMP, the table shows the number of projects implemented, the control volume, and the estimated cost. In total, these CSO control projects would cost about $330 million and would control a total of about 20.5 million gallons of stormwater. Given the large amount of uncertainty regarding these costs, the 2010 CSO Reduction Plan also provided a range of potential costs from about $182 million to $627 million. The plan relies heavily on offline storage. This BMP accounts for about 79% of total control volume and about 85% of total cost.

[118] The low end of the range represents the wet-weather CSO penalty ($2,500) times the average annual number of 24-hour CSO periods (125). The high end of the range represents the dry-weather CSO penalty ($7,500) times the average annual number of CSO events (294).

Table D-1. Summary of CSO Control Projects from 2010 CSO Reduction Plan

BMP	Number of Projects	Control Volume (gallons) | % of Total Volume	Estimated Cost | % of Total Cost
Downspout	20	831,000 | 4%	$3,270,000 | 1%
Cisterns	3	255,000 | 1%	$2,062,000 | < 1%
Bioretention	1	4,000 | < 1%	$74,000 | < 1%
Rain Gardens	9	460,000 | 2%	$4,718,000 | 1%
Permeable Pavement	2	138,000 | < 1%	$2,033,000 | < 1%
Inline Storage	8	1,677,000 | 8%	$23,881,000 | 7%
I/I Reduction	8	399,000 | 2%	$5,030,000 | 2%
Offline Storage	19	16,257,000 | 79%	$279,888,000 | 85%
Retrofit	4	484,000 | 2%	9,504,000 | 3%
Total	**74**	**20,505,000 | 100%**	**$330,460,000 | 100%**

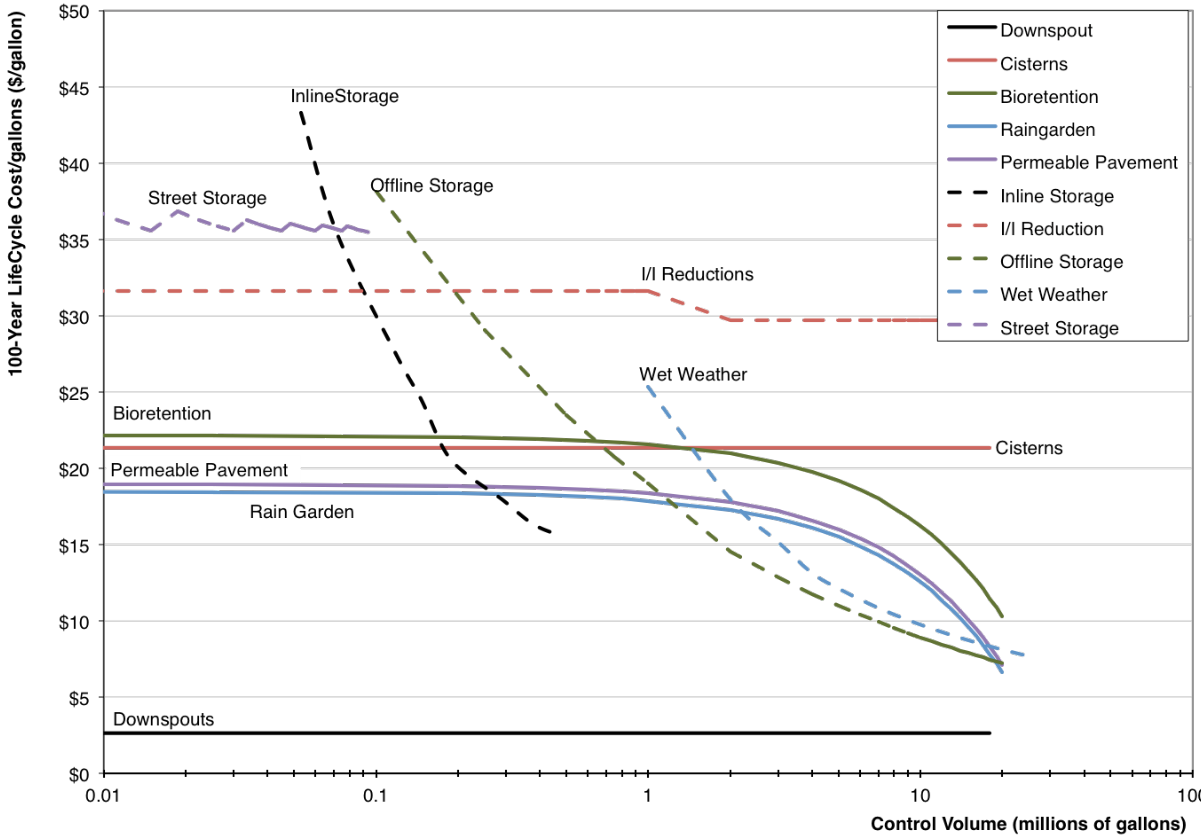
Source: Seattle Public Utilities. 2010. *2010 CSO Reduction Plan* Amendment. May. Pg. 5-14 – 5-18.

Average cost of BMP installation. Figure D-2 shows the average costs used to develop the CSO Reduction Plan and to estimate the costs of implementation. Each line shows the per-gallon cost of installing different BMPs in terms of the total size of the installation. The costs represent the 100-year lifecycle costs, which include construction costs and ongoing operations and maintenance costs. For example, a 100,000-gallon inline storage facility has a 100-year lifecycle cost of about $32 per gallon, while a 200,000-gallon inline storage facility has a 100-year lifecycle cost of about $18 per gallon.

In general, per-gallon costs decrease as the control volume increases. The main exception is disconnecting downspouts, which has a lifecycle cost of about $3 per gallon regardless of control volume. For smaller projects (less than 0.1 million gallons), several GSI BMPs offer lower lifecycle costs than gray alternatives. For example, rain gardens, permeable pavement, and bioretention cost between $18 and $23 per gallon for projects controlling less than 0.1 million gallons while other BMPs (e.g., street storage, inline storage, offline storage, and I/I reductions) are either costlier or not feasible at such small scales. For larger projects (around 1 million gallons), the lifecycle costs of implementing many different BMPs converge. In addition to cost, however, a number of factors influence these kinds of planning efforts. One of the most influential factors is feasibility. If it were possible to meet management objectives by relying solely on downspout disconnects, then agencies would not consider the other, costlier BMPs. In reality, however, the control potential for downspout disconnects is limited.

BMP selection. The process of selecting a portfolio of BMPs is best demonstrated through an example. Assuming that the objective is to control 10 million gallons of stormwater in a particular area, planning efforts must first evaluate the extent of each BMP's feasibility (e.g., What is the total feasible control volume supported by downspout disconnects, offline storage, or other measures?). Since downspout disconnects are always the least expensive option, they should be implemented wherever feasible (i.e., wherever there are downspouts to disconnect). After that, it comes down to feasibility. From a cost perspective, planners should implement the cheapest combination of BMPs that align with the feasibility of their installation within the project area. This approach may mean one large gray facility, several small GSI facilities, or something in between.

Figure D-2. Average Cost Curves for GSI and Gray Infrastructure BMPs



Source: Seattle Public Utilities. 2010. *2010 CSO Reduction Plan* Amendment. May. Pg. 5-12.
Notes: This figure shows the average cost for installing different types of BMPs based on the size of the BMP. The average costs are for single facilities, so rather than accumulating along the x-axis, new projects must begin at the left side of the figure.

Summary and Distribution

In this section, two types of benefits associated with reducing the frequency and magnitude of CSO events were discussed. First discussed are CSO-related penalties that agencies will face in the future associated with the recent Consent Decree outlining future goals for stormwater management in Seattle. Data were not sufficient to quantify the extent to which the existing inventory of GSI or the GSI installed in the build-out scenarios can decrease the frequency or magnitude of CSO events. It is clear, however, that if GSI does decrease the frequency or magnitude of CSO events, there are real benefits in the form of avoided penalties. Second discussed are the costs associated with reducing/preventing future CSO events. Data from SPU offered average per-unit costs for both GSI BMPs and gray infrastructure techniques. In some instances, GSI BMPs offer cheaper solutions to increasing the capacity of the city's stormwater system. In these instances, GSI offers a benefit equal to the avoided cost of implementing costlier gray infrastructure. GSI may not be feasible in all cases, however, and a balanced approach (as indicated in SPU's 2010 CSO Reduction Plan) will be crucial in meeting future CSO-related objectives.

These benefits affect several groups in and out of Seattle. Within Seattle, agencies and utilities can benefit by reducing future CSO-related penalties and by minimizing infrastructure costs. These benefits have the capacity to filter through to ratepayers in the form of decreased utility rates. These benefits, however, go beyond those tied to financial transactions. To the extent other individuals in Seattle, across Washington, and across the country derive benefits from improved water quality, they too derive valuable benefits from reductions in the frequency and severity of CSO events.

Managing Interest Payments

Efforts aimed at curbing CSOs oftentimes require large capital costs, which are typically covered by bond revenues. SPU must pay interest on the value of these bonds. Currently, SPU has high ratings for its Water and Drainage and Wastewater bonds by both Standard and Poor's (AA+) and Moody's (Aa1), which means that the interest rates SPU pays are relatively low. In its 2013 proposed budget, SPU indicates that interest payments will account for 15% of its expenditures, and that capital costs will account for another 20% of expenditures. Typically, these interest payments filter through to property owners or ratepayers depending on how the bonds are issued. The higher the interest rates, the larger the impact on property owners and ratepayers.

Minimizing the need for large infrastructure projects can reduce the burden of interest payments on SPU's annual budget and can lead to real savings for property owners and ratepayers. The Federal Reserve Bank of St. Louis tracks state and local bond rates through its Bond Buyer Go 20-Bond Municipal Bond Index (WSLB20). The figure below shows how the index has changed since the 1960s. Current bond rates are on the low end of the range over the past 50 years.

Sources: Hoffman, R. No Date. *Seattle Public Utilities Proposed Budget 2013*. Retrieved on July 3, 2013 from www.seattle.gov/financedepartment/13proposedbudget/documents/SPU_373_376.pdf; Federal Reserve Bank of St. Louis. 2013. *State and Local Bonds – Bond Buyer Go 20-Bond Municipal Bond Index*. Retrieved on July 3, 2013 from http://research.stlouisfed.org/fred2/graph/?s[1][id]=WSLB20.

Appendix E. Sanitary Sewer Overflows

Potential of Green Stormwater Infrastructure to Reduce Sanitary Sewer Overflows in the Ballard CSO Basin

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DATE: August 7, 2013

PROJECT NUMBER: 464422

1.0 Purpose

The purpose of this technical memorandum is to document the methodology and results of the analysis to estimate the effectiveness of Green Stormwater Infrastructure (GSI) in reducing Sanitary Sewer Overflows (SSOs) in the Ballard CSO Basin, both for current conditions and for future climate change conditions. This analysis was completed as part of the larger SPU GSI Program, one task of which is to quantify the indirect benefits of GSI.

2.0 Methodology

The first step in the analysis was to establish baseline conditions and alternative conditions in order to be able to compare the impacts of GSI on SSOs. The baseline conditions consisted of two scenarios; one with GSI implemented, and one without GSI implemented. The alternative conditions also consisted of two scenarios; one with GSI and climate change, and one without GSI but with climate change. These four scenarios made it possible to estimate the impact that climate change may have on SSOs, and GSI's ability to mitigate those impacts.

A 32-year long simulation was completed for each scenario in the calibrated Ballard CSO model. Table 1 presents a summary of the four scenarios. Table 2 presents the amounts of GSI included in each scenario. Because the model does not include all of the basin's side sewers and basement elevations, a surrogate for measuring potential SSO events was used. If the level in a maintenance hole reached within 6-feet of the ground elevation, the event was flagged as a potential SSO for further analysis. A 6-ft threshold was selected based on a previous study in the Broadview neighborhood that found the 6-foot assumption to be good estimate for basement depths within the basin.

Table 1. Summary of Modeled Scenarios

Scenario No.	Condition	Includes Climate Change?	Includes GSI?	Rainfall Scaling Factor
1	Baseline	No	No	1.0000
2	Baseline	No	Yes	1.0000
3	Future	Yes	No	1.0609
4	Future	Yes	Yes	1.0609

Table 2. Amount of GSI Modeled

Scenario No.	Roadside Raingardens (ac)	Green Alleys (ac)	Rainwise			Total (ac)	GSI Cost ($M)
			Raingardens (ac)	Raingardens in Partially Separated Areas (ac)	Cisterns (ac)		
1	0	0	0	0	0	0	$0
2	41.1	5.8	7.8	4.1	9.1	67.8	$18.9

3	0	0	0	0	0	0	$0
4	41.1	5.8	7.8	4.1	9.1	67.8	$18.9

In order to reduce model run times and to focus the results of the model, a subset of maintenance holes (MHs) and pipes were selected for inclusion in this analysis. These maintenance holes and pipes were selected based pipe surcharging from previous model simulations of the Ballard CSO Basin, which consisted of running 5-year simulations instead of 32-year simulations. Figure 1 presents an overview of the Ballard CSO Basin, and the maintenance holes and pipes included in the analysis.

3.0 Results

The result of each 32-year simulation was a list of MHs included in the analysis and the number of times the 6-ft threshold was exceeded. This list represents the number of potential SSO events at each MH during the 32-year period. Table 3 presents the average number of times per year the 6-ft threshold was exceeded for each of the four scenarios modeled. Figures 2 through 5 show the locations of threshold exceedances in the Ballard CSO Basin.

Table 3. Summary of Threshold Exceedances

Scenario No.	Average Number of Threshold Exceedances per Year
1	48.9
2	36.4
3	58.4
4	42.7

The number of threshold exceedances was then compared with actual reported SSO events in the Ballard basin in order to come up with a calibration factor that relates the number of threshold exceedances to the actual number of SSO events. This factor was needed because not all of the modeled threshold exceedances are actual SSO events. Based on conversations with SPU staff, it is estimated that approximately 5 SSO events are reported (not verified) in the Ballard basin per year (CH2M HILL, 2013). The discrepancy between the number of modeled threshold exceedances and actual reported SSO events is likely caused by many factors. For example, not all homes have basements, and those that do may have daylight basements or shallower basements, backflow preventers or elevated side sewers served by sump pumps, etc.. Other possible reasons include inherent limitations of the model, which was built and calibrated mainly to predict CSO events, and may not represent the individual contributions of blocks with as much accuracy. Because Scenario 1 represents current conditions (no GSI and no climate change), the calibration factor was calculated as follows based on Scenario 1:

5 SSO events/ 48.9 modeled threshold exceedances = 0.10 SSO events/modeled threshold exceedance

This calibration factor was then applied to the modeled threshold exceedances in order to come up with an estimated number of SSOs per year, as presented in Table 4.

Table 4. Estimated Number of SSOs per Year

Scenario No.	Estimated No. of SSO Events per Year
1	4.9
2	3.6
3	5.8
4	4.3

4.0 Discussion

Table 5 presents the estimated reduction in the number of SSO events for the two modeled conditions. The results indicate the GSI may reduce the number of SSO events in the Ballard CSO Basin by approximately 1.5 per year, or approximately 30%.

The next steps in this analysis will include quantifying the cost-savings of the reduction in SSO events due to implementing GSI.

Table 5. Reduction in Number of SSO Events

Condition	Scenarios Included	Reduction in No. of SSOs	% Reduction in No. of SSOs
Baseline	1 & 2	1.3	27%
Future	3 & 4	1.5	26%

5.0 References

CH2M HILL, 2013. Number of SSOs per Year in Ballard CSO Basin. 2013. Personal communication with Dave Jacobs/SPU. July 25, 2013.

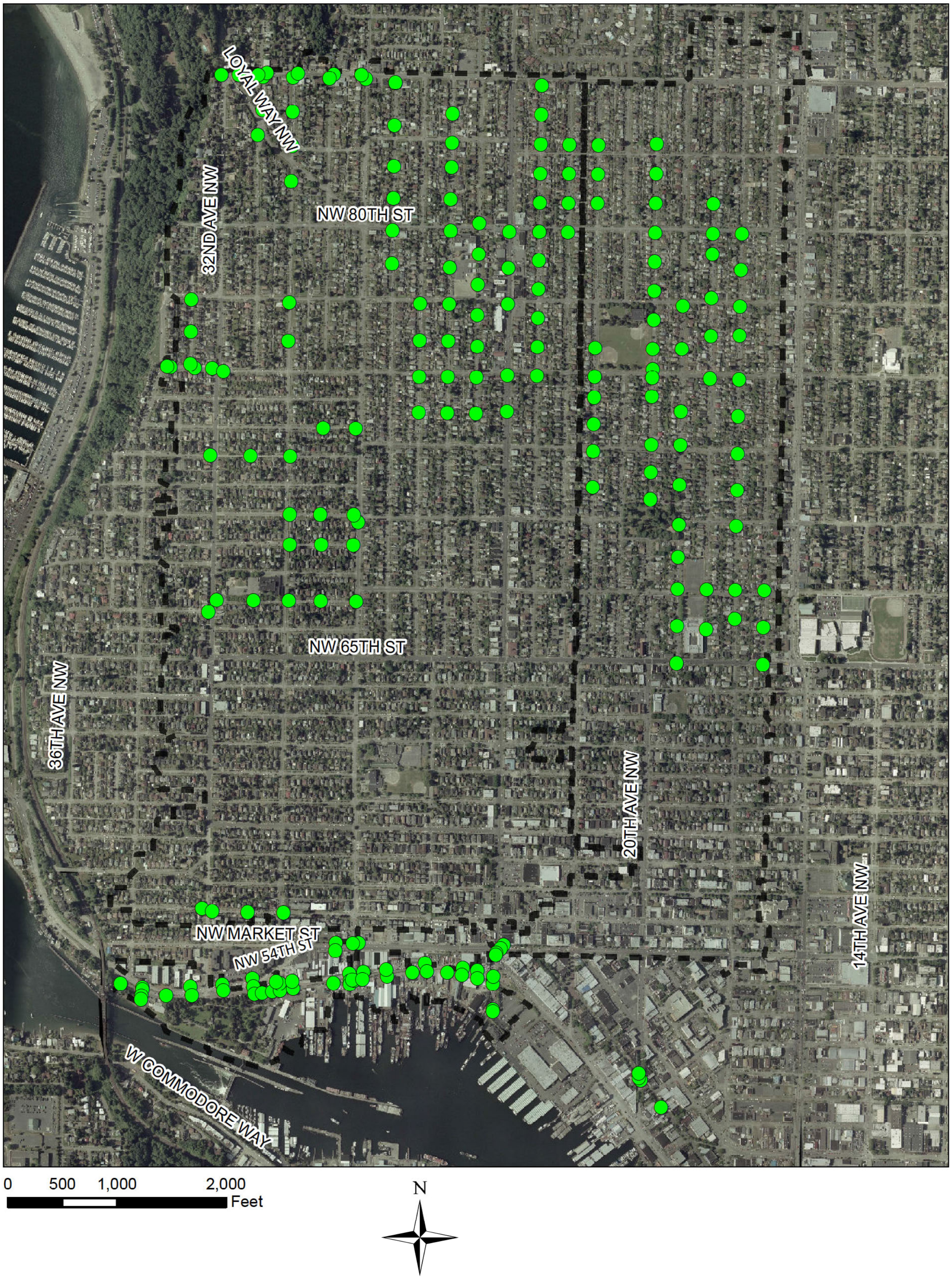

Figure 1

Ballard CSO Basin Overview

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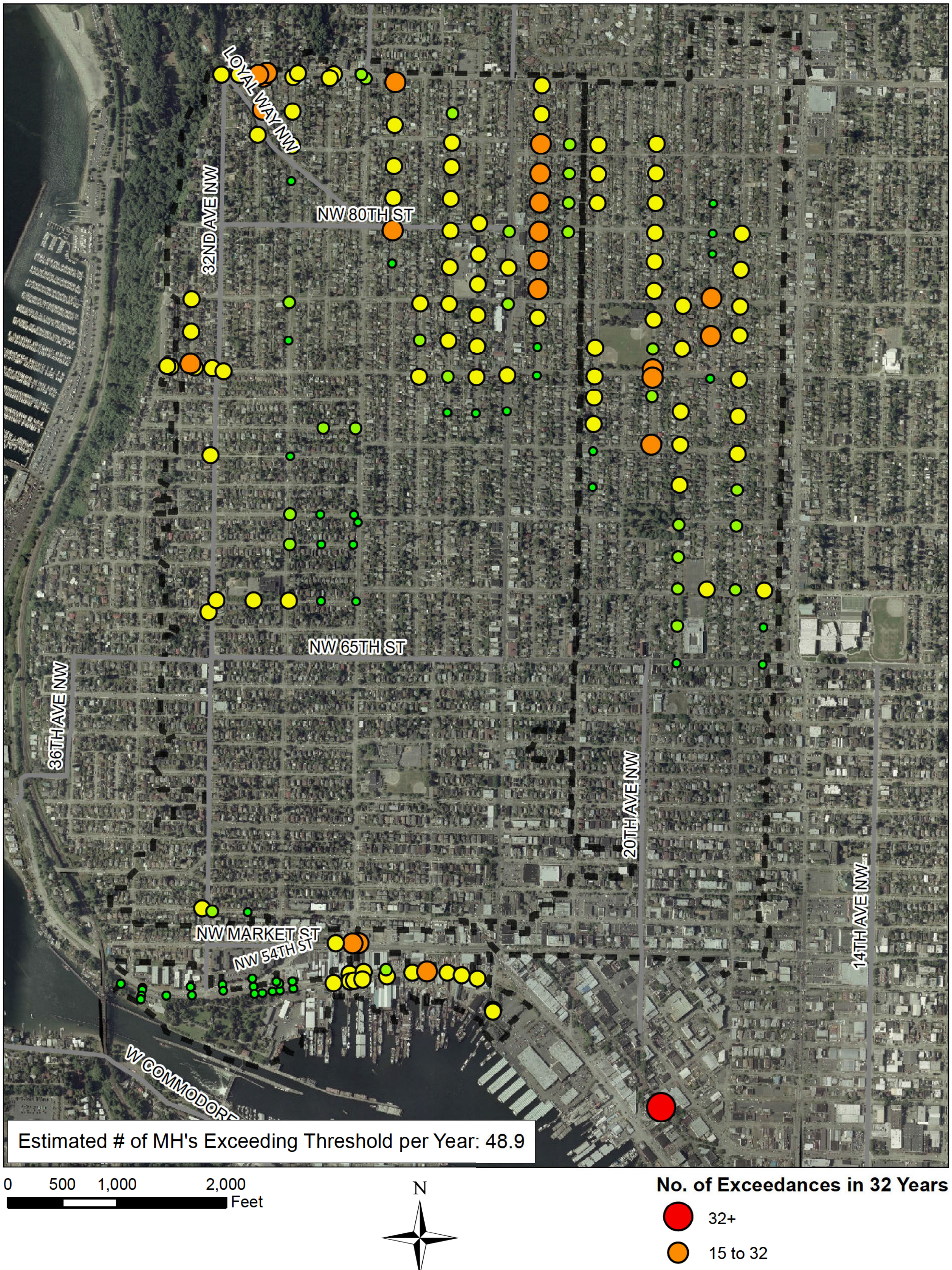

Figure 2

Scenario 1: No GSI, No Climate Change

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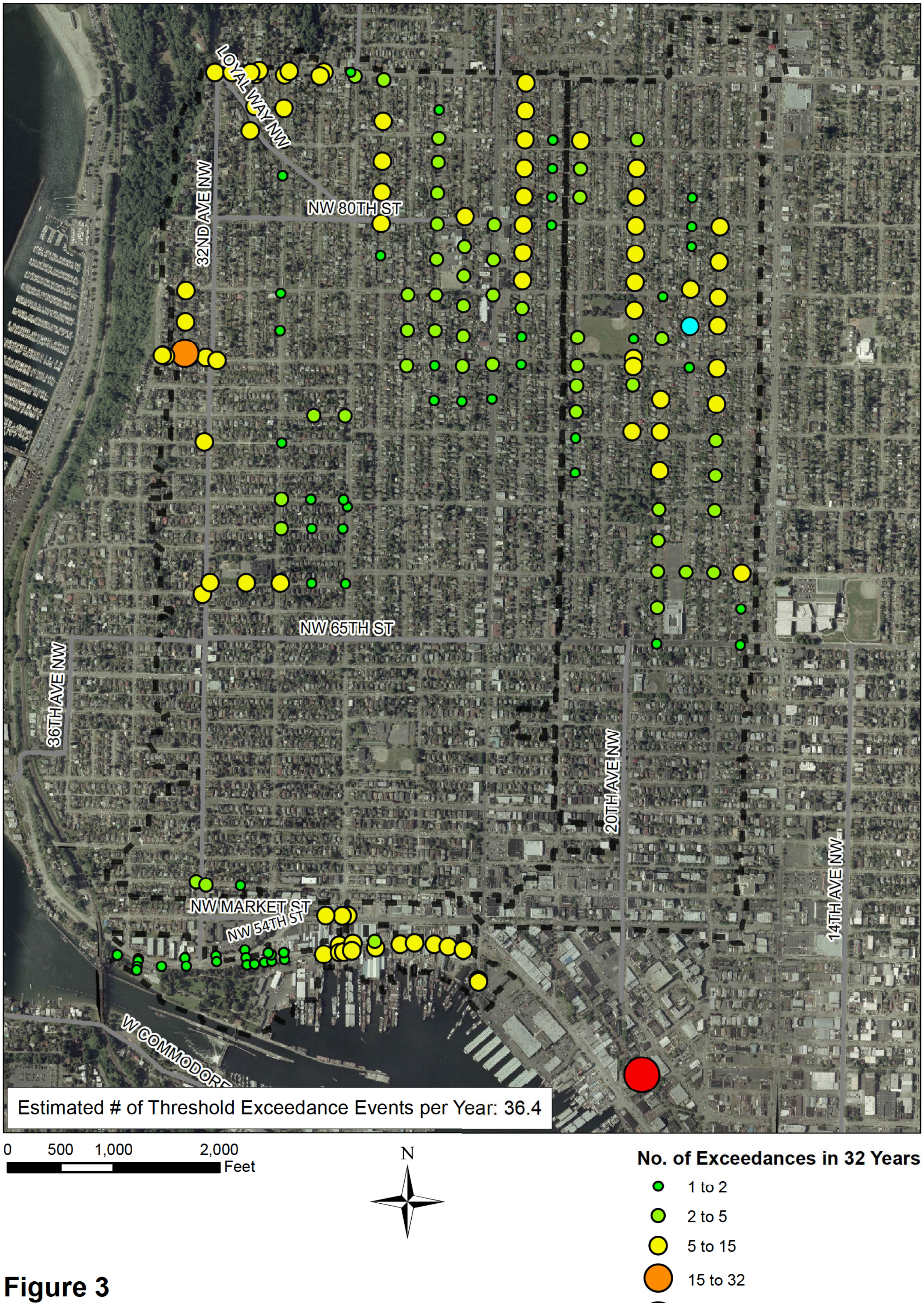

Figure 3

Scenario 2: GSI, No Climate Change

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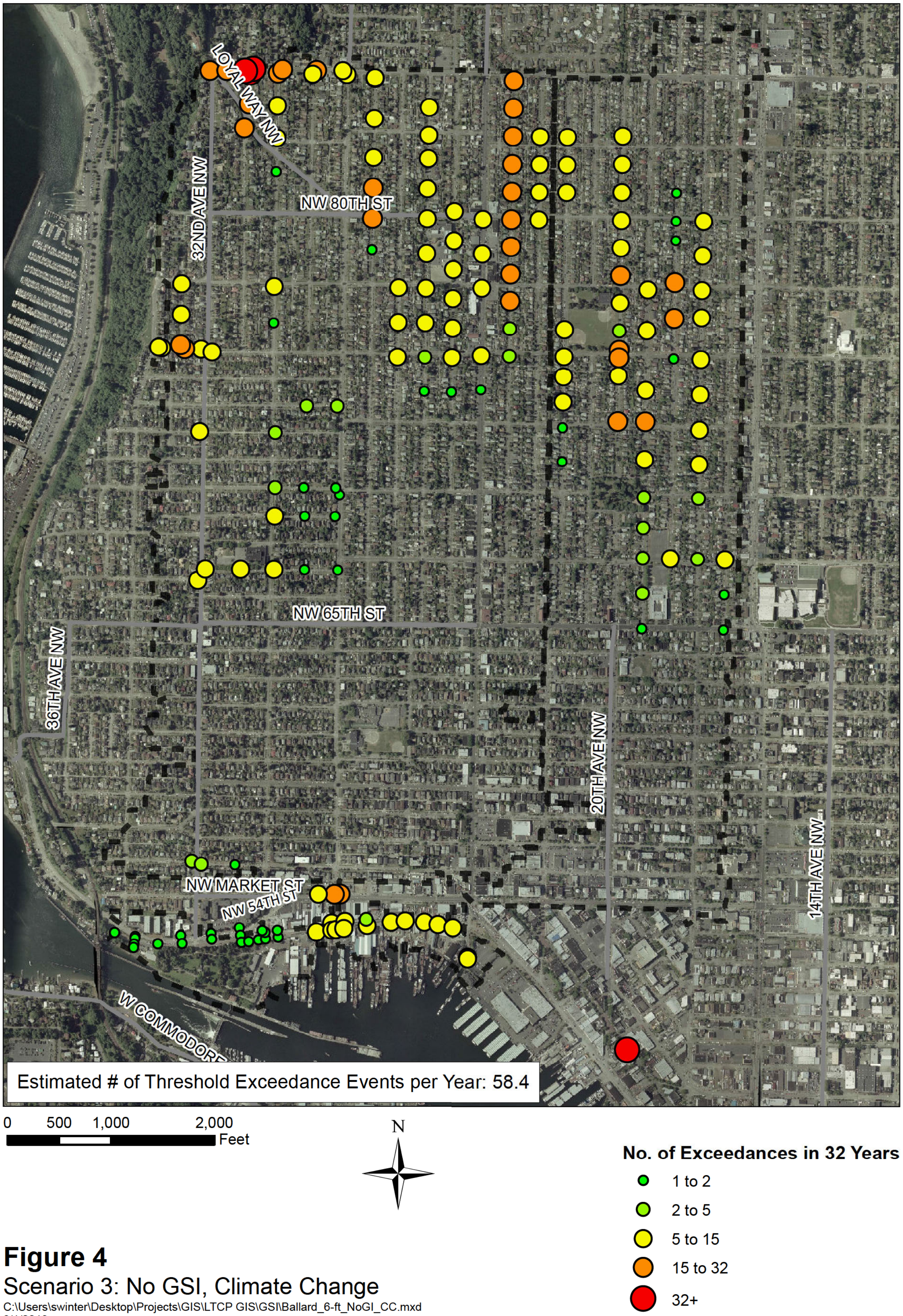

Figure 4

Scenario 3: No GSI, Climate Change

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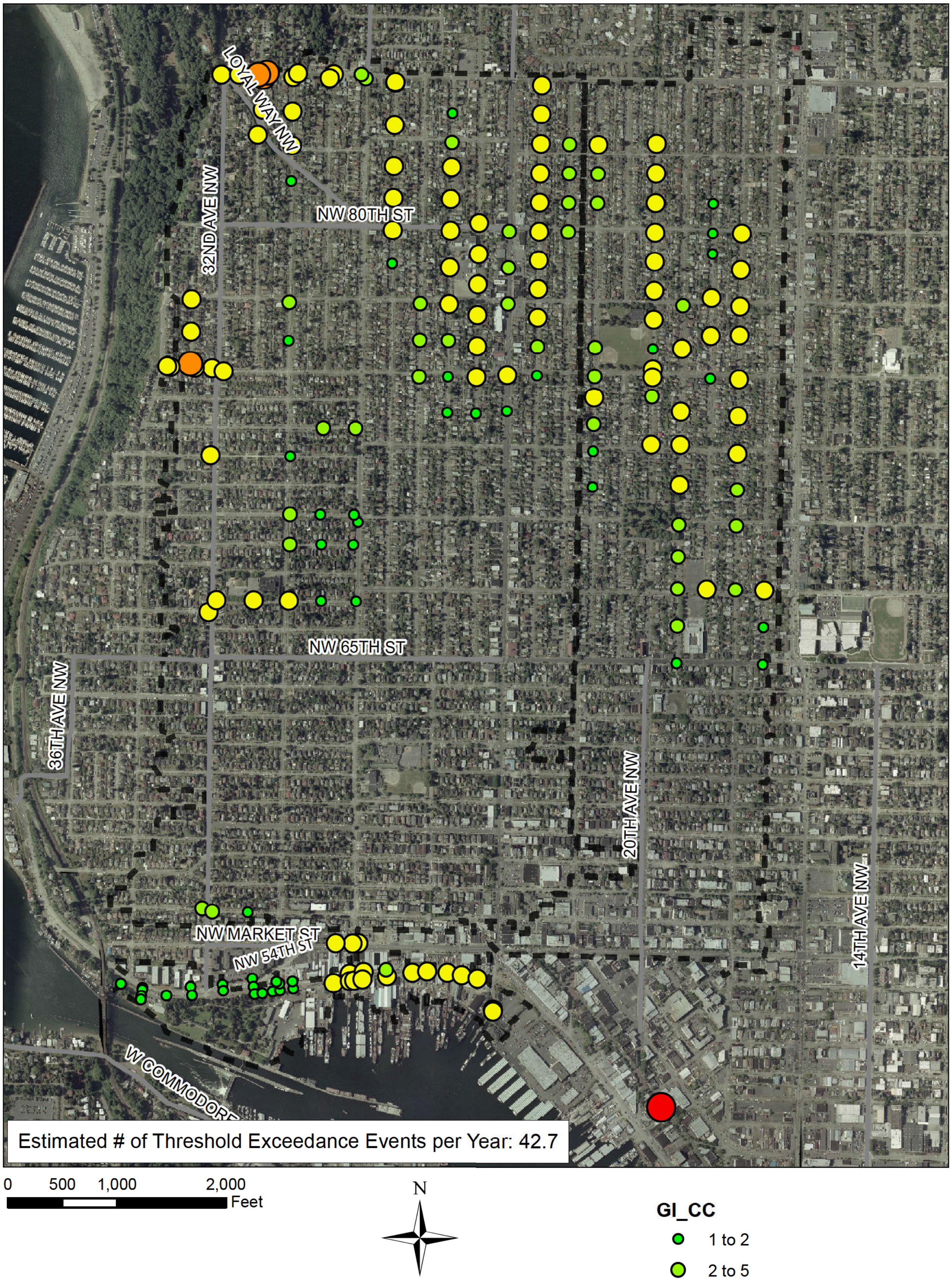

Figure 5

Scenario 4: GSI, Climate Change

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