Appendix F: Sensitive Area Study

Seattle Public Utilities | Protecting Seattle's Waterways

Long-Term Control Plan

Revised Final – Sensitive Area Study: CSO Basin Prioritization Technical Memorandum

December 2014

Seattle Public Utilities
Revised Final – Sensitive Area Study: CSO Basin Prioritization Technical Memorandum

December 2014

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SECTION 1

Introduction

This technical memorandum documents the methodology and results of the sensitive area study for the City of Seattle's (City's) Long-Term Control Plan (LTCP). This process is a high level planning tool to assist the development of Combined Sewer Overflow (CSO) reduction projects for evaluation as part of the LTCP.

This technical memorandum was revised from its original form, issued in April 2013, based on the most recently available CSO control status, frequency, and volume data available.

1.1 Purpose

The purpose of the sensitive area study (study) is to prioritize CSO basins based on their environmental impacts to receiving water bodies and impacts to human health. The results of the study will be used to identify basins where CSO reduction projects are expected to provide the highest environmental and human health benefits.

This study was undertaken to satisfy the requirement of the Environmental Protection Agency's (EPA's) CSO Control Policy, which states the following principle:

> *"EPA expects a permittee's long-term CSO control plan to give the highest priority to controlling overflows to sensitive areas. Sensitive areas, as determined by the NPDES authority in coordination with State and Federal agencies, as appropriate, include designated Outstanding National Resource Water, National Marine Sanctuaries, waters with threatened and endangered species and their habitat, waters with primary contact recreation, public drinking water intakes or their designated protection areas, and shellfish beds."*

1.2 EPA Guidance for Screening and Ranking

This study follows the guidelines established in the EPA Document 832-B-95-004, "*Combined Sewer Overflows Guidance for Screening and Ranking*" (EPA Screening and Ranking document), which is contained in Appendix A. The purpose of the EPA Screening and Ranking document is to:

> *"give communities with multiple CSOs to multiple receiving water bodies a tool for ranking CSOs. Ranking CSOs will give the communities a basis for allocating resources to eliminate or control, in accordance with the CSO Control Policy, CSOs with the most significant impacts and to maximize the environmental benefits achieved for the resources expended."*

The methodology laid out in the EPA Screening and Ranking document is described in more detail in Section 2.

1.3 Other CSO Basin Prioritization Studies

The City's "*2010 CSO Reduction Plan Amendment*" contained the results of a CSO basin prioritization study using the methodology outline in the EPA Screening and Ranking document, and the available flow monitoring and modeling data. This study divided the CSO basins into four categories, Priority A through Priority D, based on their scores. The results of the study are summarized as follows:

- 14 Priority A CSO basins
- 22 Priority B CSO basins
- 31 Priority C CSO basins
- 11 Priority D CSO basins

The CSO basin prioritization contained in this sensitive area study supercede the results of any prior CSO basin prioritizations.

SECTION 2

Methodology

This section describes the methodology used to complete the sensitive area study and develop the CSO basin prioritization.

2.1 CSO Basins Included in Study

The sensitive area study included all of the CSO basins included in the LTCP:

- Ballard: NPDES150/151 and NPDES152
- Central Waterfront: NPDES069
- Delridge: NPDES099, NPDES168, and NPDES169
- Duwamish: NPDES107 and NPDES111
- Fremont/Wallingford: NPDES147 and NPDES174
- Leschi: NPDES028, NPDES029, NPDES031, NPDES032, NPDES036
- Magnolia: NPDES060
- Montlake: NPDES020, NPDES139, and NPDES140
- North Union Bay: NPDES018
- Portage Bay/Lake Union: NPDES138

2.2 Ranking Process

CSO basins included in the study were ranked through a seven-criterion process using site-specific information. Each CSO basin received a score for each of the seven criteria. These scores were totaled, and the resulting total scores were used to rank the CSO basins. The following sections describe the seven criteria, and include a brief description of the results. A detailed table of the resulting scores for each CSO basin is included in Appendix B.

2.2.1 Criterion 1

If any CSOs pose a direct risk to public health or contribute to the non-attainment of designated uses on an ongoing basis, or if the potential impacts from CSOs are significant to areas designated under Federal or State law as sensitive or protected resources, points are assigned as follows:

- Discharges to water experiencing beach closings or where there is a significant risk to public health from direct contact with pollutants in CSOs:
  Score 250 points
- Discharges to Outstanding National Resource Waters, National Marine Sanctuaries, or waters with threatened and endangered species and their habitat; public drinking water intakes or their designated protection areas; or shellfish beds:
  Score 200 points

According to the EPA Screening and Ranking document, the primary purpose of this criterion is to identify “CSOs that endanger health and affect water quality.” CSO basins that discharge into Longfellow Creek (NPDES168 and NPDES169) received scores of 250 points, and all other CSO basins received scores of 200 points, as presented in Figure 1.

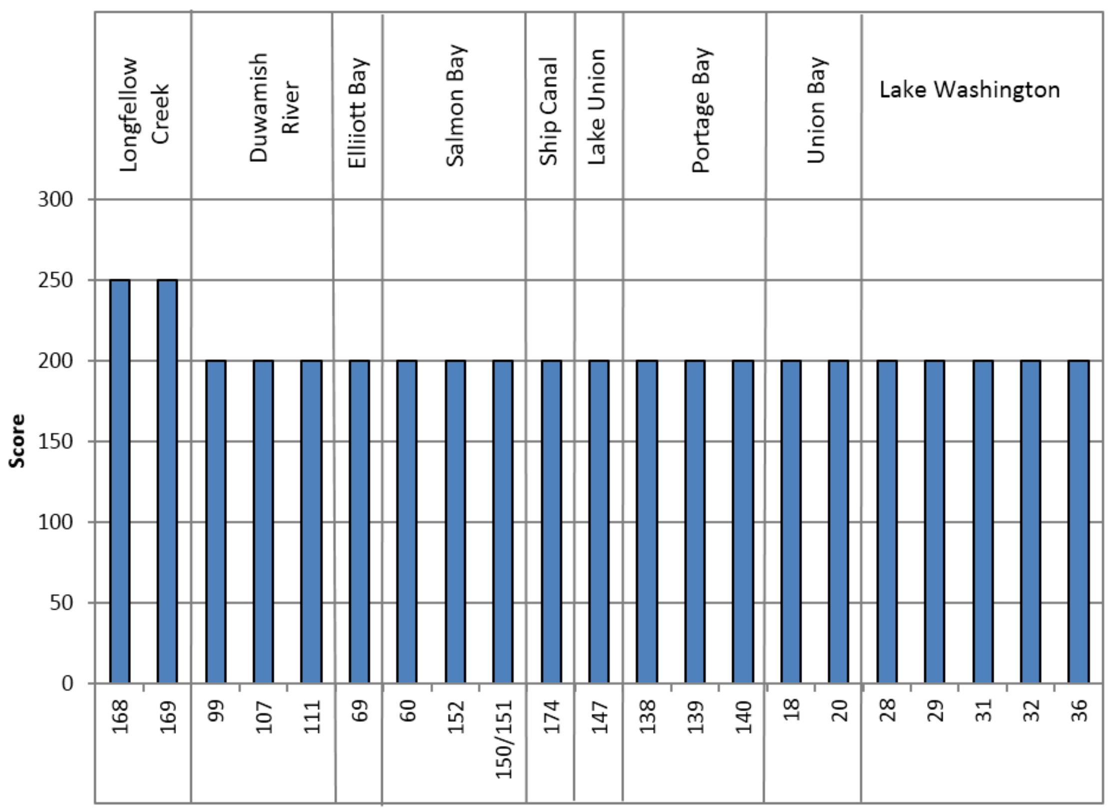

Figure 1. Breakdown of Scoring on Criterion 1 by CSO Basin and Receiving Water Body

2.2.2 Criterion 2

If dry weather overflows (DWOs) occur within the CSO basin, score the following points depending on the frequency of the DWOs:

- Chronic DWOs (i.e., they occur on a regular basis and are not caused by an occasional blockage of a regulator by debris):
  Score 150 points
- Infrequent DWOs caused by infrequent maintenance:
  Score 75 points

Because DWOs are not diluted by stormwater, they can cause significant impacts in receiving water bodies. This criterion captures the impact of those overflows. None of the LTCP CSO basins currently have issues with DWOs occurring, and all received scores of 0 points.

2.2.3 Criterion 3

Depending on the type of water body receiving the CSO, as well as the body's turbulence and mixing characteristics (energy), score points according to Table 1:

Table 1. Criterion 3 Scoring

Water Body Type	Low Energy	Medium Energy	High Energy
Estuarine and Wetland	100	N/A	N/A
Near-Shore Oceanic	60	40	20
Off-Shore Oceanic	30	15	10
Lakes and Ponds	100	N/A	N/A
River	40	20	10
Streams	60	40	20

N/A = Not Applicable

According to the EPA Screening and Ranking document, "water bodies most likely to suffer impacts from CSOs can be identified and categorized based on two factors: type of water body (e.g., estuary, river) and its relative energy (i.e., low, medium, or high)." Figure 2 presents the breakdown of how the LTCP CSO basins scored on Criterion 3.

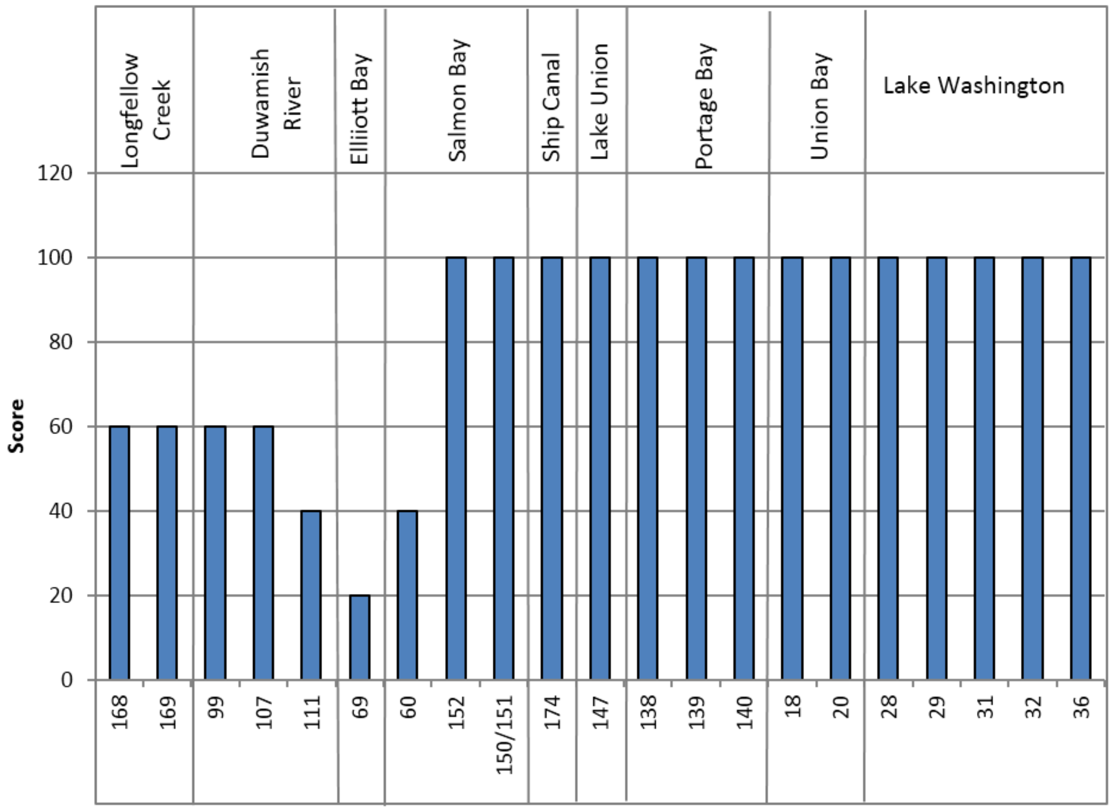

Figure 2. Breakdown of Scoring on Criterion 3 by CSO Basin and Receiving Water Body

2.2.4 Criterion 4

If the measured or estimated proportion of the flow rate(s) of all CSO outfalls to the receiving water flow rate (including CSO flow) in streams or rivers is:

- More than 50 percent: Score 50 points
- 25 to 50 percent: Score 30 points
- Less than 25 percent: Score 10 points

Note that since the proportion of CSO flow rate(s) to receiving water flow rate cannot be calculated for lakes and estuaries, they should automatically receive 30 points.

The EPA Screening and Ranking document indicates that “this criterion continues the projection of probable impacts from CSOs to water bodies begun in Criterion 3. It is based on the assumption that impacts increase as the proportion of CSO flow increases relative to receiving water flow.” NPDES168 and NPDES169 received scores of 50 points because they drain to the relatively low-flow Longfellow Creek. The majority of the other CSO basins received 30 points, as presented in Figure 3. CSO basins 60, and 69 received a score of 0 points because they discharge to bays that are connected to the ocean.

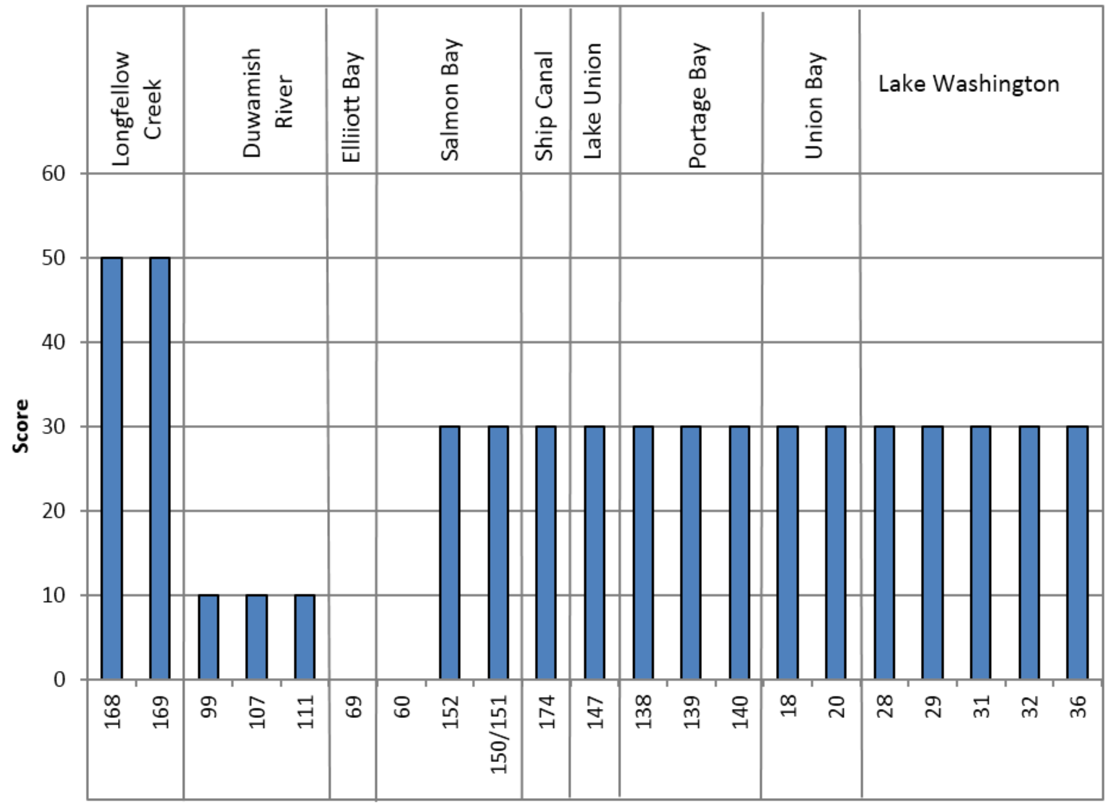

Figure 3. Breakdown of Scoring on Criterion 4 by CSO Basin and Receiving Water Body

2.2.5 Criterion 5

If a drinking water intake is within 10 miles (downstream in flowing water systems) of any CSO outfall, score the following points:

- Within 5 miles: Score 100 points
- Between 5 and 10 miles: Score 50 points

This criteria attempts to capture some of the risk that CSOs present to human health. As the EPA Screening and Ranking document indicates; "while the association between CSOs and impacts to drinking water sources may be rare, the consequences may be rather severe." None of the LTCP CSO basins are close to drinking water intakes, and all basins scored 0 points.

2.2.6 Criterion 6

If the composition of wastewater flows prior to any CSO outfall (based on dry weather flows) includes:

- More than 50 percent industrial and commercial discharges or significant individual sources of potentially toxic materials:
  Score 50 points

- 30 to 50 percent industrial and commercial discharges or significant individual sources of potentially toxic materials:
  Score 25 points
- Less than 30 percent industrial and commercial discharges or significant individual sources of potentially toxic materials:
  Score 0 points

The EPA Screening and Ranking document indicates that "this criterion uses the surrogate measure of CSO industrial/commercial contributions to address the potential impact of CSOs on the quality of the receiving water body." It is based on the assumption that: (1) industrial and commercial discharges contain higher concentrations of hazardous and toxic substances, (2) runoff volumes are larger from industrial and commercial areas, and (3) most residential areas have higher infiltration rates and lower pollutant loads.

NPDES069 in the Central Waterfront CSO Area, and NPDES107 and NPDES111 from the Duwamish CSO Areas scored 50 points each, as shown in Figure 4 below. All other CSO basins scored 0 points.

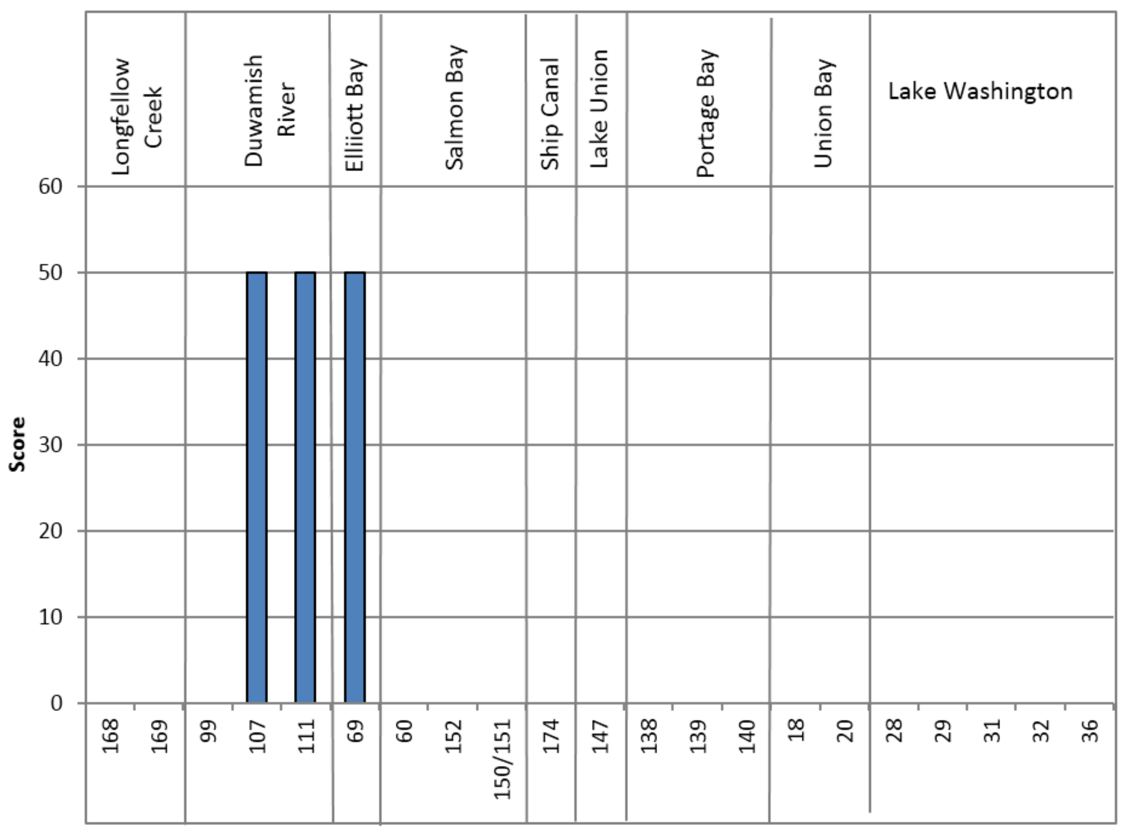

Figure 4. Breakdown of Scoring on Criterion 6 by CSO Basin and Receiving Water Body

2.2.7 Criterion 7

Criterion 7 is reserved for site-specific concerns that are not addressed in the other six criteria. For this study, points were scored for Criterion 7 based on the average annual CSO volume and frequency at the CSO outfall. As shown in Table 2, 0 to 100 points were scored for the average annual CSO frequency, and 0 to 100 points were scored for the average annual CSO volume. These scores were combined to come up with the total score for Criterion 7. The average annual CSO frequencies and volumes are based on 20-year long-term simulations using table 5-8 from the 2013 Annual CSO Report for Outfalls Meeting Performance Standard for Controlled CSOs based on Flow Monitoring Results and Modeling.

Table 2. Criterion 7 Scoring

Average Annual CSO Frequency	Frequency Score	Average Annual CSO Volume (MG)	Overflow Volume Score
>= 20	100	>= 10	100
10 - 19.99	80	5 - 9.99	80
5 - 9.99	60	2 - 4.99	60
2 - 4.99	40	1 - 1.99	40
1.51 - 1.99	20	0.1 - 0.99	20
1 - 1.5	10	< 0.1	10
0 – 0.99	0	0	0

MG = millions of gallons

The purpose of this criterion was to capture the effect of CSO volume and frequency on the environment and human health, which was not captured in the other six criteria. The resulting scores for Criterion 7 ranged from a low of 20 points to a high of 200 points, as shown in Figure 5.

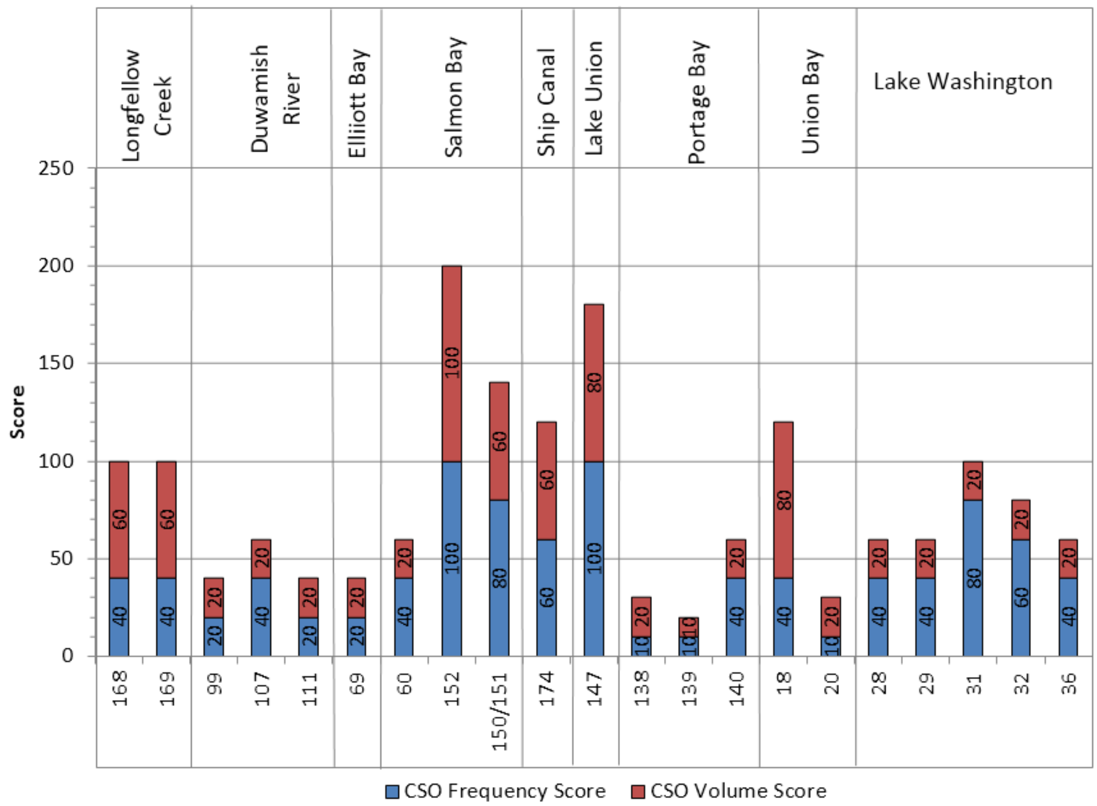

Figure 5. Breakdown of Scoring on Criterion 7 by CSO Basin and Receiving Water Body

SECTION 3
Conclusions

The following section present the results of the scoring and ranking described in the previous section, and discuss the significance of these results.

3.1 Results

Figure 6 presents the totaled scores for each CSO basin. The CSO basins were ranked from highest score to lowest score, as shown in Figure 7, and were divided into two categories; higher priority CSO basins, and lower priority CSO basins. Figure 8 presents a map of the LTCP basins and their CSO prioritization. Appendix B contains a table that shows the individual criteria scores for each CSO basin.

The higher priority CSO basins are those that discharge large quantities of CSO into sensitive water bodies.

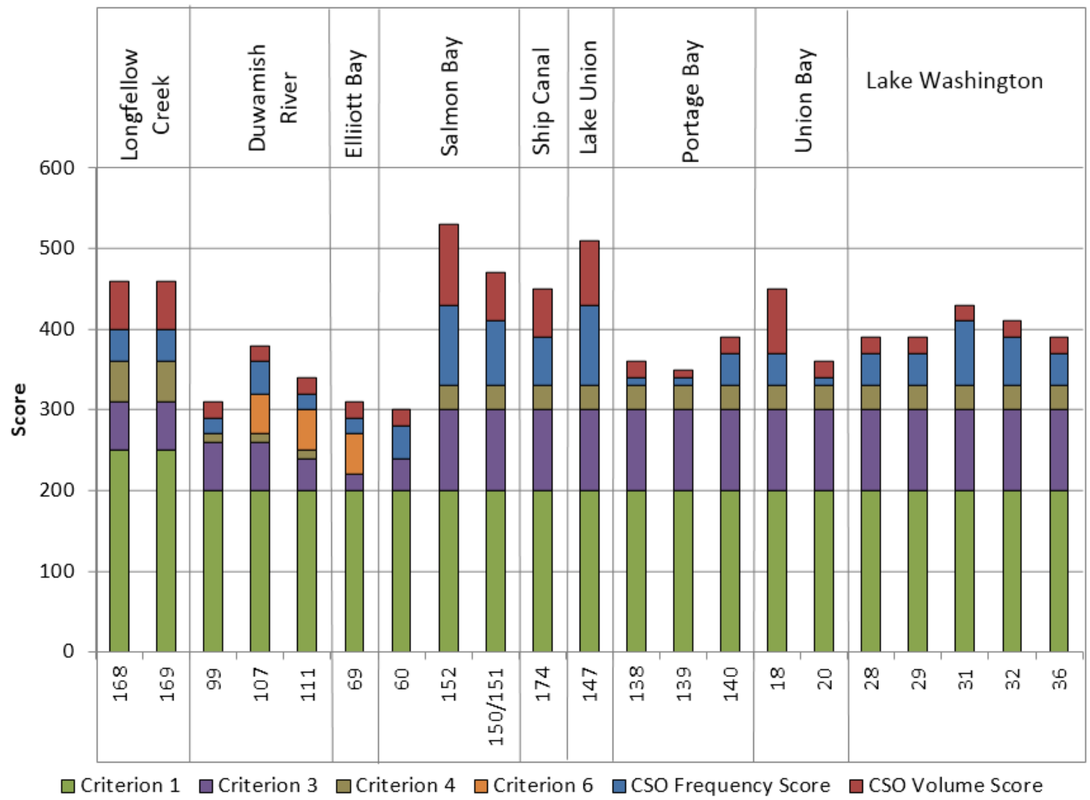

Figure 6. Totaled Scores for Each CSO Basin

Figure 7. CSO Basin Prioritization

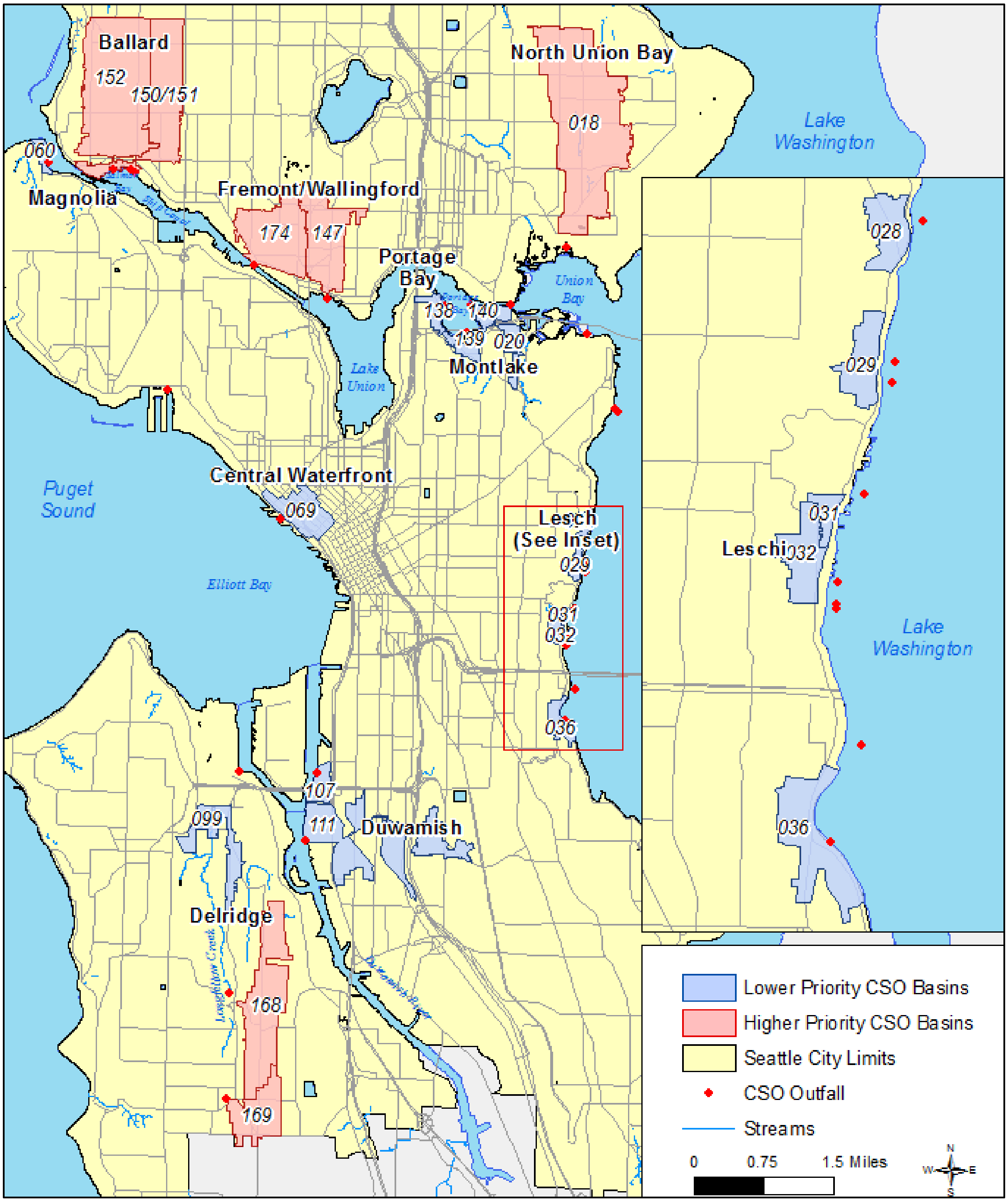

Figure 8. Map of LTCP CSO Basin Prioritization

SECTION 4
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Tetra Tech. 2010. “2010 CSO Reduction Plan Amendment”. Prepared for Seattle Public Utilities. May.

U.S. Environmental Protection Agency (EPA). 1994. “Combined Sewer Overflow (CSO) Control Policy.” Federal Register, Vol. 59, No. 75, Part VII, April 19.

U.S. Environmental Protection Agency (EPA). 1995. “Combined Sewer Overflows Guidance for Screening and Ranking.” August.

Appendix A: EPA Screening and Ranking Guidance Document

EPA Document 832-B-95-004, "*CSO Guidance for Screening and Ranking*"

EPA 832-B-95-004

COMBINED SEWER OVERFLOWS
GUIDANCE FOR SCREENING AND RANKING

Office of Wastewater Management
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

August 1995

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

AUG 31 1995

OFFICE OF WATER

MEMORANDUM

SUBJECT: Combined Sewer Overflows: Guidance for Screening and Ranking

FROM: Michael B. Cook, Director Michael B. Cook
Office of Wastewater Management (4201)

TO: Interested Parties

I am pleased to provide to you the Environmental Protection Agency's (EPA's) guidance document on a procedure for screening and ranking communities with combined sewer overflows (CSOs) for issuance of National Pollutant Discharge Elimination System (NPDES) permits. This document is one of several being prepared to foster implementation of EPA's CSO Control Policy. The CSO Control Policy, issued on April 11, 1994, establishes a national approach under the NPDES permit program for controlling discharges into the nation's waters from combined sewer systems (CSSs).

To facilitate implementation of the CSO Control Policy, EPA is preparing guidance documents that can be used by NPDES permitting authorities, affected municipalities, and their consulting engineers in planning and implementing CSO controls that will ultimately comply with the requirements of the Clean Water Act.

The primary purpose of this document is to provide guidance to NPDES permitting authorities for establishing CSO permitting priorities across CSSs under their jurisdictions. A secondary purpose is to provide permittees, especially larger municipalities with many CSOs and multiple receiving water bodies, with a tool for ranking CSOs within their systems. This can help them allocate their limited resources.

This guidance has been reviewed extensively within EPA as well as by municipal groups, environmental groups, and other CSO stakeholders. I am grateful to all who participated in its preparation and review, and believe that it will further the implementation of the CSO Control Policy.

If you have any questions on the manual or its distribution, please call Tim Dwyer in the Office of Wastewater Management, at (202) 260-6064.

NOTICE

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Mention of trade names or commercial products in this document does not constitute an endorsement or recommendation for use.

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CHAPTER 1

INTRODUCTION

1.1 Background

Combined sewer systems (CSSs) are wastewater collection systems designed to carry sanitary sewage (consisting of domestic, commercial, and industrial wastewater) and storm water (surface drainage from rainfall or snowmelt) in a single pipe to a treatment facility. CSSs serve about 43 million people in approximately 1,100 communities nationwide. Most of these communities are located in the Northeast and Great Lakes regions. During dry weather, CSSs convey domestic, commercial, and industrial wastewater. In periods of rainfall or snowmelt, total wastewater flows can exceed the capacity of the CSS and/or treatment facilities. When this occurs, the CSS is designed to overflow directly to surface water bodies, such as lakes, rivers, estuaries, or coastal waters. These overflows—called combined sewer overflows (CSOs)—can be a major source of water pollution in communities served by CSSs.

Because CSOs contain untreated domestic, commercial, and industrial wastes, as well as surface runoff, many different types of contaminants can be present. Contaminants may include pathogens, oxygen-demanding pollutants, suspended solids, nutrients, toxics, and floatable matter. Because of these contaminants and the volume of the flows, CSOs can cause a variety of adverse impacts on the physical characteristics of surface water, impair the viability of aquatic habitats, and pose a potential threat to drinking water supplies. CSOs have been shown to be a major contributor to use impairment and aesthetics degradation of many receiving waters and have contributed to shellfish harvesting restrictions, beach closures, and even occasional fish kills.

1.2 History of the CSO Control Policy

Historically, the control of CSOs has proven to be extremely complex. This complexity stems partly from the difficulty in quantifying CSO impacts on receiving water quality and the site-specific variability in the volume, frequency, and characteristics of CSOs. In addition, the financial considerations for communities with CSOs can be significant. The U.S. Environmental

Protection Agency (EPA) estimates the CSO abatement costs for the 1,100 communities served by CSSs to be approximately $41.2 billion.

To address these challenges, EPA's Office of Water issued a National Combined Sewer Overflow Control Strategy on August 10, 1989 (54 *Federal Register* 37370). This Strategy reaffirmed that CSOs are point source discharges subject to National Pollutant Discharge Elimination System (NPDES) permit requirements and to Clean Water Act (CWA) requirements. The CSO Strategy recommended that all CSOs be identified and categorized according to their status of compliance with these requirements. It also set forth three objectives:

- Ensure that if CSOs occur, they are only as a result of wet weather
- Bring all wet weather CSO discharge points into compliance with the technology-based and water quality-based requirements of the CWA
- Minimize the impacts of CSOs on water quality, aquatic biota, and human health.

In addition, the CSO Strategy charged all States with developing state-wide permitting strategies designed to reduce, eliminate, or control CSOs.

Although the CSO Strategy was successful in focusing increased attention on CSOs, it fell short in resolving many fundamental issues. In mid-1991, EPA initiated a process to accelerate implementation of the Strategy. The process included negotiations with representatives of the regulated community, State regulatory agencies, and environmental groups. These negotiations were conducted through the Office of Water Management Advisory Group. The initiative resulted in the development of a CSO Control Policy, which was published in the *Federal Register* on April 19, 1994 (59 *Federal Register* 18688). The intent of the CSO Control Policy is to:

- Provide guidance to permittees with CSOs, NPDES permitting and enforcement authorities, and State water quality standards (WQS) authorities

- Ensure coordination among the appropriate parties in planning, selecting, designing, and implementing CSO management practices and controls to meet the requirements of the CWA

- Ensure public involvement during the decision-making process.

The CSO Control Policy contains provisions for developing appropriate, site-specific NPDES permit requirements for all CSSs that overflow due to wet weather events. It also announces an enforcement initiative that requires the immediate elimination of overflows that occur during dry weather and ensures that the remaining CWA requirements are complied with as soon as possible.

1.3 Key Elements of the CSO Control Policy

The CSO Control Policy contains four key principles to ensure that CSO controls are cost-effective and meet the requirements of the CWA:

- Provide clear levels of control that would meet appropriate health and environmental objectives

- Provide sufficient flexibility to municipalities, especially those that are financially disadvantaged, to consider the site-specific nature of CSOs and to determine the most cost-effective means of reducing pollutants and meeting CWA objectives and requirements

- Allow a phased approach for implementation of CSO controls considering a community's financial capability

- Review and revise, as appropriate, WQS and their implementation procedures when developing long-term CSO control plans to reflect the site-specific wet weather impacts of CSOs.

In addition, the CSO Control Policy clearly defines expectations for permittees, State WQS authorities, and NPDES permitting and enforcement authorities. These expectations include the following:

- Permittees should immediately implement the nine minimum controls (NMC), which are technology-based actions or measures designed to reduce CSOs and their effects on receiving water quality, as soon as practicable but no later than January 1, 1997.

- Permittees should give priority to environmentally sensitive areas.

- Permittees should develop long-term control plans (LTCPs) for controlling CSOs. A permittee may use one of two approaches: 1) demonstrate that its plan is adequate to meet the water quality-based requirements of the CWA ("demonstration approach"), or 2) implement a minimum level of treatment (e.g., primary clarification of at least 85 percent of the collected combined sewage flows) that is presumed to meet the water quality-based requirements of the CWA, unless data indicate otherwise ("presumption approach").

- WQS authorities should review and revise, as appropriate, State WQS during the CSO long-term planning process.

- NPDES permitting authorities should consider the financial capability of permittees when reviewing CSO control plans.

Exhibit 1-1 illustrates the roles and responsibilities of permittees, NPDES permitting and enforcement authorities, and State WQS authorities.

In addition to these key elements and expectations, the CSO Control Policy also addresses important issues such as ongoing or completed CSO control projects, public participation, small communities, and watershed planning.

1.4 Guidance to Support Implementation of the CSO Control Policy

To help permittees and NPDES permitting and WQS authorities implement the provisions of the CSO Control Policy, EPA is developing the following guidance documents:

- *Combined Sewer Overflows—Guidance for Long-Term Control Plan* (Publication number 832-B-95-002)

- *Combined Sewer Overflows—Guidance for Nine Minimum Control Measures* (Publication number 832-B-95-003)

- *Combined Sewer Overflows—Guidance for Screening and Ranking* (Publication number 832-B-95-004)

Exhibit 1-1. Roles and Responsibilities

Permittee	NPDES Permitting Authority	NPDES Enforcement Authority	State WQS Authorities
• Evaluate and implement NMC • Submit documentation of NMC implementation by January 1, 1997 • Develop LTCP and submit for review to NPDES permitting authority • Support the review of WQS in CSO-impacted receiving water bodies • Comply with permit conditions based on narrative WQS • Implement selected CSO controls from LTCP • Perform post-construction compliance monitoring • Reassess overflows to sensitive areas • Coordinate all activities with NPDES permitting authority, State WQS authority, and State watershed personnel	• Reassess/revise CSO permitting strategy • Incorporate into Phase I permits CSO-related conditions (e.g., NMC implementation and documentation and LTCP development) • Review documentation of NMC implementation • Coordinate review of LTCP components throughout the LTCP development process and accept/approve permittee's LTCP • Coordinate the review and revision of WQS as appropriate • Incorporate into Phase II permits CSO-related conditions (e.g., continued NMC implementation and LTCP implementation) • Incorporate implementation schedule into an appropriate enforceable mechanism • Review implementation activity reports (e.g., compliance schedule progress reports)	• Ensure that CSO requirements and schedules for compliance are incorporated into appropriate enforceable mechanisms • Monitor adherence to January 1, 1997, deadline for NMC implementation and documentation • Take appropriate enforcement action against dry weather overflows • Monitor compliance with Phase I, Phase II, and post-Phase II permits and take enforcement action as appropriate	• Review WQS in CSO-impacted receiving water bodies • Coordinate review with LTCP development • Revise WQS as appropriate: Development of site-specific criteria Modification of designated use to -- Create partial use reflecting specific situations -- Define use more explicitly Temporary variance from WQS

- *Combined Sewer Overflows—Guidance for Monitoring and Modeling* (Publication number 832-B-95-005)
- *Combined Sewer Overflows—Guidance for Financial Capability Assessment* (Publication number 832-B-95-006)
- *Combined Sewer Overflows—Guidance for Funding Options* (Publication number 832-B-95-007)
- *Combined Sewer Overflows—Guidance for Permit Writers* (Publication number 832-B-95-008)
- *Combined Sewer Overflows—Questions and Answers on Water Quality Standards and the CSO Program* (Publication number 832-B-95-009)

1.5 Purpose of Manual and Target Audience

This guidance presents a process for screening and ranking CSSs with CSOs that have adverse impacts on water quality, aquatic life, or human health. Its primary purpose is to give NPDES permitting authorities (i.e., EPA Regions and States with approved NPDES programs) a method of prioritizing the issuance of NPDES permits to communities with CSSs. A secondary purpose is to give communities with multiple CSOs to multiple receiving water bodies a tool for ranking CSOs. Ranking CSOs will give the communities a basis for allocating resources to eliminate or control, in accordance with the CSO Control Policy, CSOs with the most significant impacts and to maximize the environmental benefits achieved for the resources expended. It can also help target monitoring needs. The screening and ranking process relies primarily on information readily available for most CSSs, such as a general knowledge of known or expected impacts from CSOs, estimates of CSO flows and their characteristics, and receiving water characteristics.

This guidance is not designed or intended to be used as a tool to prioritize Federal enforcement actions. Decisions to initiate an enforcement action are generally based on site-specific data and information and in accordance with the NPDES permitting authority's enforcement management system.

In this recommended screening and ranking process, the NPDES permitting authority uses the available information to assess an individual CSS. The screening process involves two criteria. If the NPDES permitting authority determines through the screening process that the CSS has a high likelihood of causing significant adverse impacts, the CSS may be assessed (i.e., scored) using the ranking process, which has seven criteria. Chapters 2 and 3 of this guidance discuss the screening and ranking processes, respectively. They present each criterion, the associated scoring, and the rationale for its use in the screening or ranking process. The scores for all ranking criteria may be totaled to determine priorities.

NPDES permitting authorities should develop and issue NPDES permits for those communities with the highest point totals and proceed, in order, to the communities with the lowest point totals.

This guidance can also be used to rank individual CSO outfalls within a CSS, to identify CSOs requiring prompt attention, to better allocate limited resources, and to prioritize any necessary modifications under individual CSO permits. Ranking individual CSO outfalls is particularly useful whenever resources or other constraints limit an NPDES permitting authority's or a community's ability to address all of its CSS and CSO problems simultaneously.

In applying this recommended screening and ranking process, it is important to recognize that, as stated in the CSO Control Policy,

> *EPA expects a permittee's long-term CSO control plan to give the highest priority to controlling overflows to sensitive areas. Sensitive areas, as determined by the NPDES authority in coordination with State and Federal agencies, as appropriate, include designated Outstanding National Resource Waters, National Marine Sanctuaries, waters with threatened and endangered species and their habitat, waters with primary contact recreation, public drinking water intakes or their designated protection areas, and shellfish beds.*

EPA also recognizes, however, that technical and financial constraints may limit a permittee's ability to implement controls for all CSOs to sensitive areas at the same time. This document can help establish priorities to phase in permitting efforts across multiple CSSs and CSOs to many sensitive areas, as well as CSOs to less sensitive areas.

1.6 Watershed Approach to Permitting

In response to the 1989 EPA National Combined Sewer Overflow Control Strategy, 30 States have received approval or conditional approval for CSO permitting strategies. EPA expects States to evaluate the need to revise their CSO strategies for consistency with the 1994 CSO Control Policy. This represents an opportunity for NPDES permitting authorities to reconsider their CSO permitting priorities in light of current or suspected environmental impacts, watershed permitting initiatives, and other factors. States and EPA Regions should review these strategies and establish appropriate permitting priorities for implementation of the CSO Control Policy. In establishing CSO permitting priorities, the NPDES permitting authority should consider factors such as the environmental impacts of CSOs (e.g., beach closings, human health hazards, and potential risk to endangered species). The NPDES permitting authority should also consider requiring immediate action for CSOs to areas that meet the CSO Control Policy's definition of "sensitive areas." This document provides guidance on establishing permitting priorities for CSSs and provides permittees with a tool for prioritizing individual CSOs within their CSSs to allow for effective allocation of resources.

EPA encourages States to use a watershed approach to set permitting priorities. Under a watershed approach, all surface water, ground water, and habitat stressors within a geographically defined area are understood and addressed in a coordinated fashion, as an alternative to addressing individual pollutant sources in isolation. To support States that want to implement a comprehensive statewide watershed approach, the Office of Water has developed guidance and training designed to assist communities and natural resource agencies that are pursuing a watershed approach. One part of the effort is the release of the NPDES Watershed Strategy. This Strategy encourages NPDES permitting authorities to evaluate water pollution control needs on a watershed basis. The CSO Control Policy supports the goals of the NPDES Watershed Strategy and urges communities to work with NPDES permitting authorities to coordinate CSO control program efforts with other point and nonpoint source activities within the watershed.

Applying a watershed approach to the CSO control program is particularly timely and appropriate since the ultimate goal of the CSO Control Policy is development of long-term CSO controls that will provide for the attainment of WQS. Since pollution sources other than CSOs are likely to be contributing to the receiving water and affecting whether WQS are achieved, the NPDES permitting authority needs to consider and understand these other sources.

NPDES permitting authorities can use this document to prioritize other wet weather sources, as well as CSOs. Assessing wet weather sources on a watershed basis will allow the NPDES permitting authority to effectively allocate resources for the greatest improvement in the quality of the receiving water bodies within the watersheds under its jurisdiction. For watersheds with interstate consideration, the respective NPDES permitting authorities should establish an ongoing dialogue to address mutual concerns for improving the watersheds' quality.

The CSO Control Policy promotes ongoing interaction between the NPDES permitting authority and the permittees during CSO control program planning and implementation. Such interaction is critical to the success of a CSO program and is important in the screening and ranking process. As the NPDES permitting authority compiles available information for the screening and ranking process, the permittee can also contribute valuable information.

CHAPTER 2

THE SCREENING PROCESS

To rank CSSs using this guidance, the NPDES permitting authority should first identify through the screening process CSSs with the greatest likelihood of causing significant adverse impacts. The screening can be based primarily on information available in documents recently prepared by States under Sections 303(d) and 305(b) of the CWA. Supplemental information can be obtained from sources such as State health departments, the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), news organizations, permittees, and consultants. (Table A-1 in Appendix A lists the sources of information obtained for 13 CSSs across the United States during a test of this screening and ranking process.) If information necessary for the screening is not available, the screening system should not be used.

2.1 Criterion 1

Does any CSO in the CSS discharge into a receiving water body recently listed in the State's 303(d), 305(b), or other similar reports as not attaining use goals or as having impacts that could be caused by CSOs?

- **Yes – Assume CSOs are a contributing problem and proceed to the ranking criteria, given in Chapter 3.**
- **No – Proceed to Criterion 2 of the screening process.**

Rationale: Under Section 305(b) of the Clean Water Act, each State is required to submit to EPA, on a biennial basis, a report that, among other things, describes the quality of all surface waters within the State and provides recommendations regarding point and nonpoint source control programs and actions to achieve the water quality goals of the Act. Under Section 303(d) and EPA's implementing regulations, 40 CFR §130.7(b), each State is also required to submit to EPA, again on a biennial basis, a list of water quality-limited segments that still require total maximum daily loads (i.e., those waters that do not or are not expected to attain water quality standards after implementation of technology-based or other controls). The

Section 303(d) lists also identify the pollutants of concern and, sometimes, the contributing sources.

For many States, these reports and lists provide information adequate to identify water bodies that do not attain applicable water quality standards, the nature of the impacts, and possibly whether CSOs are a primary or probable source of these impacts. When a water body receiving CSOs is listed as not attaining water quality standards or the goals of the Act because of pollutants or effects typically associated with CSOs (e.g., high bacteria counts), States should assume, absent information to the contrary, that CSOs contribute to the problem. In such cases, the NPDES permitting authority should continue to evaluate the CSS using the ranking process.

Another set of lists developed by the States may also be of some limited use. These lists, which were developed in 1989 or 1990 under CWA Section 304(l), identify waters not attaining water quality standards or the goals of the Act. In addition, for waters impaired by point source discharges of toxics, the lists identified the point sources of those pollutants. The Clean Water Act does not require States to update these lists; nevertheless, they might be useful screening devices in appropriate cases.

2.2 Criterion 2

Does other available information indicate that CSO-related adverse impacts might be occurring and that permitting and a CSO control program might be a high priority?

- **Yes – The NPDES permitting authority should begin discretionary review of other available information to indicate whether the CSS should be included for evaluation using the ranking process. Proceed to the ranking process given in Chapter 3.**
- **No – Infer that significant adverse CSO impacts do not occur and remove the CSS from further consideration for prioritized action.**

Rationale: This screening criterion provides the States and EPA Regions with the flexibility to include in the ranking process those CSSs with CSOs to a receiving water body that is not included in Section 303(d) or 305(b) reports. Under Screening Criterion 2, for example, the NPDES permitting authority may decide to include in the ranking process those CSSs in which solid and floatable materials are discharged in close proximity to recreational waters or raw sewage is discharged to commercial and recreational fishing areas, even if the water body is not listed in the previously mentioned reports.

Note that removal of a CSS from the screening and ranking process at this stage does not mean that it should be removed permanently from consideration in permitting and enforcement actions. Removal simply means that control of the CSS should not be the primary focus of the NPDES permitting authority. EPA expects that the NPDES permit for such a CSS, when issued, will contain appropriate CSO requirements.

Chapter 3
The Ranking Process

CSSs that are identified in the screening process as most likely to cause significant adverse impacts should be ranked through a seven-criterion process using site-specific information. Information needed for ranking may be available from many sources, including NPDES permits, NPDES permit applications, 305(b) reports, and compliance and enforcement reports. When adequate information cannot be obtained from these sources, new information can be obtained from site visits or from other outside sources (e.g., consultant reports and data from other agencies, such as USGS), as noted in more detail below. Information from outside sources on the CSSs and CSOs under evaluation can be invaluable during the ranking process. The NPDES permitting authority should make every reasonable effort to obtain the information necessary to give each CSS a score under each ranking criterion. If a particular criterion does not apply to a community (e.g., if a community has no dry weather overflows under Criterion 2), it should receive a score of zero.

In ranking individual CSOs, each individual score should be used. In ranking each CSS, the CSSs that receive the highest point totals from the ranking process should be judged as likely to cause the greatest impacts and should, in most cases, be the highest priority for NPDES permitting. Clearly, this represents a simplistic approach to the ranking of CSSs for NPDES permitting. EPA expects that additional analysis may be necessary and that in some cases it may be desirable to compare systems using "second tier" scores to reflect additional impacts.

3.1 Criterion 1

If any CSOs within the CSS pose a direct risk to public health or contribute to the non-attainment of designated uses on an ongoing basis, or if the potential impacts from CSOs are significant to areas designated under Federal or State law as sensitive or protected resources, assign points as listed below:

- **Discharges to waters experiencing beach closings or where there is a significant risk to public health from direct contact with pollutants in CSOs: Score 250 points.**

- **Discharges to Outstanding National Resource Waters, National Marine Sanctuaries, or waters with threatened and endangered species and their habitat; public drinking water intakes or their designated protection areas; or shellfish beds: Score 200 points.**

Rationale: The primary purpose of this criterion is to identify CSSs with CSOs that endanger public health and affect water quality. This criterion is assigned a high point total because it addresses observed impacts often associated with CSOs. The high point score for the first category in this criterion is consistent with the risks that the pollutants in CSOs pose to public health. Potential impacts to the sensitive areas listed under the second category are included because, as identified in the CSO Control Policy, they generally need the highest levels of protection.

Information required to determine the score for this criterion is often available from State and local public health officials, the NPDES permit, the NPDES permit application, and the 305(b) report. NPDES permit applications and permits contain the specific locations of CSO outfalls. Commonly, 305(b) reports identify whether the use of a water body is impaired and whether municipal sources are responsible; these reports may not give a specific location or specifically identify CSOs as a contributing or primary cause of the impairment. However, if the 305(b) report does not provide adequate information, an appropriate State agency often can help in completing evaluations under this criterion. Local offices of State and Federal natural resource management agencies (e.g., fish and game agencies or the U.S. Fish and Wildlife Service) can provide information on sensitive resources.

3.2 Criterion 2

If dry weather overflows (DWOs) occur within the CSS, score the following points depending on the frequency of the DWOs:

- **Chronic DWOs (i.e., they occur on a regular basis and are not caused by an occasional blockage of a regulator by debris):**
Score 150 points.

- **Infrequent DWOs caused by infrequent maintenance:**
Score 75 points.

Rationale: Dry weather flows include sanitary flows, industrial flows, and infiltration from ground water. DWOs result when dry weather flow is discharged from a CSO outfall. Many CSSs continue to have DWOs for a variety of reasons, including illegal connections to the CSS causing flows that exceed the system's design capacities, plugging of underflow (dry weather) screens, tidal or high stream flow intrusions, damaged or poorly designed flow-regulating equipment, undersized interceptor sewers, and insufficient plant capacities. Ground water may infiltrate into old, poorly designed, or poorly maintained CSSs, causing their design capacities to be exceeded. Because DWOs are not diluted by storm water, they can cause significant impacts in receiving waters.

NPDES regulations prohibit DWOs, and both the 1989 National CSO Control Strategy and the 1994 CSO Control Policy target the expeditious elimination of all DWOs. Both documents recommend that NPDES authorities take appropriate enforcement actions to eliminate all such discharges and to ensure that all CSOs comply with technology-based and water quality-based requirements of the CWA. This criterion has a relatively high maximum score (150 points) because DWOs are undiluted by storm water and, thus, are likely to cause impacts and because DWOs are prohibited.

A CSS would automatically receive a score of 150 points if the DWOs are occurring because of structural problems such as an undersized pipe. The score of 75 points addresses infrequent DWOs that result from inadequate operation and maintenance programs and procedures. The owner/operator of the CSS should be able to mitigate or eliminate these DWOs by implementing a more aggressive operation and maintenance program.

In many cases, the municipal and State personnel will know the dry weather status of a system. In some cases, however, the CSS may not have been studied and may not be well characterized. In these cases, the permittee will generally need to evaluate dry weather flows, which can often be accomplished by relatively simple observations.

3.3 Criterion 3

Depending on the type of water body receiving the CSO, as well as the body's turbulence and mixing characteristics (energy), score points according to the following table:

Water Body Type	Low Energy	Medium Energy	High Energy
Estuarine and Wetland	100 points	N/A	N/A
Near-Shore Oceanic	60 points	40 points	20 points
Offshore Oceanic	30 points	15 points	10 points
Lakes and Ponds	100 points	N/A	N/A
River	40 points	20 points	10 points
Streams	60 points	40 points	20 points

N/A = Not applicable

Rationale: Investigations done in North America and Europe provide information on the relative susceptibility of various water body types to CSO and storm water impacts. Using this information, water bodies most likely to suffer impacts from CSOs can be identified and categorized based on two factors: type of water body (e.g., estuary, river) and its relative energy (i.e., low, medium, or high). Water body energy describes the degree of turbulence and mixing in the receiving water body. Water bodies that flow rapidly and have noticeable turbulence will mix and flush more quickly than standing water systems and, therefore, are more likely to disperse any pollutant loadings from CSOs before they cause substantial impacts. Thus, flowing water systems with high energy receive proportionally lower scores than low energy flowing systems and standing water systems. This criterion assumes that lakes and ponds are always considered low energy due to minimal mixing.

Similarly, potential impacts to flowing waters are stratified because smaller flowing systems (i.e., streams) may not as readily or rapidly flush themselves of accumulated sediments and associated pollutants as would larger systems (i.e., rivers). Because systems with greater sediment accumulation rates are more prone to environmental or human health impacts, they are given more points than waters relatively less prone to sediment accumulation. This criterion can contribute a maximum of 100 points to a system's total score, substantially lower than that possible in each of the first two criteria. This is because the emphasis of this guidance is first on *actual* or *highly probable* impacts to receiving water bodies, which are emphasized under the first two ranking criteria, and then on *potential* impacts having a lesser degree of certainty, which are evaluated under this and the next three criteria. If a CSS has CSOs occurring to more than one type of water body with various energy levels, then scores for each receiving water body are not combined. Rather, the CSS is assigned the score based on the receiving water body and energy level with the highest point value.

Because of Regional differences relevant to the meanings of *streams* and *rivers,* etc., this document does not define these terms. Instead, the NPDES permitting authority should provide clear and appropriate definitions of all terms when using this guidance.

Information necessary for this criterion is generally contained in the NPDES permit. If NPDES permits are not available or if additional information on the characterization of a receiving water body is needed, information can generally be obtained from in-state offices of the USGS or State water resources offices.

3.4 Criterion 4

If the measured or estimated proportion of the flow rate(s) of all CSO outfalls to the receiving water flow rate (including CSO flow) in streams or rivers is:

- **More than 50 percent:**
  Score 50 points.

- **Twenty-five to 50 percent:**
  Score 30 points.

- **Less than 25 percent:**
  Score 10 points.

  Note that since the proportion of CSO flow rate(s) to receiving water flow rate cannot be calculated for lakes and estuaries, they should automatically receive 30 points.

Rationale: This criterion continues the projection of probable impacts from CSOs to water bodies begun in Criterion 3. It is based on the assumption that impacts increase as the proportion of CSO flow increases relative to receiving water flow. It might be difficult to evaluate the CSS under this criterion if flow information is lacking.

Authorized States and/or EPA Regional offices maintain enforcement or compliance records for many CSOs. These records can provide information on CSO occurrences, volumes, durations, and frequencies. When data are not available, Section 308 information requests or new or revised permit requirements can, as appropriate, require monitoring programs to gather needed information. Alternatively, the CSO flow can be estimated using one of several available modeling approaches. A model can predict peak runoff flow rates resulting from recurring precipitation rates for the watershed drained by the CSO. The approximate flow volume discharged from the CSO outfall is then computed by subtracting the treatment capacity (i.e., flow conveyed to the POTW treatment plant) of the CSS from the sum of the projected peak runoff and dry weather flow volumes predicted by the model.

Useful stream and river flow information may be available from the USGS network of stream and river gage stations.

3.5 Criterion 5

If a drinking water intake is within 10 miles (downstream in flowing water systems) of any CSO outfall in the CSS, score the following points:

- **Within 5 miles:**
  Score 100 points.

- **Between 5 and 10 miles:**
  Score 50 points.

Rationale: CSOs might contaminate drinking water supply systems and cause widespread human health problems associated with pathogens or toxic materials. Most drinking water treatment facilities with intakes located near CSO outfalls have developed various operational and treatment strategies to avoid such problems. But unforeseen problems, including illegal new connections or discharges of toxic wastes to the CSS, might occur, or new drinking water intakes might be constructed. While routine treatment of drinking water supplies is likely to protect public drinking water supplies from CSOs in most cases, impacts may still occur. Thus, while the association between CSOs and impacts to drinking water sources may be rare, the consequences may be rather severe. Therefore, this criterion yields a score of 100 points if the intake is within 5 miles and 50 points if it is between 5 and 10 miles of a CSO outfall.

The information necessary for this criterion should be available at the State or local public health agency offices or other State offices responsible for monitoring or regulating drinking water intakes and drinking water supplies.

(Note: During the test of this guidance, this criterion was the only one to score zero for every permittee tested. Where CSOs occur to salt or brackish water, the reason for this score is obvious. Most of the other permittees included in this test have a long history of water quality problems in the water bodies affected by CSOs. It is likely that drinking water supply intakes are not located near CSO outfalls in such cases.)

3.6 Criterion 6

If the composition of wastewater flows prior to any CSO outfall (based on dry weather flows) in the CSS includes:

- **More than 50 percent industrial and commercial discharges or significant individual sources of potentially toxic materials:**
  Score 50 points.

- **Thirty to 50 percent industrial and commercial discharges or significant individual sources of potentially toxic materials:**
  Score 25 points.

- **Less than 30 percent industrial and commercial discharges or significant individual sources of potentially toxic materials:**
  Score 0 points.

Rationale: This criterion uses the surrogate measure of CSO industrial/commercial contributions to address the potential impact of CSOs on the quality of the receiving water body. It is based on the following assumptions: (1) possible discharges to the CSS of potentially hazardous materials, including oils, greases, and spilled materials, are greatest for industrial users and intermediate for commercial users, (2) runoff volumes would be greatest from industrial and commercial areas because of their high proportions of impervious surfaces and the likelihood of runoff contamination is higher in these areas, and (3) most residential areas have relatively higher rates of wet weather infiltration, lower traffic volumes, and thus lower potentials for the release of toxic chemicals in significant quantities.

State agencies generally do not have the information needed for this criterion. Often, the permittee's staff or consultant reports prepared for the permittee are the best sources of this information. When this information is not otherwise available, USGS topographic maps can be used to delineate the drainage basin. Then, land-use or zoning maps available for most cities can be laid over the USGS maps, and the percent composition of the area can be delineated using planimetry or a related method.

3.7 Criterion 7

For any site-specific concern not addressed through the other criteria that is a major concern to the NPDES permitting authority:

Score 0 to 200 points.

Rationale: This criterion recommends that the NPDES permitting authority increase the score and rank of any CSS where special concerns not addressed in other criteria are attributable to actual or potential impacts from the system. Permit writers can assign a score based on best professional judgment and the relative impacts of the system. Concerns considered under this criterion might include CSOs that threaten aesthetics or human health. For example, if floatables from CSOs compromise the aesthetics in an area used for recreational boating, this criterion might receive a score of 100. If the concern is a threat to human health (e.g., CSOs entering streets or basements), a permit writer should assign a score of 200 for this criterion.

The value of this criterion was illustrated during the test of this guidance (see Appendix A). If it were not for this criterion, the CSS for Sacramento, California, would have scored only 50 points, primarily because Criteria 1 to 6 focus on impacts to receiving waters. For Sacramento, however, CSO impacts on receiving waters appear to be relatively minor, but there is a major problem with CSOs onto city streets and into homes and commercial basements in the older sections of the city. Because of this impact to human environments, an additional score of 200 points was assigned under this criterion.

APPENDIX A

TESTING OF THE GUIDANCE FOR SCREENING AND RANKING COMBINED SEWER SYSTEMS

EPA tested the usability and effectiveness of the screening and ranking process for CSSs using information available for 13 CSSs in 11 cities and 7 EPA Regions. All of the CSSs evaluated were identified previously as causing serious water quality impacts. For most of these systems, remediation is already underway or being planned. In brief, the evaluation determined that the screening and ranking process described in this guidance provides useful information that is relevant for ranking CSO problems of the 13 CSSs examined and is relatively easy to apply.

A.1 Methods

Table A-1 presents the locations of the CSSs examined in this evaluation and the source of each major category of information used. EPA Headquarters and Regional offices provided applicable NPDES permits, NPDES permit applications, enforcement and compliance reports, 305(b) reports, and other relevant information. State agencies also were contacted to obtain additional needed information that was not available from EPA. Generally, enough information was compiled by this point to allow complete evaluation of most CSSs through the first six ranking criteria. In some cases, however, more detailed information had to be obtained from the permittees and, sometimes, their consultants.

A.2 Results and Conclusions

Information in NPDES permits and in 305(b) reports, which are often available from EPA Regional offices, was sufficient to complete the screening process for some CSSs. In all cases but one, NPDES permits were useful in identifying specific CSO outfall locations for each CSS. The 305(b) reports adequately identified specific use attainability problems in Connecticut, Maine, Massachusetts, Michigan, New York, Oregon, and Pennsylvania, but CSOs were not always shown as likely causes. Additional information about CSSs in Maine, Pennsylvania, and California was necessary to confirm the occurrence of surface water impacts from CSOs or other CSO-related problems. Using all ranking criteria generally required information from EPA, State, and municipal sources (Table A-1).

Table A-1. Sources From Which Needed Information Was Acquired for Screening and Ranking Process Criteria[a]

City	Sources for Screening	Sources for Ranking[c]						
		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7
Region 1								
Hartford, CT	E	E	S	S[b]	S[b]	S[b]	S[b]	
Bridgeport, CT	E	E	S	E	E	S	S	
South Portland, ME	S	S	S	S	S	S	P	
Gloucester, MA	E	E	S	E	E	S	S	
Holyoke, MA	E	E	E	E	S	E	E	
Region 2								
Brooklyn, NY	E	P	P	P	P	P	C	
Region 3								
Philadelphia, PA NPDES Permit #0026662	E	E	E	E	E	E	P	
Philadelphia, PA NPDES Permit #0026689	E	E	E	E	E	E	P	
Philadelphia, PA NPDES Permit #0026671	E	S	S	E	E	E	P	
Region 4								
Chattanooga, TN	S	S	S	S	P	S	S	
Region 5								
Inkster, MI	E	E	E	S	C	S	C	
Region 9								
Sacramento, CA	E	E	E	E	E	S	S	E
Region 10								
Portland, OR	E	E	P	P	P	S	P	

Key: E = EPA Regional Offices
S = State Agencies
P = Permittees
C = Consultants

[a] If information for a criterion was obtained from more than one source, only the most local source is given. Consultant reports obtained from the EPA Regional office are identified by E and those obtained from a State agency are identified by S.

[b] This information was acquired from a state-chartered utility group, which serves a number of municipalities.

[c] USGS offices in individual States provided stream flow information for municipalities that discharge to flowing waters.

Table A-2 summarizes the results of each screening and each ranking process for the 13 CSSs. The test of this process suggested that the information most frequently needed to assess CSSs seems to be readily available from the EPA Regional or State offices.

The screening and ranking process as described in this guidance was reasonably easy to follow and provided useful information for ranking the severity of problem associated with CSSs. The process proved general enough to allow assessment of all CSO problems encountered. In addition, it helped bring together valuable information and provided a useful method to evaluate and rank environmental impacts typically associated with CSOs. All CSSs evaluated during this test were identified previously as having CSO problems. By applying the techniques described in this guidance, all CSSs were ranked for priority permitting, receiving scores ranging from a high of 555 to a low of 250 points.

Table A-2. Summary of Results Obtained in Applying the Screening and Ranking Process to 13 CSSs

City	Ranking Scores							
	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Total Points
Hartford, CT	250	75	10	10	0	0	0	345
Bridgeport, CT	250	75	60	30	0	25	0	440
South Portland, ME	200	0	100	30	0	0	0	330
Gloucester, MA	200	0	100	30	0	25	0	355
Holyoke, MA	250	75	10	30	0	0	0	365
Brooklyn, NY	250	150	100	30	0	25	0	555
Philadelphia, PA, #1	250	150	100	30	0	0	0	530
Philadelphia, PA, #2	250	150	100	30	0	0	0	530
Philadelphia, PA, #3	200	150	100	30	0	0	0	480
Chattanooga, TN	250	0	20[a]	10	0	25	0	305
Inkster, MI	250	75	60[a]	50	0	0	0	435
Sacramento, CA	0	0	40[a]	10	0	0	200	250
Portland, OR	250	75	10[a]	10	0	0	0	345

[a] Values reflect assumptions regarding the energy levels of the receiving waters.

Note: The cities analyzed in this test were cities with known CSO problems. Many cities may experience point totals significantly lower than these.

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Appendix B: Detailed Scoring Results

Each CSO Basin Evaluated Against Each Criteria

Table 3. Detailed Scoring Results for All LTCP CSO Basins

CSO Area	Outfall NPDES Number	Receiving Water Body	Criterion 1 (0 -250)	Criterion 2 (0 - 150)	Criterion 3 (0-100)	Criterion 4 (0 - 50)	Criterion 5 (0 - 100)	Criterion 6 (0 - 50)	EPA Criterion 1 - 6 (0-700)	V22 Modeling Report Frequency	V22 Modeling Report Volume (MG)	Frequency Score (0-100)	Volume Score (0-100)	CSO Score Criterion 7 (0-200)	Total Score (0-900)
Ballard	152	Salmon Bay	200	0	100	30	0	0	330	45.8	21.4	100	100	200	530
Fremont/Wallingford	147	Lake Union	200	0	100	30	0	0	330	38.1	8.1	100	80	180	510
Ballard	150/151	Salmon Bay	200	0	100	30	0	0	330	17.1	2.7	80	60	140	470
Delridge/Longfellow	168	Longfellow Creek	250	0	60	50	0	0	360	2.7	4.6	40	60	100	460
Delridge/Longfellow	169	Longfellow Creek	250	0	60	50	0	0	360	2.7	2.8	40	60	100	460
Fremont/Wallingford	174	Lake Union	200	0	100	30	0	0	330	8.7	3.3	60	60	120	450
North Union Bay	18	Union Bay	200	0	100	30	0	0	330	4.1	5.1	40	80	120	450
Leschi	31	Lake Washington	200	0	100	30	0	0	330	13.1	0.9	80	20	100	430
Leschi	32	Lake Washington	200	0	100	30	0	0	330	5.4	0.3	60	20	80	410
Montlake	140	Ship Canal	200	0	100	30	0	0	330	3.9	0.3	40	20	60	390
Leschi	28	Lake Washington	200	0	100	30	0	0	330	2.7	0.9	40	20	60	390
Leschi	29	Lake Washington	200	0	100	30	0	0	330	2.7	0.1	40	20	60	390
Leschi	36	Lake Washington	200	0	100	30	0	0	330	2.1	0.1	40	20	60	390
Duwamish	107	Duwamish River	200	0	60	10	0	50	320	4.9	0.9	40	20	60	380
Portage Bay	138	Portage Bay	200	0	100	30	0	0	330	1.5	0.3	10	20	30	360
Montlake	20	Ship Canal	200	0	100	30	0	0	330	1.4	0.6	10	20	30	360
Montlake	139	Ship Canal	200	0	100	30	0	0	330	1.2	0.0	10	10	20	350
Duwamish	111	Duwamish River	200	0	40	10	0	50	300	1.8	0.5	20	20	40	340
Delridge/Longfellow	99	Duwamish River	200	0	60	10	0	0	270	1.6	0.8	20	20	40	310
Central Waterfront	69	Elliott Bay	200	0	20	0	0	50	270	1.6	0.8	20	20	40	310
Magnolia	60	Salmon Bay	200	0	40	0	0	0	240	2.7	0.3	40	20	60	300

Appendix G: Long-term Model Simulation Results

Seattle Public Utilities | Protecting Seattle's Waterways

Long-Term Control Plan

Long-Term Model Simulation Results

April 2014

Seattle Public Utilities
Long-Term Control Plan; Long-Term Model Simulation Results

April 2014

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List of Abbreviations

Term	Definition
BECV	best-estimate control volume
CSO	combined sewer overflow
CSS	combined sewer system
CV	control volume
DEIS	Draft Environmental Impact Statement
Ecology	Washington State Department of Ecology
GOF	goodness-of-fit
LTCP	Long-Term Control Plan
LTS	long-term simulation
MGS	MGS Engineering Consultants Inc.
NPDES	National Pollutant Discharge Elimination System

Introduction

This document describes the computation of revised control volumes (CV) and average annual overflow frequency and volume from Long-Term Control Program (LTCP) simulations using hydraulic models re-calibrated or refined in EPA-SWMM5 Build 5.0.022 (version 22). The hydraulic models had previously been calibrated and CVs computed using EPA-SWMM5 Build 5.0.018 (version 18). Errors that were discovered in the version 18 build required re-calibration of the models and recalculation of the CVs.

The protocol of the CV computation includes assignment of uncertainties according to the procedures described in *Methods for Estimating Control Volumes for CSO Reduction: Technical Guidance Manual* (CSO Technical Guidance Manual) (prepared for Seattle Public Utilities by MGS Engineering Consultants, Inc. [MGS], March 2010) as described below.

The CVs determined by this process are to be the starting point for alternatives analysis in the LTCP. Compliance with Washington Department of Ecology (Ecology) regulations will be determined by showing that selected alternatives result in a rolling average of no more than 20 overflows in the previous 20 years. This will be the subject of separate documentation.

Computer modeling of combined sewer systems (CSSs) is technically challenging because it involves both hydrologic modeling in an urban environment and hydraulic modeling within complex sewer systems. Achieving the desired modeling objectives is made more difficult by uncertainties from several sources that can result in wide confidence bounds on model-predicted values. Experience has shown that uncertainties can yield wide confidence bounds on model-predicted values even for a well-calibrated model. The hydraulic model development and calibration work were documented in the December 2012 LTCP Hydraulic Model Reports.

The effect of uncertainties on model-predicted values was recognized early in project planning. This consideration resulted in development of methods of analysis that specifically addressed quantifying the magnitude of uncertainties and the effect of uncertainties on model-predicted values. The adopted solution methodology utilizes long-term simulations (LTSs) with the calibrated basin model to obtain a best-estimate control volume (BECV) and uncertainty bounds (see Figure 1 for example). The spread of the uncertainty bounds provides information on how the actual value of the combined sewer overflow (CSO) CV may differ from the computed BECV due to uncertainties.

Figure 1. Control volume best estimate, uncertainty bounds, and amplification factor for the Ballard 152 CSO Basin Overflow Structure

The following sections describe the procedures that were used to conduct long-term computer simulations of the CSS and to conduct an uncertainty analysis to assess the effects of uncertainties on model-predicted values. Additional details about the methods used for conducting the uncertainty analysis are described in the CSO Technical Guidance Manual (MGS, 2010).

Long-Term Simulations and Sources of Uncertainty

The basic approach to assess sewer system performance is to conduct LTSs using a calibrated basin model and a historical precipitation time-series from a nearby precipitation gauge to develop a time series of computer-simulated overflows. Uncertainties in the model and data are assessed to develop a statistical range of control volumes. The process is shown in Figure 2.

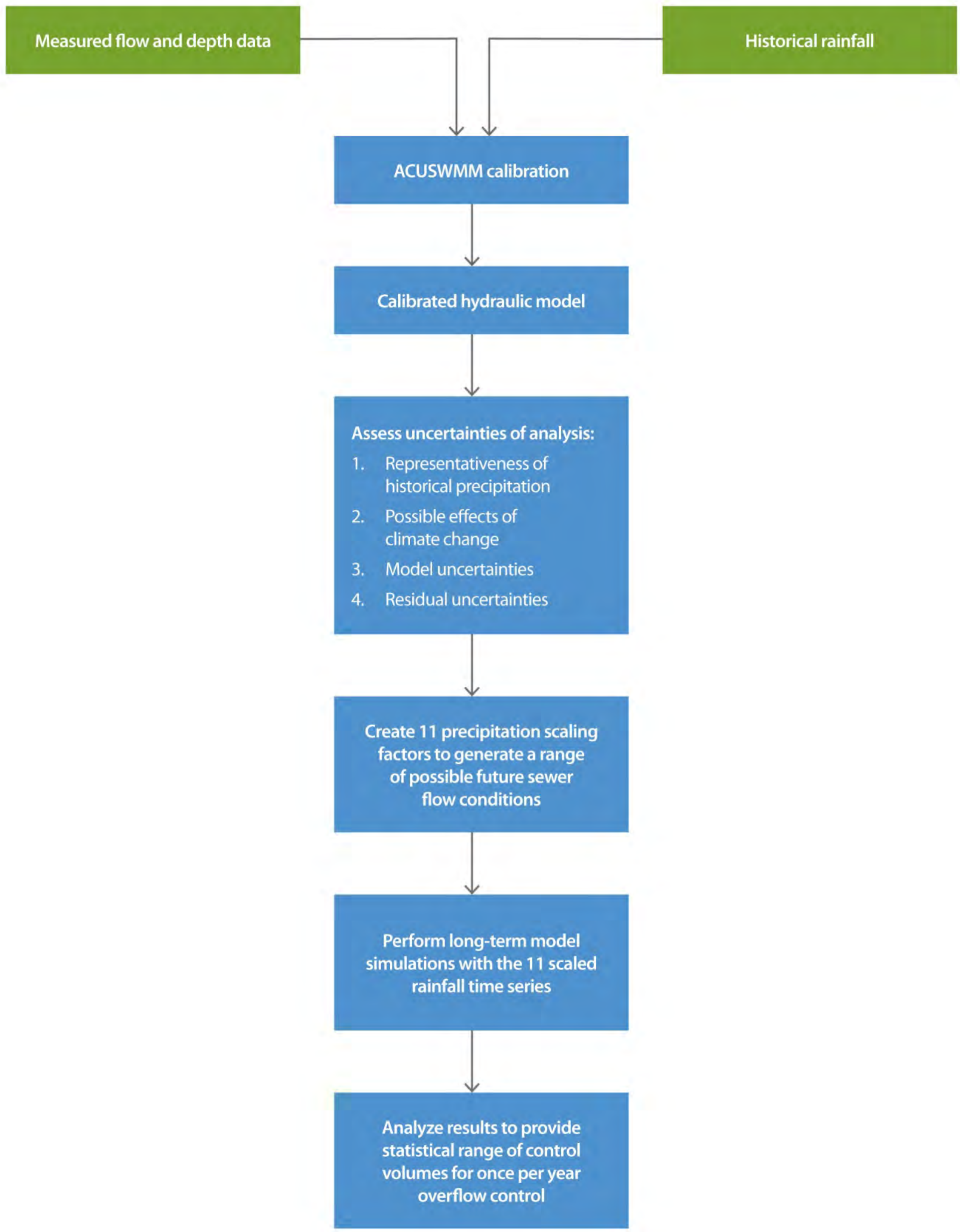

Figure 2. Process to develop control volumes

LTSs were conducted using a 32- or 34-year precipitation time series (1978 through 2009 or 2011). The shorter period was used for overflow structures in Ballard, Central Waterfront, and Fremont/Wallingford CSO Basins (associated with CSO Outfalls 069, 150/151, 152, 147, and 174), which are dependent on depths of flow in the King County interceptor. These boundary conditions, furnished by King County from results of its modeling, were available only through the end of 2009.

A CSO CV with a once-per-year frequency is determined by choosing the 32nd or 34th largest overflow volume from the time-series of computer-simulated overflows. In the uncertainty analysis, 11 separate LTSs are conducted where the historical precipitation time-series is scaled in a manner to reflect the magnitude of uncertainties from several sources. This approach yields 11 plausible futures with regard to the manner in which uncertainties can affect the magnitude of sewer flows and overflow volumes. These 11 plausible futures allow determination of the CSO BECV and uncertainty bounds. The ACU-SWMM software package was used to conduct the LTSs and compute CSO CVs and uncertainty bounds for CSO volumes with a once-per-year frequency of occurrence.

The four sources of uncertainty are described below and detailed descriptions of the computational procedures for LTSs can be found in the CSO Technical Guidance Manual (MGS, 2010).

1. **Representativeness of historical precipitation time-series:** Use of the historical precipitation time-series record to model the characteristics of future precipitation produces uncertainties in model-predicted flows for future conditions. Assuming a stationary climate, the longer the historical record is, the more likely it becomes that that record will be representative of future storm characteristics. Assessment of the precipitation record using the results from statewide and Seattle-specific precipitation-frequency studies results in a standard error of estimation (standard deviation) for precipitation-frequency of 5 percent. Thus, using conventional sampling statistical theory, the range and distribution of future precipitation can be modeled as the historical long-term time-series scaled by a precipitation scaling factor with a mean of 1.00 and a standard deviation of 0.05 drawn from a normal distribution.

2. **Possible effects of climate change:** Scientific consensus is that the climate is not stationary and that climate change is underway. The historical precipitation time-series already contains any effects of climate change in the recent past (1978–2011). The primary interest for the future 30-year planning period is what additional changes may occur in the future. A simplified probabilistic model was formulated that considers that precipitation in the future 30-year planning period may range from no change to an increase of 15 percent, with a most-likely value being a 5 percent increase. An empirical likelihood function was developed for use in conducting the uncertainty analysis and is described in the CSO Technical Guidance Manual (MGS, 2010). The range of effects of

climate change are mimicked by scaling the historical precipitation time-series by a precipitation scaling factor obtained from Monte Carlo selection from the climate change likelihood function. A 6 percent scaling factor was selected. Including this factor provides an upper bound to CV values. Excluding it provides a lower bound.

3. **Model uncertainties:** Uncertainties exist in model-predicted flow values because of inaccuracies and uncertainties in the model inputs and imperfections in the structure and governing algorithms used to make predictions. The magnitude of uncertainties in model-predicted sewer flows, described in Section 5 of the LTCP Hydraulic Model Reports, was estimated using global goodness-of-fit (GOF) measures computed during the model calibration process. Ideally, uncertainties in prediction of sewer flows for the LTSs would be modeled by adjusting the predicted sewer flows at locations within the SWMM5 model. However, this approach is impractical in the SWMM5 model. Alternatively, precipitation scaling factors were used to re-scale the historical precipitation time-series as a surrogate, forcing function to mimic changes in sewer flows. This was a practical approach recognizing the linearity of the response of stormwater runoff from impervious areas to small changes in precipitation.

4. **Residual uncertainties:** Residual uncertainties account for uncertainties that arise from sources other than the three categories described above. This includes the effect of the number of flow meters, quality of flow data, and representativeness of precipitation used in model calibration. It also includes uncertainties associated with hydraulic components such as HydroBrakes, pump stations, flap gates, overflow weirs, and storage tanks that add to the uncertainty of system performance in the long-term future period. The effects of residual uncertainties were mimicked using precipitation scaling factors in the same manner as described above for model uncertainties.

Discussion of Model and Residual Uncertainty

Basin models are developed because of their usefulness in the analysis of system operation and in design of system components. Nonetheless, it is recognized that all hydrologic and hydraulic models are imperfect in their ability to predict future outcomes. This occurs because there are inaccuracies and uncertainties in the model inputs and imperfections in the structure of a computer model to numerically mimic real-world hydrologic and hydraulic processes. Thus, while great care was taken in model construction and model calibration, uncertainties remain in model predictions such as sewer flows, hydraulic depths, and overflow volumes. These uncertainties are discussed in the following paragraphs. Uncertainty values for each overflow structure in the LTCP models are contained in Appendix A.

Model Uncertainties

Two numerical GOF measures were computed during model calibration to characterize the level of uncertainty by describing how well model-predicted sewer flow hydrographs replicated recorded sewer flow hydrographs for individual storm/sewer flow events and globally for the collection of storm/sewer flow events. For a given subbasin, GOF measures were computed for comparison of model-predicted and recorded sewer flow volume and peak discharge. A standard deviation was also computed for the collection of GOF measures for sewer flow volume from individual storms to characterize the uncertainty in the accuracy of model-predicted sewer flow volumes.

The measures of model uncertainty of interest are applicable to the outlet of the CSO basin where sewer flows are tributary to the overflow structure. In many cases, this location in the sewer system includes sewer flow contributions from several upstream subbasins that have been calibrated separately. In these cases, global GOF measures for model uncertainty are computed as a weighted average of the GOF measures for the upstream subbasins where the weights are based on the proportion of sewer flow contribution from each subbasin.

Model bias was assessed primarily by examining how well simulated sewer flow volumes replicated recorded sewer flow volumes for all upstream subbasin models. A mean value of 1.00 for the global GOF measure of sewer flow volume indicates that on average the simulated sewer flow volumes replicated recorded sewer flow volumes and a value below or above 1.00 indicates under-simulation or over-simulation, respectively. The global GOF measure for peak discharge for all upstream subbasins was also considered in addition to the global GOF values for sewer flow volumes in assessing model bias, where a value of 1.00 indicates that on average the simulated peak discharge replicated the recorded peak discharge.

The variability in prediction (under-simulation/over-simulation) among all sewer flow events for all upstream subbasin models was computed as the standard deviation of sewer flow volumes for simulated versus recorded hydrographs. A value of 0.00 for the global GOF measure of the standard deviation of volume indicates perfect replication across all hydrographs. Increasingly larger values of the global GOF standard deviation volume measure indicate greater variability and lower predictive capability from sewer flow event to sewer flow event. The proportion of flow from each subbasin was used in weighting global GOF measures from each subbasin in computing weighted averages of the uncertainty measures.

In assessing model bias, the global GOF values for peak discharge for all upstream subbasins was considered in addition to the global GOF values for sewer flow volumes. The standard deviation of sewer flow volumes was taken to be the weighted average of the global GOF measures for the upstream subbasin models.

Residual Uncertainties

The measure of residual uncertainties accounts for additional contributors to uncertainty beyond the three sources discussed previously. Specifically, the adequacy of the GOF measures computed during model calibration is dependent upon the number and quality of flow meters and the representativeness of storm characteristics in the calibration period relative to the diversity of durations, intensities, and seasonality of storms anticipated in the future period. Uncertainties in the operation of hydraulic components such as HydroBrakes, pump stations, flap gates, and overflow weirs also add to the uncertainty of system performance in the long-term future period.

- **Number and quality of flow meters:** Obtaining high-quality flow data is technically challenging in the sewer system. The quality of flow measurement data affects the reliability of computed GOF measures. In addition, any single flow meter may systematically measure high or low at a given installation due to site-specific hydraulic characteristics. Consideration of sampling statistics indicates that greater reliability is achieved in computed GOF measures when more meters are used in the computation. Table 1 provides guidance in assessing the uncertainty contribution based on the number of meters used in computing GOF measures.

Table 1. Guidelines for Evaluating Adequacy of Number of Flow Meters for Computing GOF Measures

Number of meters	0	1	2	3	4
Residual uncertainty	10%	6%	4%	2%	0%

- **Representativeness of storm characteristics in calibration period:** The reliability of model calibration is higher when there is diversity of storm characteristics in the calibration period that represents what is anticipated to occur in the future long-term period. Diversity of storm characteristics would include long-duration storms with low to moderate intensities in the fall and winter months that produce sustained sewer flows with varying amounts of groundwater inflow. It would also include storms with short durations and high intensities in the drier months of the year, which can produce a flashy sewer flow response with minimal groundwater inflow. Table 2 provides guidance for selection of the magnitude of residual uncertainty associated with the representativeness of storms in the calibration period.

Table 2. Guidelines for Evaluating Adequacy of Representativeness of Storms in Calibration Period

Representativeness of storms	Poor	Fair	Good	Very good
Residual uncertainty	10%	4%	2%	0%

- **Uncertainties from other sources in the sewer system:** Other basin-specific sources of uncertainty can contribute to the total residual uncertainty. In particular, hydraulic elements such as HydroBrakes, pump stations, orifices, flap gates, operation of storage tanks, etc. can affect the distribution of sewer flows arriving at, or within, the overflow structure. Table 3 provides guidance in selection of the level of residual uncertainty contributed by hydraulic elements.

Table 3. Guidelines for Assessing Residual Uncertainties for Hydraulic Components

Qualitative impact of uncertainty from hydraulic components	Minor	Moderate	Major	
Residual uncertainty	2%–4%	4%–7%	High 7%–10%	Very high >10%

Precipitation Scaling Factors

Prediction of sewer flows for the future period were modeled using the SWMM5 calibrated basin model and long-term precipitation time-series that were scaled to incorporate effects from the four sources of uncertainty described previously. Monte Carlo sampling procedures were used to assemble a representative sample set of 11 precipitation scaling factors that were used to scale the historical precipitation time-series for conducting the uncertainty analysis for CSO CVs. These 11 long-term precipitation time-series generated 11 sewer flow time-series, which represent 11 plausible outcomes of how the sewer system will perform in the future period. Normal distributions were used to model the distribution of precipitation scaling factors for uncertainties for the long-term historical precipitation time-series, model uncertainties, and residual uncertainties. An empirical likelihood function was used for modeling of precipitation scaling factors for climate change uncertainty. Precipitation scaling factors so derived are included in the attached CV_Summary spreadsheets.

Amplification Factor, Non-Linearity of Overflow Volumes

The results from prior uncertainty analyses indicate that the sewer system response for prediction of sewer flows is nearly linear for the magnitude of uncertainties commonly encountered in the Seattle CSS. However, estimates of sewer overflow volumes are often highly non-linear because sewer overflows are the diverted portion of a larger flow in the main line. Small increases in the magnitude of sewer flow in the inflow main line can produce relatively large increases in the magnitude of diverted flow that overflows. This non-linearity in prediction of overflow volumes is termed the amplification factor and is a characteristic of a specific overflow structure configuration and magnitude of inflows. For example, if actual sewer flows are 10 percent larger than predicted, the majority of the 10 percent excess could be directed to the overflow weir. If the computed amplification factor were 5.0 in this case, the 10 percent error in estimated sewer flow would result in a 50 percent increase in the overflow volume.

The amplification factor is computed strictly as the ratio of the coefficient of variation of non-zero CVs divided by the coefficient of variation of the precipitation scaling factors that produced non-zero CVs. Where all precipitation factors produce CVs, the amplification factor is approximately the ratio of the change in CV for a 10 percent change in precipitation scaling factor.

The non-linear behavior of sewer overflow volumes is the primary cause for wide uncertainty bounds for the CSO BECV. Amplification factors were computed for each of the model CSO basins. These are presented as qualitative expressions of the change in overflow volume to be expected for a unit error in estimation of sewer flows. The qualitative amplification factors are associated with ranges of computed numerical factors, as shown in Table 4.

Table 4. Association of Qualitative Amplification Factors to Computed Numerical Ranges

Qualitative amplification factor	Range of computed numerical values
Low	0–1.25
Moderate	1.25–2.5
High	2.5–5.0
Very high	5.0–10.0
Extreme	>10

Summary of Results

For each CSO basin (with the exception of the East Waterway CSO Basin discussed in Appendix B), 11 LTSs were conducted using the calibrated basin model and the historical precipitation time-series scaled (multiplied) by the 11 precipitation scaling factors. These 11 LTSs represent 11 plausible futures based on what might be the actual conditions in the future for the four sources of uncertainty.

ACU-SWMM computes the volume and duration of each overflow event simulated during the period of each LTS. The collection of overflows is ranked from largest to smallest and the once-per-year CV for each LTS is computed. The CSO BECV is computed as the mean of the 11 CVs found in the 11 LTSs. Uncertainty bounds are computed by fitting a three-parameter Gamma Distribution to the 11 CVs. The results of these analyses for each modeled basin are listed in Table 5. Computed CVs, uncertainty statistics, and computed overflows that are the basis for Table 5 are contained in Appendix A.

Table 5 includes the BECVs computed with SWMM5 version 18 as well as those computed with version 22 after re-calibration and hydraulic refinement. The version 22 BECVs are included together with the 16th, 50th, and 84th percentile values that express the statistical variation in the potential CV. The BECV is often near the 50th percentile, but it should be recognized that the actual value may be higher or lower. The version 22 BECVs will be used for preliminary sizing and analysis of CSO control measures in the LTCP, and to assess environmental impacts in the LTCP DEIS.

Table 5 includes the qualitative amplification factor, which is a qualitative expression of the change in overflow volume to be expected for a unit error in estimation of sewer flows as described above.

The “change in BECV” column in Table 5 expresses the percent change in the version 22 BECV compared to the version 18 values.

The “probability of control” column in Table 5 is an estimation of the likelihood of the CSO basin complying with the once-per-year regulation accounting for uncertainties. It is computed as the number of LTSs that did not result in at least as many overflows as the simulation period (thus not having a once-per-year overflow volume) as a percentage of the total number of LTSs (11).

The two columns in Table 5 labeled “overflow frequency” and “annual volume” present the average frequency of overflows per year and the average overflow volume per year found from LTSs using a precipitation scaling factor of 1.0 (existing rainfall historical precipitation time-series).

The final column in Table 5, labeled “version 22 CV w/o climate change,” presents the BECV estimated after the uncertainty associated with climate change is removed.

Table 5. Control Volume Results													
CSO Basin	Overflow Structure	Version 18 BECV[f]	Version 22 BECV [f]	16%[a,f]	50%[a,f]	84%[a,f]	Amplification factor[b]	Change in BECV	Probability of control[c]	Current overflow frequency per/yr	Current annual volume (MG/yr)	V22 CV w/o climate change[e,f]
		MG	*MG*	*MG*	*MG*	*MG*		*%*	*%*	*Model[d]*	*Model[d,f]*	*MG*
Ballard	150/151	0.47	0.62	0.40	0.59	0.84	High	33	0	16.00	2.90	0.45
Ballard	152	4.07	5.38	3.29	5.11	7.46	High	32	0	47.80	23.50	4.38
Delridge	099	0.07	0.17	0.03	0.15	0.31	Very high	137	9	1.50	0.81	0.11
Delridge	168	2.49	2.00	0.76	1.94	3.23	Very high	-17	0	2.30	4.42	1.45
Delridge	169	0.47	1.19	0.43	1.09	1.94	Very high	166	0	1.80	2.81	0.74
Duwamish	111(B)	0.01	< 0.01	< 0.01	< 0.01	0.01	Very high	-58	9	1.10	0.20	< 0.01
Duwamish	111(C)	0.00	< 0.01	0.00	< 0.01	< 0.01	Extreme	0	18	1.10	0.20	< 0.01
Duwamish	111(H)	0.09	0.01	0.00	0.00	0.02	Extreme	-92	63	0.70	0.21	< 0.01
East Waterway[g]	107	NA	0.50	NA	NA	NA	NA	NA	0	5.7	1.50	0.45
Fremont	147A	1.86	2.08	1.74	2.07	2.42	Moderate	12	0	37.50	8.60	1.9
Fremont	147B	0.06	0.07	0.04	0.07	0.10	High	31	0	4.40	0.30	0.06
Fremont	174	0.93	1.06	0.91	1.05	1.22	Low	14	0	8.60	3.80	0.99
Interbay	068A	0.06	0.02	0.00	0.00	0.05	Extreme	-66	64	0.50	0.18	< 0.01
Interbay	068B	0.00	0.01	0.00	0.00	0.02	Extreme	--	45	0.60	0.09	< 0.01
Leschi	026	0.00	0.00	0.00	0.00	0.00	NA	--	100	0.10	<0.01	0
Leschi	027	0.00	0.00	0.00	0.00	0.00	NA	--	100	0.00	0.00	0
Leschi	028	0.01	< 0.01	0.00	< 0.01	0.01	Extreme	-72	18	1.20	0.03	< 0.01
Leschi	029	0.01	0.02	0.01	0.01	0.02	Very high	113	0	1.60	0.01	0.01
Leschi	030	< 0.01	< 0.01	0.00	0.00	0.01	Extreme	31	72	0.60	0.06	< 0.01
Leschi	031	0.13	0.31	0.21	0.29	0.41	High	142	0	16.00	0.93	0.25
Leschi	032(A)	0.02	0.01	< 0.01	0.01	0.01	Very high	-67	0	1.70	0.05	< 0.01
Leschi	032(B)	0.02	0.07	0.05	0.06	0.09	High	225	0	6.60	0.22	0.05
Leschi	033	< 0.01	0.00	0.00	0.00	0.00	NA	-100	100	0.10	<0.01	0
Leschi	034	0.29	0.03	0.00	0.01	0.05	Extreme	-91	27	0.90	0.30	< 0.01
Leschi	035	0.00	< 0.01	0.00	< 0.01	< 0.01	Extreme	--	18	1.10	0.01	< 0.01
Leschi	036	0.03	0.03	0.01	0.03	0.05	Very high	-17	9	2.10	0.12	0.017

Table 5. Control Volume Results												
CSO Basin	Overflow Structure	Version 18 BECV[f]	Version 22 BECV [f]	16%[a,f]	50%[a,f]	84%[a,f]	Amplification factor[b]	Change in BECV	Probability of control[c]	Current overflow frequency per/yr	Current annual volume (MG/yr)	V22 CV w/o climate change[e,f]
		MG	*MG*	*MG*	*MG*	*MG*		*%*	*%*	*Model[d]*	*Model[d,f]*	*MG*
Madison Park	022	--	< 0.01	0.00	< 0.01	0.00	Extreme	--	45	0.80	0.01	< 0.01
Madison Park	024	0.50	0.11	0.00	0.09	0.23	Very high	-78	18	1.30	0.39	0.07
Madison Park	025	0.04	0.01	0.00	<0.01	0.02	Extreme	-86	45	0.80	0.06	< 0.01
Magnolia	060	--	0.11	< 0.01	0.06	0.24	Very high	--	18	3.10	0.26	0.09
Montlake	020	0.08	0.16	0.00	0.07	0.39	Very high	111	27	1.10	0.64	0.12
Montlake	139	< 0.01	0.01	< 0.01	0.01	0.01	Very high	143	9	1.20	0.04	< 0.01
Montlake	140	0.02	0.05	0.01	0.04	0.10	Very high	205	0	4.40	0.28	0.02
North Union Bay	018A	0.15	0.26	0.14	0.24	0.37	Very high	75	0	4.10	0.70	0.19
North Union Bay	018B	2.15	1.37	0.66	1.31	2.08	Very high	-36	0	2.40	4.30	0.98
Portage Bay	138	0.07	0.11	0.04	0.10	0.18	Very high	61	0	1.70	0.31	0.07
CWF Vine Street	069	--	0.07	0.01	0.06	0.13	Very high	--	9	1.40	0.54	0.05

[a] *Uncertainty statistics taken from 32- or 34-year simulations; 32-year simulations for Ballard, Fremont, and Vine Street CSO Basins due to lack of boundary condition data.*

[b] *Relative change in expected overflow volume due to error in flow estimation.*

[c] *Probability of control computed as the number of long-term simulations with fewer overflows than the simulation length divided by 11. Includes climate change uncertainty.*

[d] *From 32- or 34-year simulation with Rainfall scaling = 1.0.*

[e] *Estimated control volume after removal of climate change uncertainty but keeping other uncertainties.*

[f] *Estimated control volumes less than 5,000 gallons are shown as < 0.01. Control volumes of 0.005 to 0.01 are rounded up to 0.01.*

[g] *See Appendix B for method and results*

Appendix A: Control Volume Summaries and Uncertainty Parameters

Long-Term Simulation Results Appendix A Contents

All Files Submitted Electronically. NPDES is used for convenience in file naming. Files refer to individual overflow structures in the basins tributary to CSO outfalls with indicated numbers.

CV Summaries

NPDES150_Ballard_CV_Summry_32Year.xlsx
NPDES152_Ballard_CV_Summry_32Year.xlsx
NPDES99_Delridge_CV_Summary_34Year.xlsx
NPDES168_Delridge_CV_Summary_34Year.xlsx
NPDES169_Delridge_CV_Sumary_34Year.xlsx
NPDES111B_Duwamish_CV_Summary_34Year.xlsx
NPDES111C_Duwamish_CV_Summary_34Year.xlsx
NPDES111H_Duwamish_CV_Summary_34Year.xlsx
NPDES147A_Fremont_CV_Summary_32Year.xlsx
NPDES147B_Fremont_CV_Summary_32Year.xlsx
NPDES174_Fremont_CV_Summary_32Year.xlsx
NPDES68A_Interbay_CV_Summary_34Year.xlsx
NPDES68B_Interbay_CV_Summary_34Year.xlsx
NPDES28_Leschi_CV_Summary_34year.xlsx
NPDES29_Leschi_CV_Summary_34year.xlsx
NPDES30_Leschi_CV_Summary_34year.xlsx
NPDES31_Leschi_CV_Summary_34year.xlsx
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NPDES22_Madison_CV_Summary_34year.xlsx
NPDES24_Madison_CV_Summary_34year.xlsx
NPDES25_Madison_CV_Summary_34year.xlsx
NPDES60_Magnolia_CV_Summary_34year.xlsx
NPDES20_Montlake_CV_Summary_34year.xlsx
NPDES139_Montlake_CV_Summary_34year.xlsx
NPDES140_Montlake_CV_Summary_34year.xlsx
NPDES18A_NUB_CV_Summary_34year.xlsx
NPDES18B_NUB_CV_Summary_34year.xlsx
NPDES138_PortageBay_CV_Summary_34year.xlsx
NPDES69_VineSt_CV_Summary_32Year.xlsx

Uncertainty Parameters and Derived Precipitation Scaling Factors

AllUncertaintyParameters.xlsx

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Appendix B: Long-Term Control Plan Determination of Control Volume for the East Waterway CSO Basin

Seattle Public Utilities

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Long-Term Control Plan Determination of Control Volume – East Waterway CSO Basin

January 2014

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List of Abbreviations

Term	Definition
BECV	best estimate control volume
CSO	combined sewer overflow
EBI	Elliott Bay Interceptor
KC	King County
MG	million gallon (s)
mgd	million gallon (s) per day
NPDES	National Pollutant Discharge Elimination System
RS	regulator station
PS	pump station
SCADA	supervisory control and data acquisition
SPU	Seattle Public Utilities

SECTION 1

Introduction

A hydraulic model was constructed for the East Waterway Combined Sewer Overflow (CSO) Basin associated with CSO Outfall107 (CH2M Hill/Brown and Caldwell, 2014). That model was constructed using King County (KC) supervisory control and data acquisition (SCADA) data for the flow from the Duwamish pump station (PS), the West Seattle PS, and the level in the Elliott Bay Interceptor (EBI) at the inflow point from the Hanford Regulator Station (RS). The following sections describe use of this model to predict the overflow frequency and control volume for this basin.

SECTION 2

Methodology

Calibration and verification of this model indicated that it reliably predicted the number of reported overflow events and event durations from 2009 through 2012. The model also shows that overflows at the East Waterway overflow structure are directly associated with high levels in the EBI.

King County furnished results of its 2010 model run (model used to develop the King County CSO Plan) for use in long-term simulations of this basin. Results were provided for the Duwamish PS discharge, the West Seattle PS discharge, the EBI level at the junction with the Hanford RS, and the EBI level just downstream of the Duwamish PS. Examination of these results compared to SCADA data in the overlapping period of 2009 indicated that the KC model results for this period did not reliably reflect the observed data. If the KC model results were used in place of SCADA data for the 2009 period, the East Waterway model would predict significantly lower overflow volumes and number of events compared to Seattle Public Utility (SPU) reports.

The SPU annual CSO reports prior to 2007 are known to have questionable data accuracy. For example, the model (using KC model data) predicted seven overflows in 2006, whereas none were reported. In addition, the East Waterway model was shown to both overestimate and underestimate reported overflow volumes in the 2009–12 period. As a result, the control volume for this basin was estimated with the following approach:

1. Overflows were compiled for the last 20 years (moving 20-year average) using a combination of reported and model-simulated events. Model results were used where the model predicted higher volumes or greater frequency than the reported data, and vice versa to determine compliance with the requirements outlined in the Consent Decree lodged July 3, 2013, under Section IV, paragraph 9 (ee) as follows:

   "Section IV, Paragraph 9 (ee). "Twenty Year Moving Average" shall mean the average number of untreated discharge events per CSO Outfall over a twenty year period for purposes of compliance with WAC 173- 245-020(22). For previously Controlled CSO Outfalls and where monitoring records exist for the past 20 consecutive years, the twenty year moving average shall mean the average number of untreated discharges per CSO Outfall over the 20 year record. On an annual basis, the twenty year moving average will be calculated and includes the current monitored year and each of the previous 19 years of monitored CSO data. For CSO reduction projects and Controlled CSO Outfalls where a complete twenty year record of monitored data does not exist, missing annual CSO frequency data will be generated based on the predicted CSO frequency for a given year as established in the approved engineering report or facility plan. For each CSO reduction project, the engineering report or facility plan shall predict the CSO frequency for each CSO Outfall (s) based on long-term simulation modeling using a 20-year period of historical rainfall data, the hydraulic model, the CSO control project design and assuming the CSO control project existed throughout the 20-year period. For CSO reduction projects, the level of control is the number of discharge events per CSO Outfall per year that are estimated to occur based on the designed CSO control project over a 20-year period. The level of control will be estimated for each year for a period of 20 years in the engineering report or facility plan."

2. The compiled series of overflow events was used to estimate both the frequency of overflows for the last 20 years and the control volume necessary to reduce the frequency to once per year.

SECTION 3

Results

The compiled overflow series is shown in Figures 3-1 and 3-2, and listed in Appendix A. Figure 3-1 presents the overflow volumes for all events occurring in the 10-year period from January 1, 2003, through December 31, 2012. Figure 3-2 presents overflow volumes for all events occurring from January 1, 1993, through December 31, 2002. The frequency of predicted or observed overflows per year in the period from 1993 through 2012 is shown in Figure 3-3.

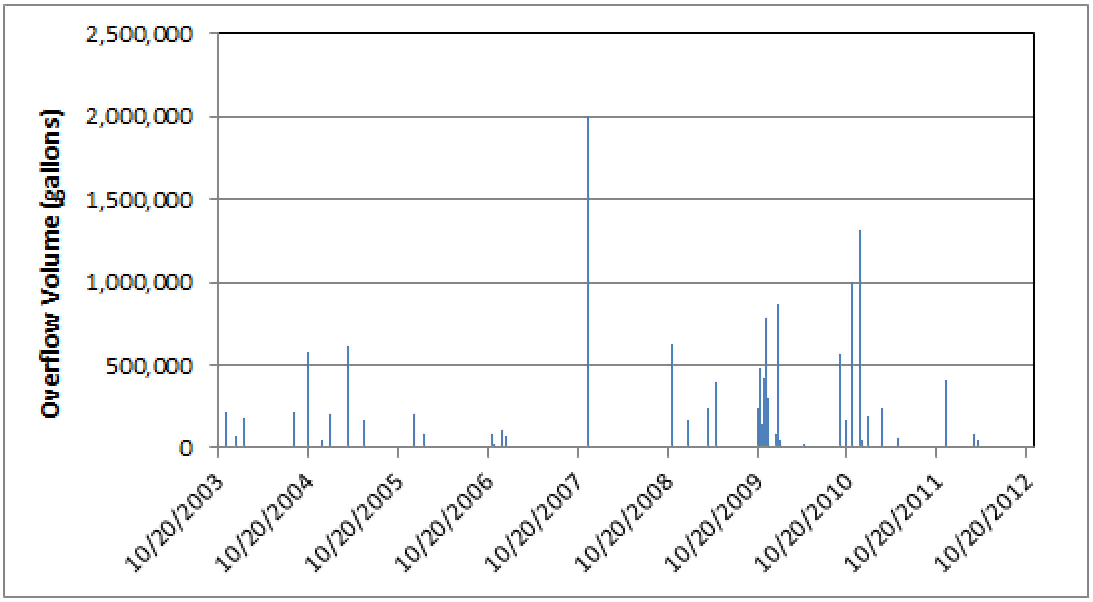

Figure 3-1. East Waterway overflow volumes from 1/1/2003 through 12/31/2012

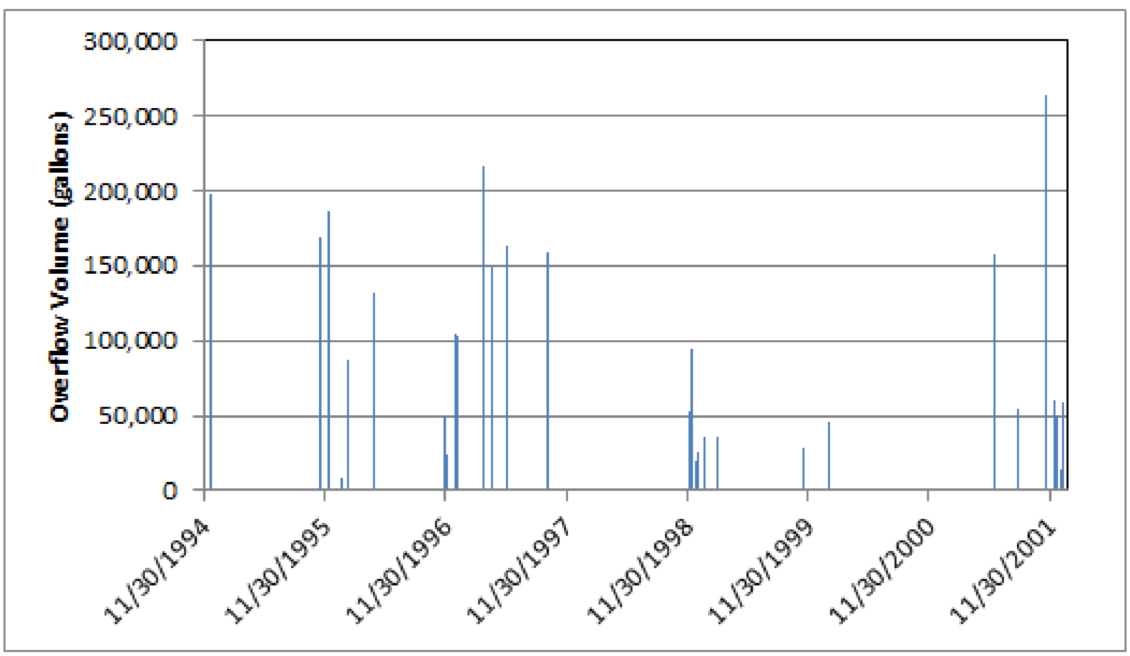

Figure 3-2. East Waterway overflow volumes from 1/1/1993 through 12/31/2002

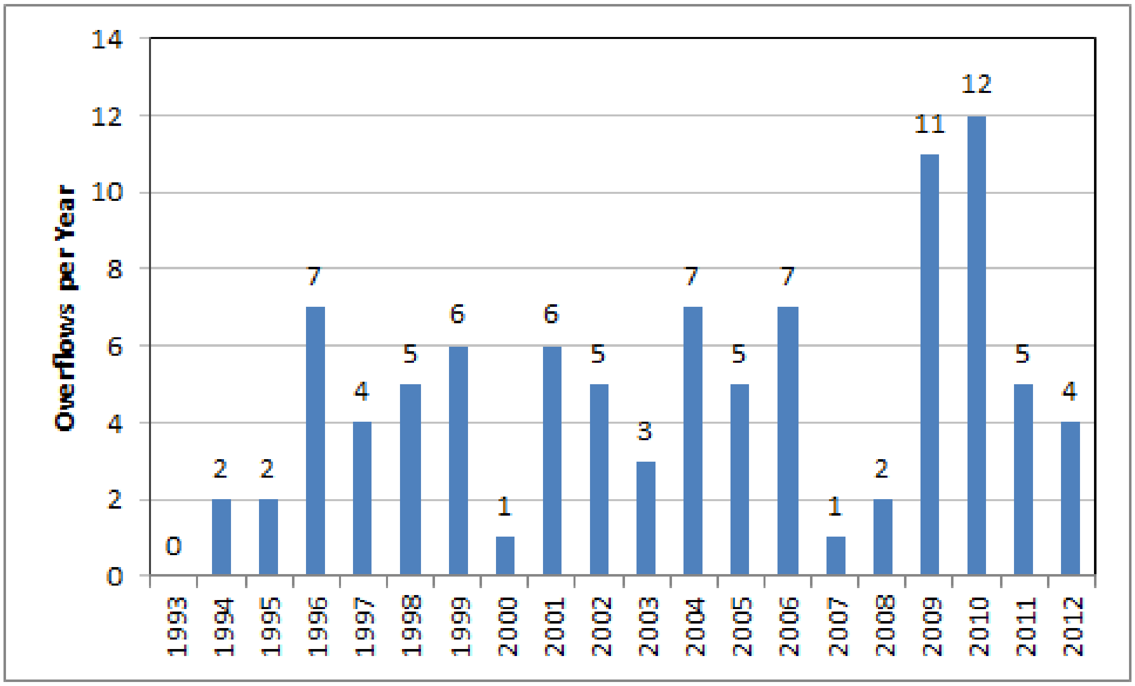

Figure 3-3. East Waterway overflow frequency per year from 1993 through 2012

Examination of Figures 3-1 through 3-3 indicates the following:

1. The overflow volumes in the 1993 through 2002 period (Figure 3-2, principally from a simulation using the KC model results that are believed to produce a low overflow volume) are significantly lower than the results for the last 10 years (Figure 3-1).
2. The frequency of events in 2009 and 2010 are approximately twice that of any other 2-year period in the series. Overflow volumes in these years are also significantly higher on average than other years in the series. The overflows in this period are well represented by the model using KC SCADA data.

Selection of a control volume to achieve a once per year overflow frequency over the last 20 years of analysis would result in an overflow frequency of 1.5 per year in the last 10 years due to the extraordinary period of 2009–10. As a consequence, the control volume was set to achieve no more than 10 overflows in the last 10 years (2003–12).

The best estimate control volume (BECV) was derived based on the above-described approach by finding the control volume for existing rainfall and assigning a low amplification factor (CH2M Hill/Brown and Caldwell, 2013) based on the East Waterway model response to increased rainfall. The BECV was thereby estimated to be 0.5 million gallons (MG). Table 3-1 summarizes the results of these analyses.

Parameter	Existing system[a]	After BECV (0.5 MG) implementation
Overflow frequency (per year)	5.7 (4.8)	1.0
Overflow volume (MG/yr)	1.5 (0.9)	0.5
Maximum overflow rate (mgd)[b]	5.0	NA

Table 3-1. Summary of East Waterway Control Volume Analyses

a. *Values are averages for the 10-year period 2003–12. Values in parentheses are for the 20-year period 1993–2012).*

b. *Value equaled or exceeded once per year on average.*

SECTION 4

Summary

The analysis of a time series of overflows expected at the East Waterway CSO Basin overflow structure (associated with CSO Outfall107) over the last 20 years was developed by compiling reported data and model predictions where they were believed to be more accurate. Using the compiled series, a BECV of 0.5 MG was estimated for the East Waterway CSO Basin.

Overflows in the East Waterway are directly associated with high levels in the King County EBI. Modeling suggests that overflow frequency and volume would be significantly reduced if a check valve were installed separating the basin from the EBI.

SECTION 5

References

CH2M HILL, Brown and Caldwell (2013). Long-Term Control Plan Long-Term Model Simulation Results.

CH2M HILL, Brown and Caldwell (2014). Long-Term Control Plan Hydraulic Model Report Modeling Report, East Waterway NPDES107.

Appendix A: Compiled Overflow Time Series

Table A-1. Compiled East Waterway CSO Basin Overflow Events

(Yellow highlighted values from East Waterway hydraulic model)

Date	Duration (hr)	Overflow Volume (Gallons)	Max Overflow Rate (mgd)
11/19/2012	11.03	242,586	2.76
05/03/2012	0.63	12,428	0.91
03/29/2012	1.03	45,310	0.87
03/15/2012	1.33	84,733	2.44
12/28/2011	0.43	14,830	0.70
11/22/2011	24.23	413,300	2.35
5/14/2011	1.90	63,270	1.08
3/9/2011	13.67	244,984	2.25
1/12/2011	24.10	193,122	1.92
12/13/2010	0.90	42,710	0.78
12/11/2010	16.73	1,317,790	3.24
12/8/2010	1.27	47,630	1.06
11/1/2010	7.87	997,810	4.73
10/9/2010	3.00	166,775	1.87
9/17/2010	28.67	569,936	4.69
4/21/2010	1.13	25,800	0.90
1/15/2010	1.67	43,680	1.07
1/13/2010	1.03	34,540	1.20
1/11/2010	6.10	868,057	4.43
1/8/2010	1.63	49,692	1.37
1/4/2010	1.30	79,758	2.20
11/26/2009	3.80	295,660	2.75
11/22/2009	3.07	785,230	8.97
11/19/2009	2.07	183,001	3.29
11/16/2009	13.03	418,365	1.00
11/6/2009	12.63	146,038	2.60
10/26/2009	4.90	486,610	4.50
10/16/2009	16.03	239,803	4.20
10/14/2009	0.97	12,772	1.90
5/5/2009	2.50	402,134	7.30
4/2/2009	1.83	244,327	5.30
1/7/2009	5.75	165,998	3.00
11/6/2008	12	625,537	3.00
3/23/2008	1.0	1,820	0.30
12/2/2007	29	2,008,192	3.80
12/26/2006	5	72,610	0.91
12/14/2006	5.58	107,700	2.50
11/12/2006	1	17,140	1.60
11/6/2006	3	77,980	4.10
11/4/2006	0.75	3,381	0.60
2/2/2006	0.17	81,000	0.30
1/29/2006	8.58	32,580	1.74
12/25/2005	1.17	174,655	0.90
12/24/2005	2.08	200,386	1.90
5/31/2005	0.25	170,266	1.10
3/27/2005	12	617,204	4.50
1/17/2005	4.67	208,049	0.90
12/11/2004	2	7,091	NA
12/10/2004	3	47,740	NA
12/8/2004	3	4,323	NA
10/17/2004	4	572,604	NA
10/8/2004	1	45	NA
8/22/2004	5.33	213,863	3.00
1/29/2004	26	179,248	0.50
12/27/2003	0.17	67,153	0.30
11/18/2003	22.42	218,157	1.10
10/20/2003	8	266,100	2.90

Date	Duration (hr)	Overflow Volume (Gallons)	Max Overflow Rate (mgd)
1/25/2002	7	32,874	NA
1/6/2002	18	58,122	NA
1/5/2002	1	42	NA
1/3/2002	1	1,522	NA
1/2/2002	2	14,798	NA
12/16/2001	12	49,711	NA
12/13/2001	8	60,656	NA
11/19/2001	3	17,962	NA
11/13/2001	25	263,820	NA
8/22/2001	6	54,862	NA
6/11/2001	5	157,002	NA
2/1/2000	8	45,173	NA
11/11/1999	4	27,883	NA
2/27/1999	10	35,586	NA
1/21/1999	2	7,076	NA
1/20/1999	1	365	NA
1/18/1999	2	4,108	NA
1/17/1999	8	35,007	NA
12/29/1998	8	25,871	NA
12/27/1998	4	14,994	NA
12/25/1998	4	19,588	NA
12/13/1998	23	93,855	NA
12/2/1998	7	53,503	NA
10/4/1997	0.17	159,210	0.44
5/31/1997	1.67	163,999	0.26
4/19/1997	0.17	149,256	0.18
3/18/1997	29.17	217,091	0.78
12/31/1996	40.08	102,700	1.34
12/29/1996	4	104,800	2.13
12/4/1996	2.33	23,840	1.94
11/27/1996	1.58	49,290	1.09
4/23/1996	12	131,200	0.99
2/8/1996	19.33	87,980	1.21
1/20/1996	0.17	7,711	2.22
12/10/1995	4.92	186,466	0.69
11/11/1995	0.92	169,754	0.30
12/19/1994	1.5	197,833	0.72
11/30/1994	2	189,432	2.38

Appendix H: Inflow and Infiltration Analysis Report

Seattle Public Utilities

Protecting Seattle's Waterways

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 20 - Montlake
NPDES 30 - Leschi
NPDES 34 - Leschi
NPDES 152 - Ballard

December 2012

Prepared by
Seattle Public Utilities
Project Management and Engineering Division

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List of Abbreviations

Term	Definition
BECV	Best Estimate Control Volume
CMOM	Capacity, Management, Operations and Maintenance Guidelines
CSO	Combined Sewer Overflow
EPA	Environmental Protection Agency
Gal	gallons
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
GSI	Green Stormwater Infrastructure
I/I	Inflow and Infiltration
LTCP	Long Term Control Plan
mgd	million gallons per day
NPDES	National Pollution Discharge Elimination System
SPU	Seattle Public Utilities

SECTION 1

Background

Inflow and infiltration (I/I) are identified within SPU's 2010 CSO Reduction Plan Amendment, prepared by Tetra Tech dated May 2010, as being a possible source of CSO control for several basins. The basins include Ballard (NPDES 152), Leschi (NPDES 30 and 34), and Montlake (NPDES 20). The purpose of this document is to evaluate the effectiveness and estimated financial cost to address I/I within these basins.

Sewage collection and conveyance systems are frequently subjected to infiltration of groundwater and inflow of surface water. Infiltration is the water which enters a sewer system from the ground, through such means as defective pipes, pipe joints, side sewer connections or maintenance holes. Inflow is water discharged into a sewer system from roof leaders, yard and area drains, foundation drains, maintenance hole lids and combined sewer connections from right-of-way areas via inlets and catch basins. Sources of I/I are shown in Figure 1-1.

Recent studies by King County estimate that up to 75% of the peak flow to the South Wastewater Treatment Plant, which serves only separated sewers, comes from I/I. Excess I/I can drive the need for enlarging and replacing conveyance facilities (pipes and pump stations) and can also lead to combined sewer overflows. If cost-effective methods for I/I control can be identified and implemented, capital costs for conveyance improvements and CSO storage facilities could be reduced or eliminated. Optimizing system capacity by reducing infiltration and/or inflow is one of the standards that the U.S. Environmental Protection Agency (EPA) has required of wastewater utilities in Consent Orders and Capacity, Management, Operations, and Maintenance (CMOM) guidelines.

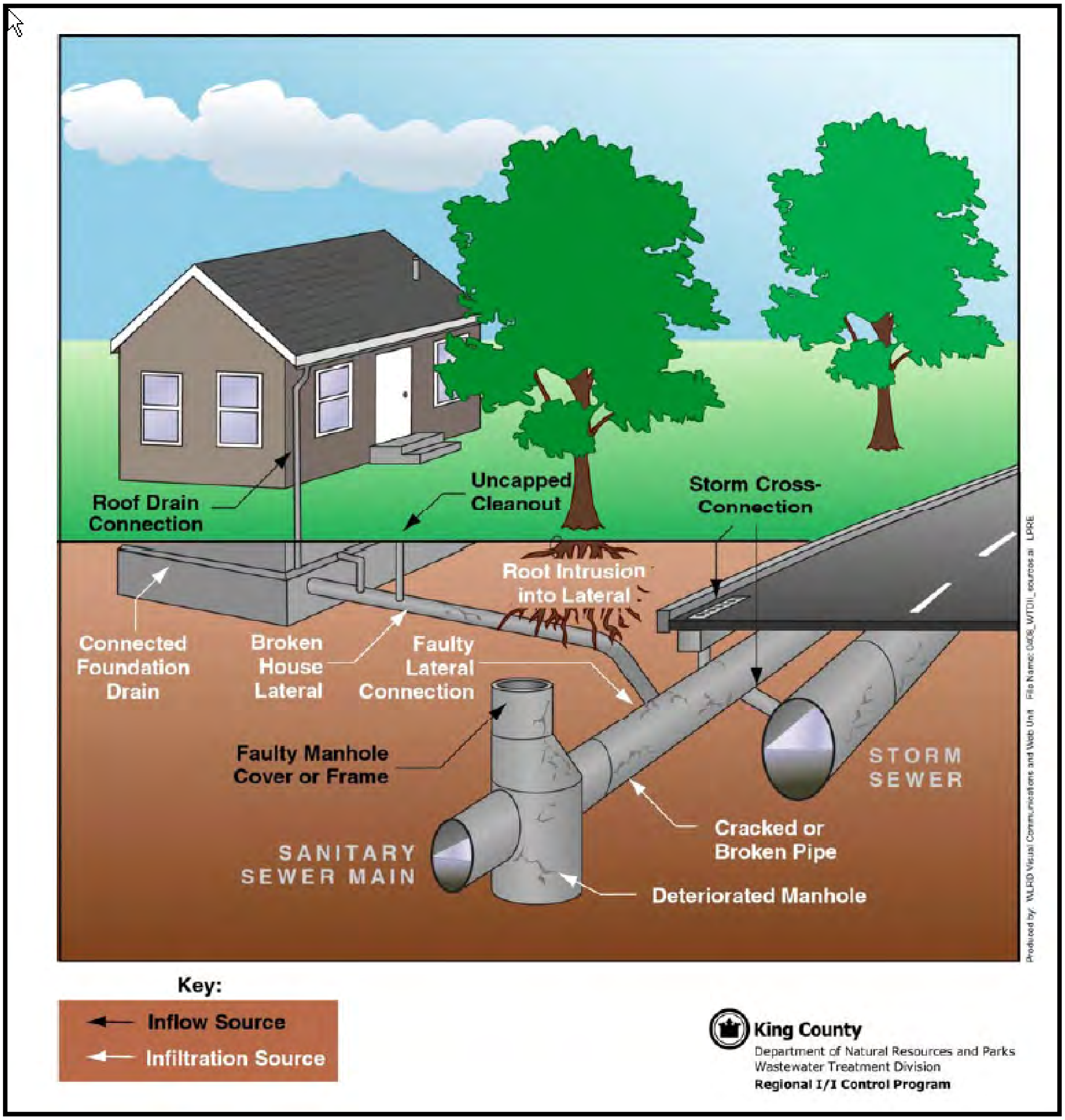


Figure 1-1 Sources of Inflow and Infiltration. Graphic courtesy of King County.

Rehabilitation Methods

Although I/I have the common effect of reducing sewer system capacity, they have different rehabilitation techniques. Methods of reducing inflow include disconnecting roof drains that tie directly into the combined sewer system. Flow can be routed to a proposed cistern or rain garden as outlined by SPU's rainwise program. If available, roof downspouts may also be connected to an existing stormwater system.

Understanding and rehabilitating infiltration within a basin can be more complex than inflow. Significant research has been done on techniques for reducing infiltration. Regionally, King County has completed a series of pilot projects in 2003 and 2004; refer to "Pilot Project Report, Regional Infiltration and Inflow Control Program, King County, Washington" (Earth Tech Team, 2004). Note that references are listed in Section 4 of this document. This study indicates that in order to achieve significant reduction in infiltration, private laterals as well as mainlines must be addressed. Relining or repairing the sewer mainline in the right-of-way may not provide significant flow reduction. This introduces additional complexities in terms of legal issues as well as public acceptance for any proposed project.

There are several means and methods to address infiltration. They include:

- Flood Grouting – *The process of internally flooding an entire reach of sewer and the side sewers with a chemical compound that leaches out into the surrounding soil through pipe defects to seal the pipe from infiltration*.
- Joint Grouting – *The process of injecting grout into each joint in the mainline and side sewers using an inflatable bladder to isolate a portion of the sewer system. The process is repeated as necessary.*
- Pipe Bursting – *A trenchless technology where a new pipe is pulled through the existing pipe thereby replacing the existing pipe. This process can be used to replace both the mainline and the side sewer.*
- CIPP Lining – *The Cured-in-place pipe (CIPP) lining process inserts a resin-impregnated lining tube into the existing pipe. The lining tube is expanded and cured in place thereby creating a sealed pipeline.*

Although the methods above have their particular advantages, the analysis in this report assumes that infiltration reduction will be obtained by relining sewer mains within the right-of-way and that side-sewers or laterals owned by the resident will be replaced. Inflow will be reduced via roof disconnects and installation of green stormwater infrastructure (GSI) consistent with the SPU's Rainwise program.

SECTION 2

LTCP I/I Analysis

Four basins are addressed as part of the LTCP I/I analysis. The basins are Ballard (NPDES 152), Leschi (NPDES 30 and 34), and Montlake (NPDES 20). This section details the approach and methodology employed to determine existing flow characteristics for each basin, existing inflow and infiltration, proposed I/I reduction and estimated cost.

Methodology

The approach employed in this analysis is based on a spreadsheet derived methodology developed by HDR consulting engineers for SPU's Henderson CSO reduction project. The basin hydrograph during the control event is determined along with the associated inflow and infiltration rates under existing conditions. Participation rates, I/I removal effectiveness and other parameters are then used to determine the flow reduction for the control event. The total cost is then estimated based on the number of homes rehabilitated required to control the basin (if possible).

Although the analysis was performed for the four (4) basins referenced above, this section provides a step-by-step explanation of the analysis using NPDES 30 as a template.

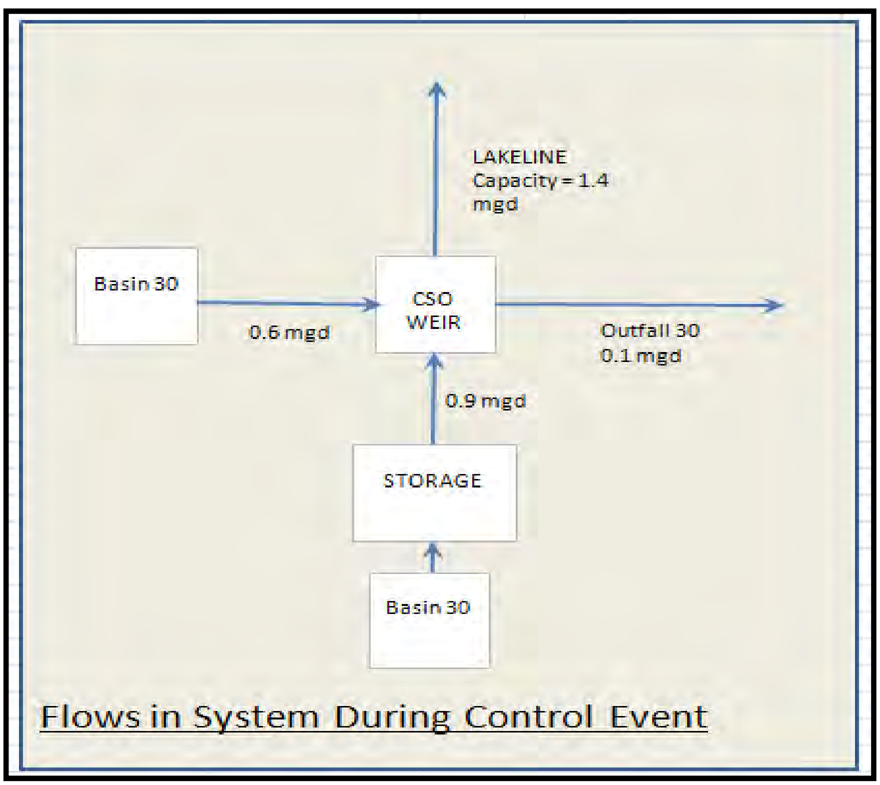


Figure 2-1 NPDES 30 flow schematic

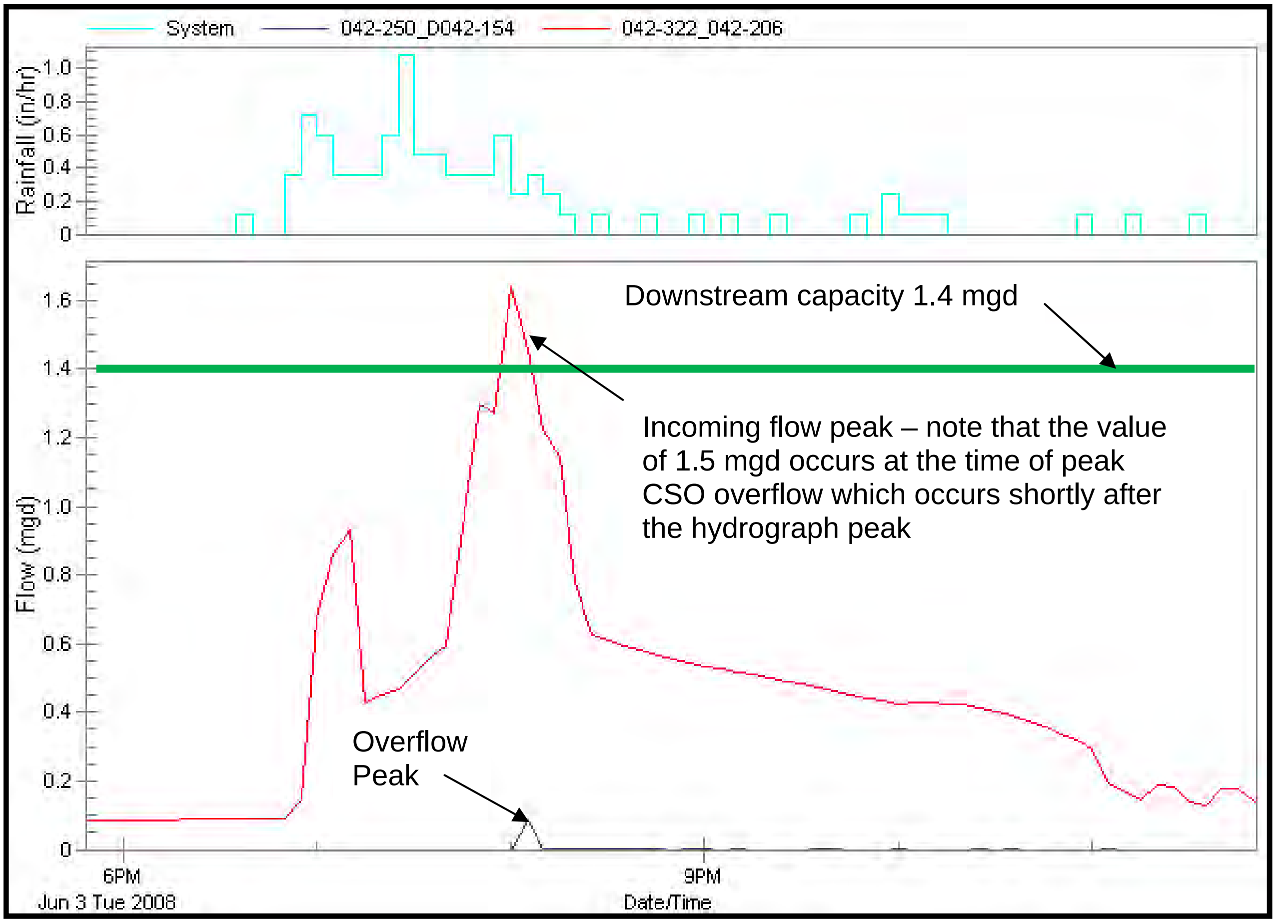


Figure 2-2 Model output for the peak flow values at the NPDES 30 control structure during the control event.

The first step in the analysis is to establish the existing flow characteristics of the basin during the control storm event. The control storm event is considered the 32nd ranked overflow event by volume when comparing overflows volume for a 32-year model simulation. The flow characteristics are obtained by using the calibrated models developed for the LTCP.

For NPDES 30 the flow regime for the June 3, 2008 control event is shown in Figure 2-1. A combined 1.5 mgd flow enters the CSO control chamber - 0.6 mgd from the western section of the basin, 0.9 mgd from the southern section of the basin. The downstream capacity of the Leschi Lakeline at that location is 1.4 mgd. The difference between the incoming 1.5 mgd and the system capacity of 1.4 mgd is 0.1 mgd which overflows the weir and enters Lake Washington.

Figure 2-2 plots the overflow rate (blue line) and the incoming hydrograph (red line) and the overall system capacity downstream of the CSO weir (horizontal green line). As shown in the figure, the incoming flow has a value of 1.5 mgd at the time the system overflows. This value is slightly lower than the incoming peak of 1.6 mgd that occurs just before the system has a CSO. The difference in incoming flow and the system capacity is the overflow rate. If the incoming peak flow can be reduced to 1.4 mgd, then the basin may be considered in control.

The flow characteristics and peak flows are determined from the hydraulic model and are then converted in a unit hydrograph for analysis. Figure 2-3 describes the overflow hydrograph and Figure 2-4 describes the incoming basin hydrograph.

Assumed Control Volume Event Hydrograph

Control Volume	1,000	gal
Peak Overflow Rate	0.1	mgd
Calculated Overflow Duration for a triangular Unit Hydrograph	0.5	hrs

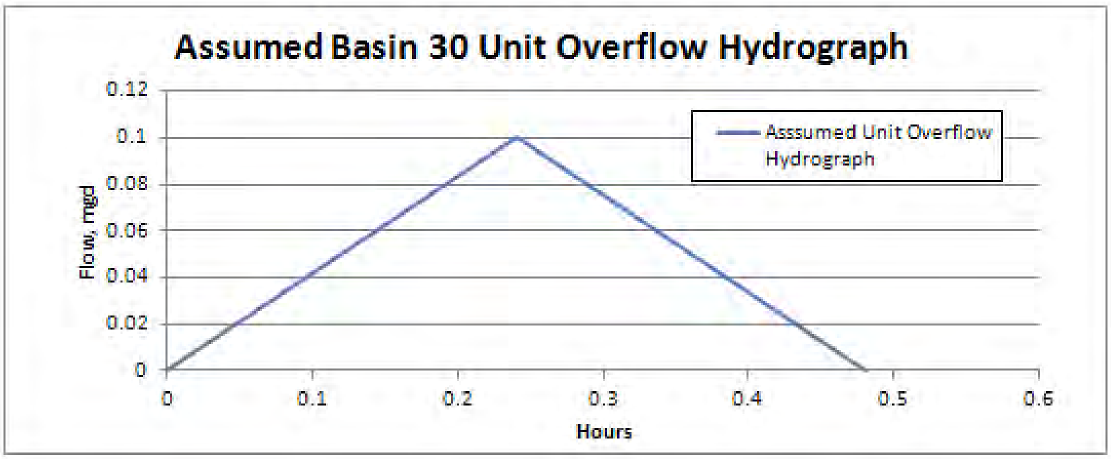


Figure 2-3 Unit hydrograph of NPDES 30 CSO Overflow

Calculated Basin 30 Flow Hydrograph

Peak Basin Flow	1.5	mgd
Event Duration	7.2	hrs

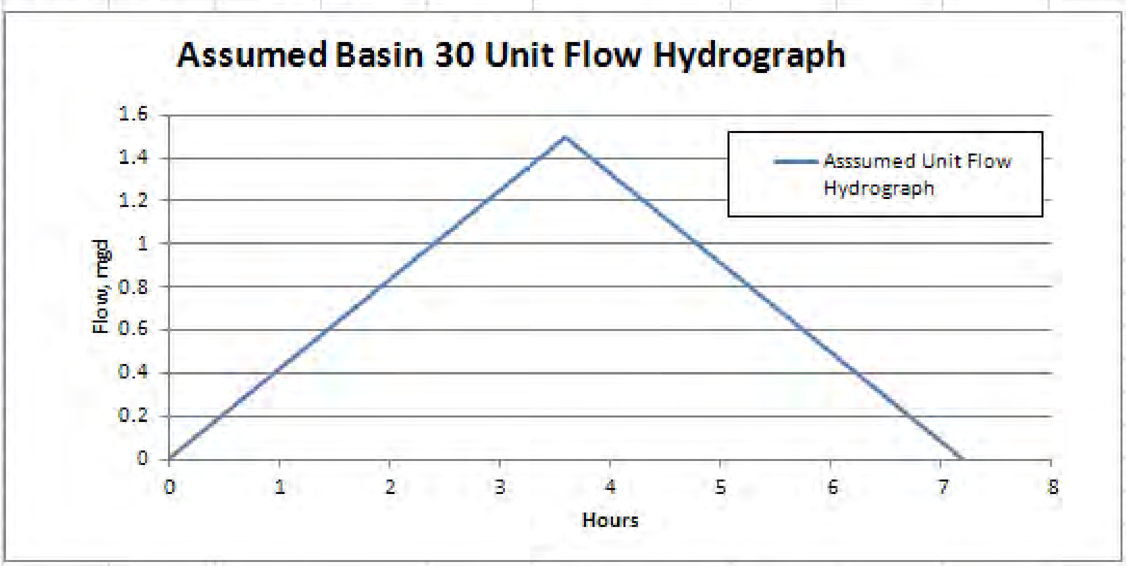


Figure 2-4 NPDES Basin 30 Hydrograph for the control event

Existing Base Conditions

Basin Flow Parameters

Peak Wet Weather Flow	1.5	mgd	
Control Volume	1,000	gal	
Percent of Flow from Private Property	85%		(See Note 1)
Flow From Private Property	1.28	mgd	
Flow from Public ROW	0.23	mgd	
Base System Capacity	1.40	mgd	
Storm Event Flow Duration	7.2	hours	
Flow Rate Exceeding Base Capacity (ie overflo	0.1	mgd	
Overflow Duration	0.5	hours	

Figure 2-5 Screen capture from the basin flow parameters module

Basin flow characteristics are then entered into the I/I spreadsheet as data input. A screen shot of the basin flow parameters spreadsheet is shown is Figure 2-5. Note that the I/I spreadsheets for all of the basins are included in Appendix A of this document.

Once the existing flow regime of the system is determined, the next step in the analysis establishes the inflow and infiltration characteristics within the basin. In a given basin, inflow and infiltration originates either from private property or within the right-of-way. The King County I/I study (refer to Section 4) found that approximately 75% of the infiltration/inflow within a basin originates from private property. As the majority of the basins are combined, 85% of the flow is assumed to originate from private property.

For private property, the infiltration and inflow per home is determined. The number of homes within a basin is determined using the City of Seattle GIS database layer ‘address points’. This layer includes all locations (residential and commercial) that have a unique address point. As the majority of the basin is single family residential units, all address points are considered residential. It is also assumed that 100% of homes contribute equally to infiltration and the percentage of homes that contribute to inflow is based on data from the report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010. This study conducted an in-depth review of roof and area drain connections to the sewer in the combined areas of the basin.

The ratio of private inflow to infiltration is based on a simple rational method calculation. For typical Seattle area storm events the rainfall intensity is likely to range between 0.5 to 1 inches

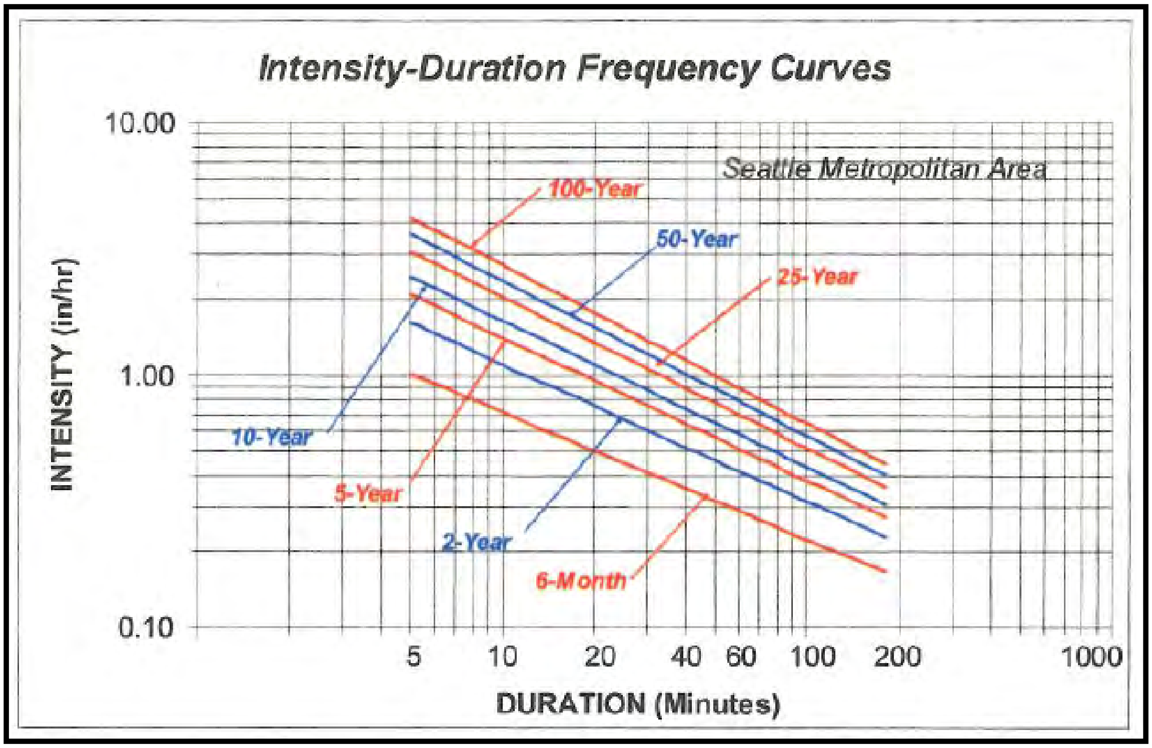


Figure 2-6 Seattle area IDF curve.

per hour. Refer to Figure 2-6 for a copy of the Seattle area IDF curve.

Given a typical 1,200 sf house and using the rational formula, the peak flow from a single house is between 6 to 12 gpm. The percentage of flow from inflow is adjusted to match this flow rate. The remainder of the flow is considered infiltration. Refer to Figure 2-7 for a screenshot of the Private Property module from the I/I spreadsheet.

The NPDES 30 basin contains 253 homes. All of the homes contribute infiltration and according to previous studies (refer to Section 4 'References'), 96 homes also contribute to inflow. The infiltration rate from a home is approximately 1.0 gpm, while inflow per connected home is 6.7 gpm. Multiplying these values by the total number of homes contributing to infiltration and inflow gives a total flow of inflow and infiltration from private property of 1.28 mgd with the remainder of the existing flow (0.23 mgd) coming from public right-of-way.

Private Property			
Number of Homes	253		
Homes with Infiltration	253		
Percentage of Homes with Inflow	38%		
Homes with Inflow	96		
Ratio of Private Inflow to Infiltration	7 :1		
Infiltration Flow per Home	1.0 gpm		
Infiltration from Homes	242 gpm		0.35 mgd
Inflow per Home for Homes Connected	6.7 gpm		
Inflow from Homes	644 gpm		0.93 mgd
		Total	1.28 mgd
Public Right-of-Way			
Flow from ROW	156 gpm		0.23 mgd
	Total Existing Flow		**1.50 mgd**

Figure 2-7 Screen capture from the I/I existing conditions private property module.

Note that the baseline sewer flow during the control event in this basin ranges from 0.05 to 0.11 mgd over the span of a day due to diurnal patterns. This is included within the peak wet weather flow hydrograph.

The predicted conditions analysis is outlined in Figure 2-8. The percent of homes with inflow rehabilitated (participation rate) is based on data from the report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010. Inflow rehabilitation, such as roof drain disconnection, is assumed to be 100% effective in removing flow from the sewer system. If this reduction does not bring the basin into compliance, infiltration reduction per house is applied.

The number of homes with infiltration rehabilitation ranges from 0 to 100% depending on the size of the control volume. The effectiveness of infiltration rehabilitation, assumed to be 75%, is based on monitoring data provided in the “King County Regional Infiltration and Inflow Control Program Study” prepared by King County dated October 2004.

For this analysis it is assumed that an infiltration reduction project for a given residence also includes rehabilitation to the mainline sewer that fronts the property. The effectiveness of the mainline infiltration reduction is assumed to be 50%.

For NPDES 30, with an inflow rehabilitation rate of 10% (residential participation rate), only 1% of the homes need to be rehabilitated for infiltration in order to reduce the peak basin flow to below system capacity (1.4 mgd). The resulting basin hydrograph is depicted in Figure 2-9.

Predicted Conditions Resulting from Rehabilitation

Percent of Homes - Infiltration Rehabilitated	1%			
Effectiveness of Infiltration Rehabilitation	75%			
Percent of Homes with Inflow Rehabilitated	10%			
Homes with Inflow Remaining	86			
Predicted Infiltration Rate from Priv. Prop.		241 gpm	0.35 mgd	
Predicted Inflow Rate From Private Property		577 gpm	0.83 mgd	
		817 gpm	1.18 mgd	
Percent of Public I/I Rehabilitated	1%			(same as % infiltration rehab for homes)
Effectiveness of Public I/I Removal	50%			
Predicted Flow Rate from Public ROW			0.22 mgd	
Predicted Flow from Basin			1.40 mgd	
Flow Rate Exceeding Base Capacity (ie overflow rate)			0.00 mgd	
Overflow Duration			0.0 hours	
Remaining Overflow Volume			**0 gallons**	

Figure 2-8 Screen capture from the proposed conditions module.

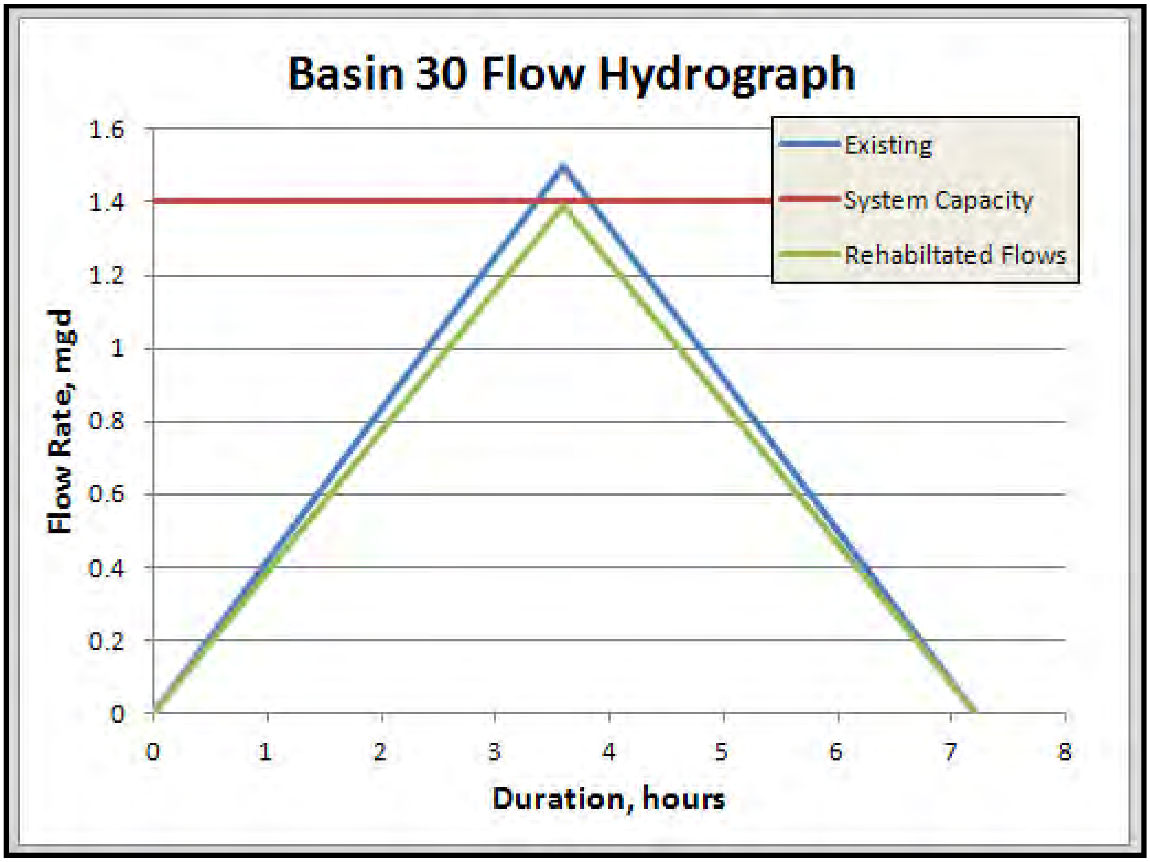


Figure 2-9 Proposed conditions hydrograph

The existing peak flow is shown in blue, the system capacity is depicted by the red line and the proposed peak flow is shown in green. The plot reveals that the proposed peak incoming flow is just below system capacity and no overflow is expected during the control storm event.

Cost Estimate

The analysis uses a simple ‘per home’ multiplier to establish a Class 5 cost estimate. For infiltration reduction (replace side sewer on private property and slip lining the length of mainline adjacent to the property), the anticipated cost is $15,000 per home. For private property inflow reduction (roof disconnects and installation of a rain garden), the anticipated cost is $9,000 per home – Refer to Appendix B “Cost Estimate – Basin Specific Cost Estimate”. This report employs SPU’s cost estimating guideline to determine total project cost. The Class 5 cost estimate is shown in Appendix B “Cost Estimate – Total Project Cost Estimate”.

These values appear consistent with other inflow/infiltration project cost estimates. The Henderson CSO reduction project assumed a $15,700 per home. The King County Skyway project received construction bids between $9,300 to $15,100 per home and SPU’s Broadview Sewer Rehabilitation project estimated $14,500 per home.

NPDES 20 Analysis

NPDES 20 is located in the Montlake neighborhood and is partially separated. The basin primarily consists of single family homes and is 74 acres in size. Tables 2-1, 2-2 and 2-3 summarize the existing conditions flow regime as well as the proposed conditions. The spreadsheets used in this analysis are included in Appendix A. Cost estimates are included in Appendix B. Basin exhibits are included in Appendix C.

Table 2-1. NPDES 20 Existing Basin Characteristics

NPDES Basin	LTCP Version 18 32nd Storm Event CV[1]	Existing System Peak Flow Rate at CSO Structure	Existing System Capacity	Existing CSO Overflow Rate
20	33,000 gal	4.7 mgd	1.2 mgd	3.5 mgd

1. *Refer to Section 3 for a discussion of the LTCP Version 22 Best Estimate Control Volume.*

Table 2-2. NPDES 20 Proposed Basin Characteristics

NPDES Basin	CV Reduction	Proposed System Peak Flow Rate at CSO Structure	Existing System Capacity	Proposed CSO Overflow Rate
20	21,000 gal (64%)	2.8 mgd	1.2 mgd	1.6 mgd

Table 2-3. NPDES 20 Proposed Cost Summary

NPDES Basin	No. Homes within Basin	Proposed No. of Homes Rehabilitated for Infiltration / Inflow	'Class 5' Construction Cost	'Class 5' Total Project Cost
20	366	366 / 10	$6,100,000	$9,700,000

NPDES 30 Analysis

NPDES 30 is 109 acres in size and is located in the Leschi Basin. The basin primarily consists of single family homes. The basin is partially separated. The existing sewer system was constructed in a range that spans the 1919 to 1984.

Table 2-4. NPDES 30 Existing Basin Characteristics				
NPDES Basin	**LTCP Version 18 32nd Storm Event CV[1]**	**Existing System Peak Flow Rate at CSO Structure**	**Existing System Capacity**	**Existing CSO Overflow Rate**
30	1,000 gal	1.5 mgd	1.4 mgd	0.1 mgd

1. *Refer to Section 3 for a discussion of the LTCP Version 22 Best Estimate Control Volume.*

Table 2-5. NPDES 30 Proposed Basin Characteristics				
NPDES Basin	**CV Reduction**	**Proposed System Peak Flow Rate at CSO Structure**	**Existing System Capacity**	**Proposed CSO Overflow Rate**
30	1,000 gal (100 %)	1.4 mgd	1.4 mgd	0 mgd

Table 2-6. NPDES 30 Proposed Cost Summary				
NPDES Basin	**No. Homes within Basin**	**Proposed No. of Homes Rehabilitated for Infiltration / Inflow**	**'Class 5' Construction Cost**	**'Class 5' Total Project Cost**
30	253	3 / 10	$140,000	$222,000

NPDES 34 Analysis

NPDES 34 is located in the Leschi Basin and is partially separated. The basin primarily consists of single family homes. The basin is 21 acres in size and the existing sewer system was constructed between 1930 to 1986. Figure 2-10 provides a detailed map of NPDES 34's CSO control structure and vicinity. The NPDES 34 outfall is governed by flows from both NPDES 34

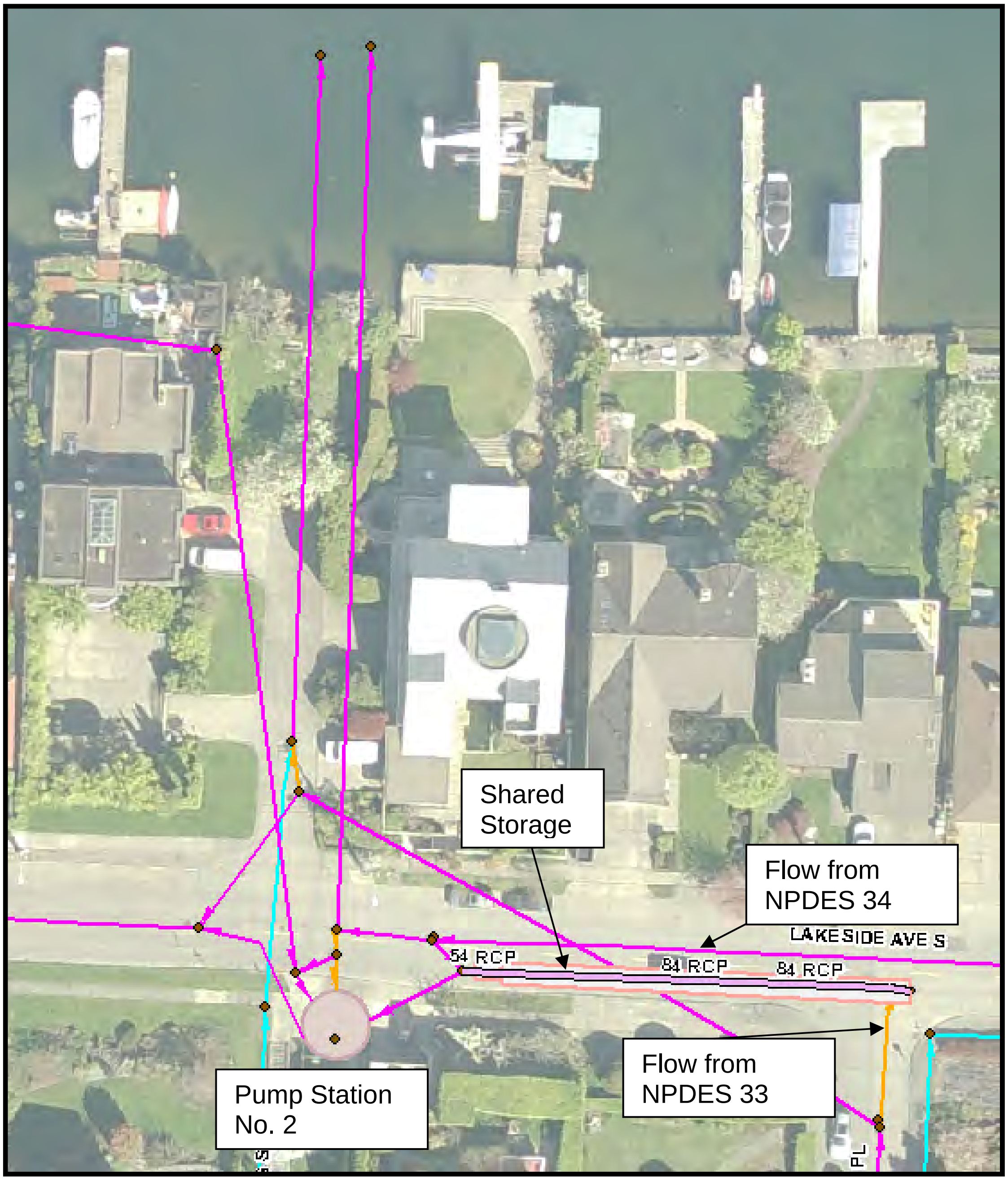


Figure 2-10 Detail of NPDES 34 overflow structure and vicinity.

and NPDES 33. During the control storm event, August 22, 2004, model results show that approximately 67% of the flow over the CSO weir is from NPDES 33 with the remainder from NPDES 34. Therefore, the total control volume of 200,000 gallons can be split as 134,000 gallons from NPDES 33 and 66,000 gallons from NPDES 34. Using I/I reduction methods in NPDES 34 can result in the elimination of the control volume for the NPDES 34 – but there will remain a 134,000 gallon component from NPDES 33 that overflows via the NPDES 34 outfall.

Table 2-7. NPDES 34 Existing Basin Characteristics

NPDES Basin	LTCP Version 18 32nd Storm Event CV[1]	Existing System Peak Flow Rate at CSO Structure	Existing System Capacity	Existing CSO Overflow Rate
34	66,000 gal	1.7 mgd	1.0 mgd	0.7 mgd

1. *Refer to Section 3 for a discussion of the LTCP Version 22 Best Estimate Control Volume.*

Table 2-8. NPDES 34 Proposed Basin Characteristics

NPDES Basin	CV Reduction	Proposed System Peak Flow Rate at CSO Structure	Existing System Capacity	Proposed CSO Overflow Rate
34	66,000 gal (100%) *After implementing proposed improvements, a 134,000 gallon CV contributing from NPDES 33 into the NPDES 34 overflow will remain*	1.0 mgd	1.0 mgd	0 mgd

Table 2-9. NPDES 34 Proposed Cost Summary

NPDES Basin	No. Homes within Basin	Proposed No. of Homes Rehabilitated for Infiltration / Inflow	'Class 5' Construction Cost	'Class 5' Total Project Cost
34	135	112 / 5	$1,900,000	$2,900,000

NPDES 152 Analysis

NPDES 152 is located in the Ballard neighborhood and is partially separated. The basin primarily consists of single family homes. The basin is 677 acres in size.

Table 2-10. NPDES 152 Existing Basin Characteristics

NPDES Basin	LTCP Version 18 32nd Storm Event CV[1]	Existing System Peak Flow Rate at CSO Structure	Existing System Capacity	Existing CSO Overflow Rate
152	2,800,000 gal	27.6 mgd	12.5 mgd	15.1 mgd

1. *Refer to Section 3 for a discussion of the LTCP Version 22 Best Estimate Control Volume.*

Table 2-11. NPDES 152 Proposed Basin Characteristics

NPDES Basin	CV Reduction	Proposed System Peak Flow Rate at CSO Structure	Existing System Capacity	Proposed CSO Overflow Rate
152	2,768,000 gal (99%)	13.6 mgd	12.5 mgd	1.1 mgd

Table 2-12. NPDES 152 Proposed Cost Summary

NPDES Basin	No. Homes within Basin	Proposed No. of Homes Rehabilitated for Infiltration / Inflow	'Class 5' Construction Cost	'Class 5' Total Project Cost
152	4,811	4,811 / 522	$84,000,000	$133,000,000

SECTION 3

Conclusion and Summary

By a combination of sewer main relining, roof disconnects and replacing residential side sewers the control volume for NPDES 20, 30, 34 and 152 can be significantly reduced or eliminated. Table 3-1 provides a summary of the proposed CV reduction and total project costs.

Table 3-1. NPDES Basin CV and Cost Summary for LTCP Version 18 CV

NPDES Basin	LTCP Version 18 32nd Storm Event CV	CV Reduction (gallon / %)	'Class 5' Total Project Cost	CV Reduction Cost per Gallon
20	33,000	21,000 (64%)	$9,700,000	$460
30	1,000	1,000 (100%)	$222,000	$220
34[1]	66,000	66,000 (100%)	$2,900,000	$40
152	2,800,000	2,768,000 gal (99%)	$133,000,000	$50

1. *After implementing proposed improvements, a 134,000 gallon CV contributing from NPDES 33 into the NPDES 34 overflow will remain.*

The analysis in this report was performed using the LTCP Version 18 control volumes and associated hydrologic and hydraulic models. The LTCP finalized the Version 22 control volumes and associated hydrologic and hydraulic models in December 2012. The total project cost for the LTCP Version 22 Best Estimate Control Volume (BECV) using the CV reduction cost per gallon established in this report is described in Table 3-2.

Table 3-2. NPDES Basin CV and Cost Summary for LTCP Version 22 BECV

NPDES Basin	LTCP Version 18 32nd Storm Event CV	LTCP Version 22 Best Estimate CV (gallon)	CV Reduction (gallon / %)	CV Reduction Cost per Gallon	Assumed Total Project Cost using Ver 22 BECV
20	33,000	163,000	21,000 (13%)	$460	$9,700,000
30	1,000	2,000	2,000 (100%)	$220	$440,000
34[1]	66,000	25,000	25,000 (100%)	$40	$1,000,000
152	2,800,000	5,400,000	2,768,000 gal (51%)	$50	$133,000,000

1. *After implementing proposed improvements, a portion of the CV contributing from NPDES 33 into the NPDES 34 overflow will remain.*

This analysis provides an approach to understanding the role of I/I in SPU's combined sewer system. The spreadsheets used in the analysis can be modified to reflect changing conditions. In order to increase confidence in the analysis additional monitoring should be conducted to isolate areas of infiltration. In addition, CCTV inspections of system components should be conducted. Lastly, these four basin were reviewed based on finding presented in the SPU's 2010 CSO Reduction Plan Amendment.

SECTION 4

References

King County Department of Natural Resources, Pilot Project Report – Regional Infiltration and Inflow Control Program, October 2004

Seattle Public Utilities, City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation, November 2010

Seattle Public Utilities and Brown and Caldwell, Infiltration Reduction Utilizing Flood Grouting Technology, 2012

HDR, Inc., Henderson CSO Analysis – emails and spreadsheets, May 2011

Seattle Public Utilities, CH2M-Hill, Brown and Caldwell and MGS Engineering Consultants, Inc., Hydraulic Model Report for Ballard, October, 2012.

Seattle Public Utilities, CH2M-Hill, Brown and Caldwell and MGS Engineering Consultants, Inc., Hydraulic Model Report for Leschi, October, 2012.

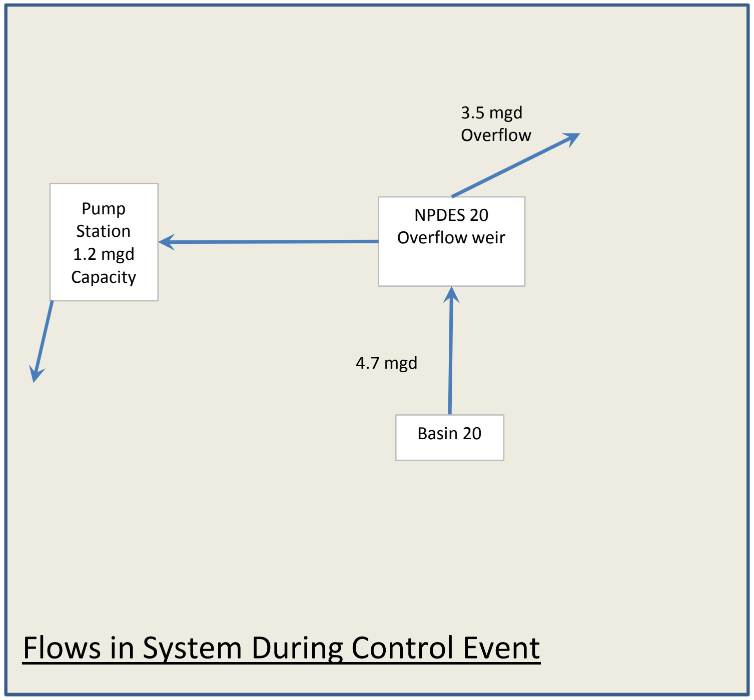
Seattle Public Utilities, CH2M-Hill, Brown and Caldwell and MGS Engineering Consultants, Inc., Hydraulic Model Report for Montlake, October, 2012.

Seattle Public Utilities and Tetra Tech, 2010 CSO Reduction Plan Amendment, May 2010.

Appendix A: Basin I/I Spreadsheets

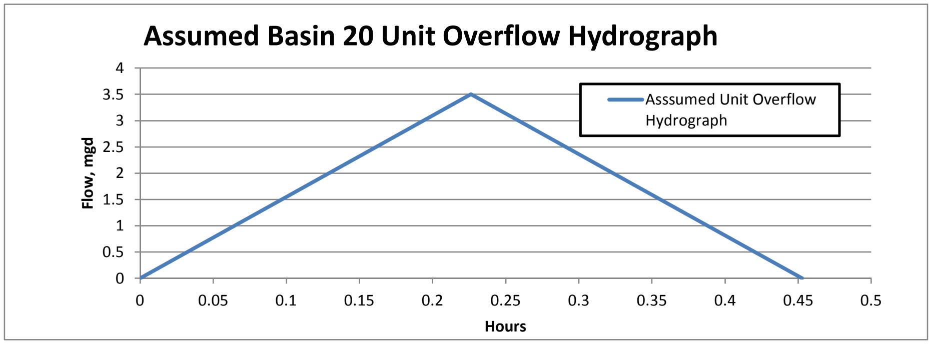
NPDES 20

Based on the Model Approximate Flows in the system are shown below



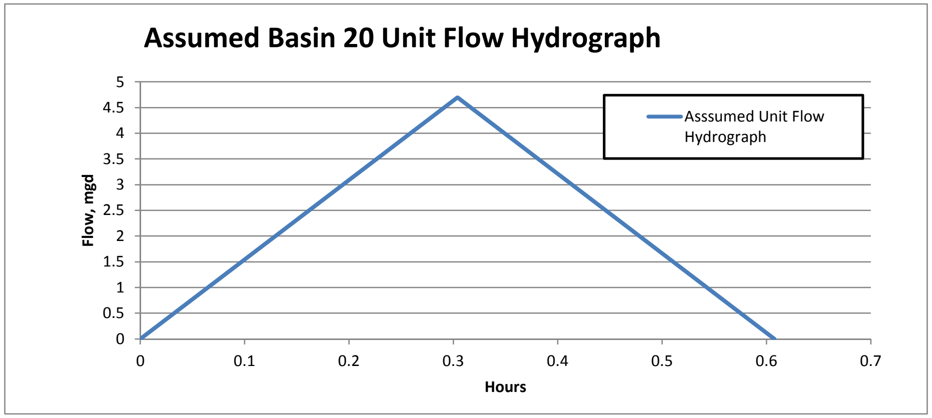
Assumed Control Volume Event Hydrograph

Control Volume	33,000	gal
Peak Overflow Rate	3.5	mgd
Calculated Overflow Duration for a triangular Unit Hydrograph	0.5	hrs



Calculated Basin 20 Flow Hydrograph

Peak Basin Flow	4.7	mgd
Event Duration	0.6	hrs



Basin 20
Infiltration Reduction Benefit Model

Existing Base Conditions

Basin Flow Parameters

Peak Wet Weather Flow	4.7	mgd		
Control Volume	33,000	gal	(See Note 8)	
Percent of Flow from Private Property	85%		(See Note 1)	
Flow From Private Property	4.00	mgd		
Flow from Public ROW	0.71	mgd		
Base System Capacity	1.20	mgd		
Storm Event Flow Duration	0.6	hours		
Flow Rate Exceeding Base Capacity (ie overflow rate)	3.5	mgd		
Overflow Duration	0.5	hours		

Private Property

Number of Homes	366			
Homes with Infiltration	366			
Percentage of Homes with Inflow	54%		(See Note 2)	
Homes with Inflow	198			
Ratio of Private Inflow to Infiltration	2	:1	(See Note 3)	
Infiltration Flow per Home	3.6	gpm		
Infiltration from Homes	1334	gpm	1.92	mgd
Inflow per Home for Homes Connected	7.3	gpm		
Inflow from Homes	1443	gpm	2.08	mgd
		Total	4.00	mgd

Public Right-of-Way

Flow from ROW	490	gpm	0.71	mgd
Total Existing Flow			**4.70**	**mgd**

Predicted Conditions Resulting from Rehabilitation

Percent of Homes - Infiltration Rehabilitated	100%		(See Note 4)	
Effectiveness of Infiltration Rehabilitation	75%		(See Note 5)	
Percent of Homes with Inflow Rehabilitated	5%		(See Note 6)	
Homes with Inflow Remaining	188			
Predicted Infiltration Rate from Priv. Prop.	333	gpm	0.48	mgd
Predicted Inflow Rate From Private Property	1370	gpm	1.97	mgd
	1703	gpm	2.45	mgd
Percent of Public I/I Rehabilitated	100%		(same as % infiltration rehab for homes)	
Effectiveness of Public I/I Removal	50%		(See Note 7)	
Predicted Flow Rate from Public ROW			0.35	mgd
Predicted Flow from Basin			2.80	mgd
Flow Rate Exceeding Base Capacity (ie overflow rate)			1.60	mgd
Overflow Duration			0.3	hours

Remaining Overflow Volume 12,000 gallons

Notes:

1 For the KC I/I pilot projects approximately 75% of the flow originated from private property. These were separated basins. A portion of the basin is combined so a higher percentage of flow is assumed to originate from private property

2 Based on a data from a report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010.

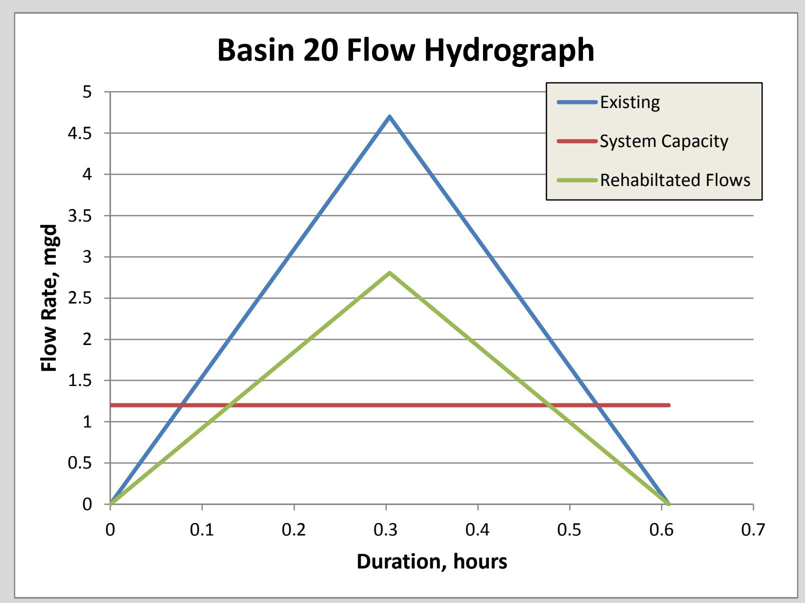
3 For typical storms the intensity is likely to range between 0.5 to 1 inches pe hour. With a 1200 sf house and using the Rational formula the peak flow from a single house is between 6 to 12 gpm. The ratio is adjusted to generate inflow from homes to match this flow rate. The balance of flow is allocated to infiltration sources. (Refer to Figure 2-6 for Seattle IDF curves

4 This value represents the percent participation needed to obtain CSO compliance

5 King County I/I program found 85% reduction of I/I in the Skyway project; however, this is for a separated basin and if foundation drains or other infiltration sources were found during construction, they were disconnected. A lower effectiveness is expected in the basin

6 Based on a data from a report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010.

7 There is little information to support what reduction that will be achieved by the rehabilitation of sewers in the right-of-way. A value of 50% is assumed. The percent of Public I/I rehabed is the same as the percent of homes rehabilitated.



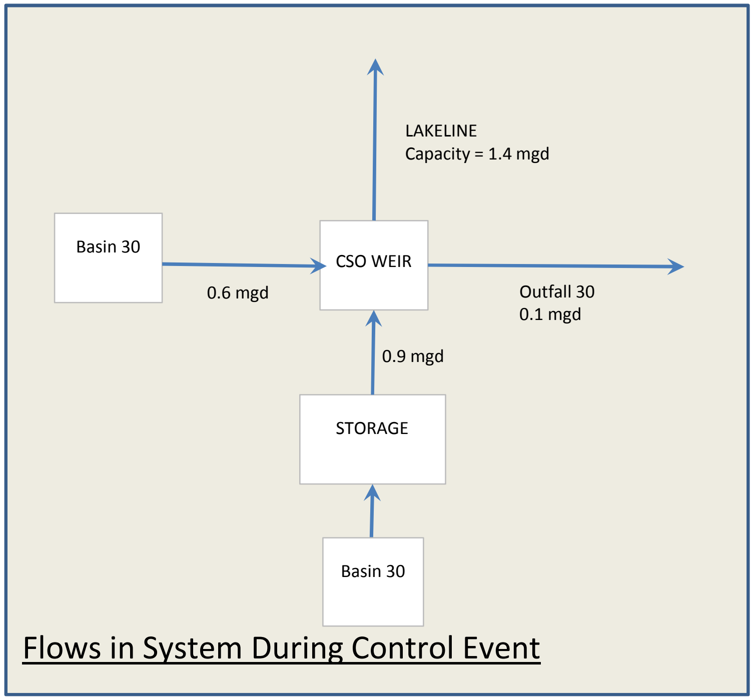
The flow above the System Capacity (red line) represents the overflow from the basin. The Existing (blue line) represents peak basin flows during the control event. The Rehabilitated Flows (green line) represents the remaining flows after the rehabilitation work is completed. Again, the remaining overflow is that portion that is above the red line.

Cost Summary - Refer to Appendix B for detailed Cost Estimate

$15,000	per home for infiltration reduction (includes ROW mainline rehab)
$9,000	per home with only inflow reduction
10	Homes with inflow reduction
366	Homes with infiltration reduction
$90,000	Cost for inflow reduction
$5,490,000	Cost for infiltration reduction
$5,580,000	Construction 'Line Item' Cost

NPDES 30

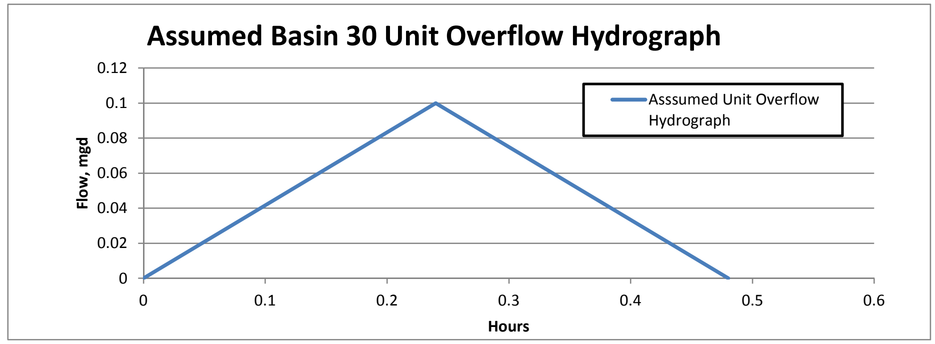
Based on the Model Approximate Flows in the system are shown below



Flows in System During Control Event

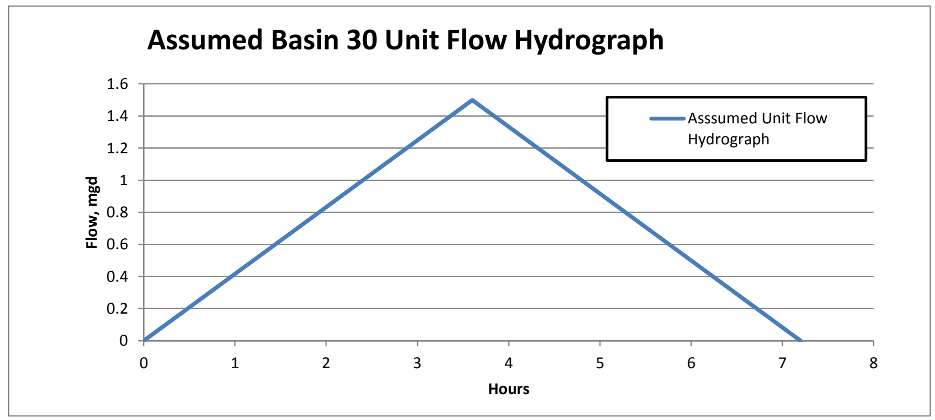
Assumed Control Volume Event Hydrograph

Control Volume	1,000	gal
Peak Overflow Rate	0.1	mgd
Calculated Overflow Duration for a triangular Unit Hydrograph	0.5	hrs



Calculated Basin 30 Flow Hydrograph

Peak Basin Flow	1.5	mgd
Event Duration	7.2	hrs



Basin 30

Infiltration Reduction Benefit Model

Existing Base Conditions

Basin Flow Parameters

Peak Wet Weather Flow	1.5	mgd		
Control Volume	1,000	gal		
Percent of Flow from Private Property	85%		(See Note 1)	
Flow From Private Property	1.28	mgd		
Flow from Public ROW	0.23	mgd		
Base System Capacity	1.40	mgd		
Storm Event Flow Duration	7.2	hours		
Flow Rate Exceeding Base Capacity (ie overflow rate)	0.1	mgd		
Overflow Duration	0.5	hours		

Private Property

Number of Homes	253			
Homes with Infiltration	253			
Percentage of Homes with Inflow	38%		(See Note 2)	
Homes with Inflow	96			
Ratio of Private Inflow to Infiltration	7	:1	(See Note 3)	
Infiltration Flow per Home	1.0	gpm		
Infiltration from Homes	242	gpm	0.35	mgd
Inflow per Home for Homes Connected	6.7	gpm		
Inflow from Homes	644	gpm	0.93	mgd
		Total	1.28	mgd

Public Right-of-Way

Flow from ROW	156	gpm	0.23	mgd
Total Existing Flow			**1.50**	**mgd**

Predicted Conditions Resulting from Rehabilitation

Percent of Homes - Infiltration Rehabilitated	1%		(See Note 4)	
Effectiveness of Infiltration Rehabilitation	75%		(See Note 5)	
Percent of Homes with Inflow Rehabilitated	10%		(See Note 6)	
Homes with Inflow Remaining	86			
Predicted Infiltration Rate from Priv. Prop.	241	gpm	0.35	mgd
Predicted Inflow Rate From Private Property	577	gpm	0.83	mgd
	817	gpm	1.18	mgd
Percent of Public I/I Rehabilitated	1%		(same as % infiltration rehab for homes)	
Effectiveness of Public I/I Removal	50%		(See Note 7)	
Predicted Flow Rate from Public ROW			0.22	mgd
Predicted Flow from Basin			1.40	mgd
Flow Rate Exceeding Base Capacity (ie overflow rate)			0.00	mgd
Overflow Duration			0.0	hours

Remaining Overflow Volume **0 gallons**

Notes:

1 For the KC I/I pilot projects approximately 75% of the flow originated from private property. These were separated basins. A portion of the basin is combined so a higher percentage of flow is assumed to originate from private property

2 Based on a data from a report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010.

3 For typical storms the intensity is likely to range between 0.5 to 1 inches per hour. With a 1200 sf house and using the Rational formula the peak flow from a single house is between 6 to 12 gpm. The ratio is adjusted to generate inflow from homes to match this flow rate. The balance of flow is allocated to infiltration sources. (Refer to Figure 2-6 for Seattle IDF curves

4 This value represents the percent participation needed to obtain CSO compliance

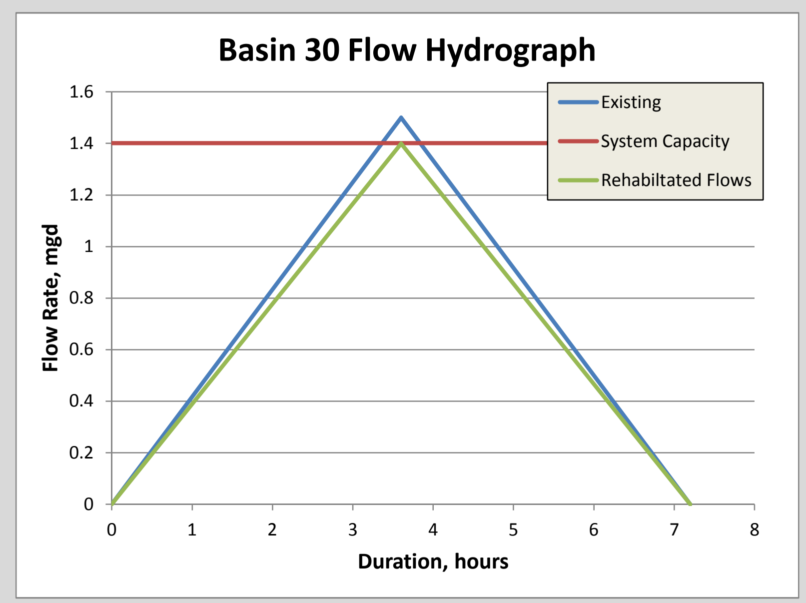
5 King County I/I program found 85% reduction of I/I in the Skyway project; however, this is for a separated basin and if foundation drains or other infiltration sources were found during construction, they were disconnected. A lower effectiveness is expected in the basin

6 Based on a data from a report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010.

7 There is little information to support what reduction that will be achieved by the rehabilitation of sewers in the right-of-way. A value of 50% is assumed. The percent of Public I/I rehabed is the same as the percent of homes rehabilitated.

Cost Summary - Refer to Appendix B for detailed Cost Estimate

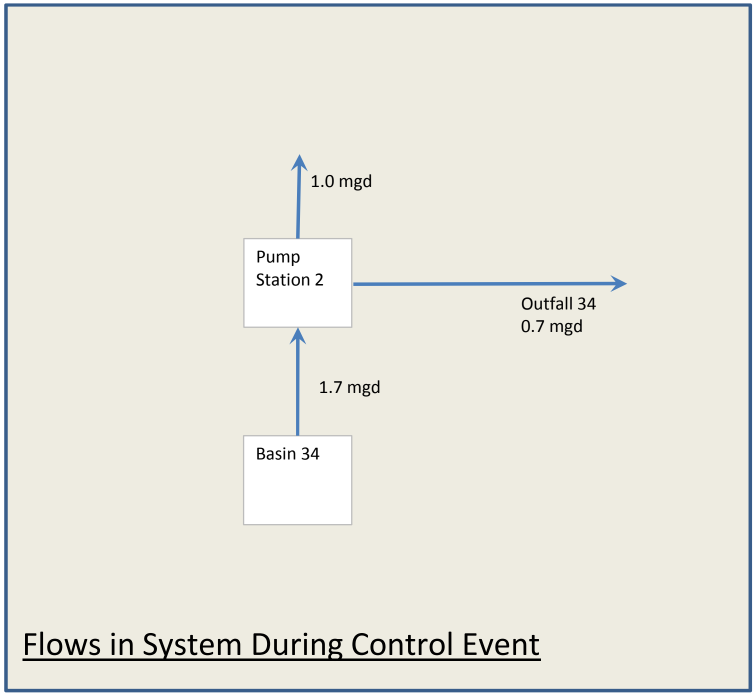
$15,000	per home for infiltration reduction (includes ROW mainline rehab)
$9,000	per home with only inflow reduction
10	Homes with inflow reduction
3	Homes with infiltration reduction
$90,000	Cost for inflow reduction
$37,950	Cost for infiltration reduction
$127,950	Construction 'Line Item' Cost



The flow above the System Capacity (red line) represents the overflow from the basin. The Existing (blue line) represents peak basin flows during the control event. The Rehabilitated Flows (green line) represents the remaining flows after the rehabilitation work is completed. Again, the remaining overflow is that portion that is above the red line.

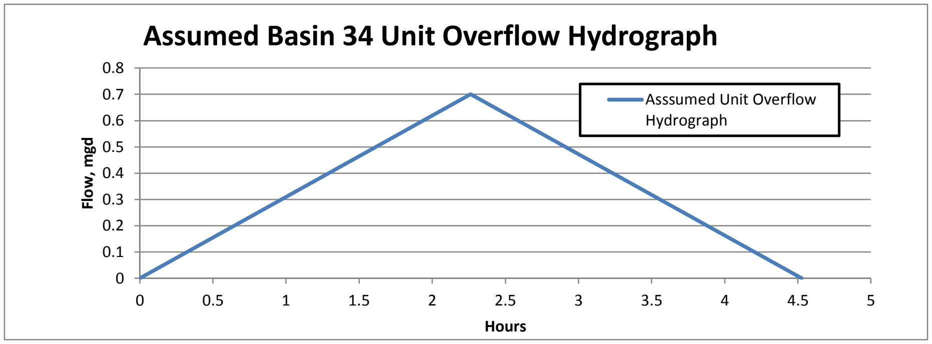
NPDES 34

Based on the Model Approximate Flows in the system are shown below



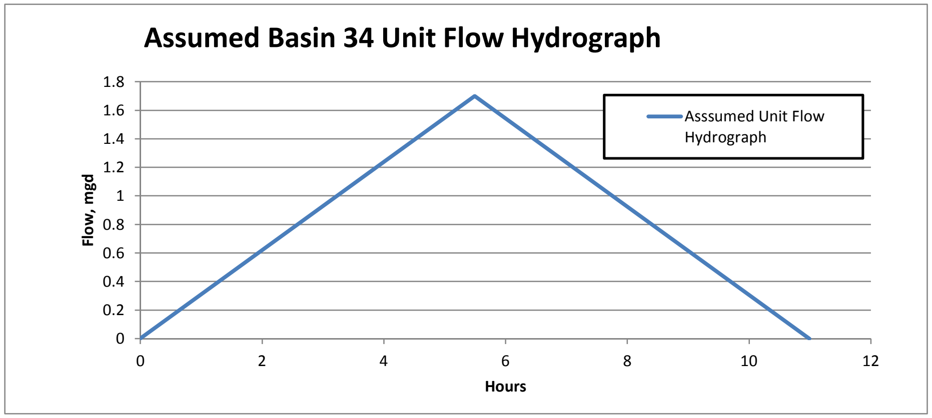
Assumed Control Volume Event Hydrograph

Control Volume	66,000	gal
Peak Overflow Rate	0.7	mgd
Calculated Overflow Duration for a triangular Unit Hydrograph	4.5	hrs



Calculated Basin 34 Flow Hydrograph

Peak Basin Flow	1.7	mgd
Event Duration	11	hrs



Basin 34
Infiltration Reduction Benefit Model

Existing Base Conditions

Basin Flow Parameters

Peak Wet Weather Flow	1.7 mgd		
Control Volume	66,000 gal	(See Note 8)	
Percent of Flow from Private Property	85%	(See Note 1)	
Flow From Private Property	1.45 mgd		
Flow from Public ROW	0.26 mgd		
Base System Capacity	1.00 mgd		
Storm Event Flow Duration	11 hours		
Flow Rate Exceeding Base Capacity (ie overflow rate)	0.7 mgd		
Overflow Duration	4.5 hours		

Private Property

Number of Homes	135		
Homes with Infiltration	135		
Percentage of Homes with Inflow	35%	(See Note 2)	
Homes with Inflow	47		
Ratio of Private Inflow to Infiltration	2 :1	(See Note 3)	
Infiltration Flow per Home	4.4 gpm		
Infiltration from Homes	592 gpm	0.85 mgd	
Inflow per Home for Homes Connected	8.8 gpm		
Inflow from Homes	412 gpm	0.59 mgd	
	Total	1.45 mgd	

Public Right-of-Way

Flow from ROW	177 gpm	0.26 mgd	
Total Existing Flow		**1.70 mgd**	

Predicted Conditions Resulting from Rehabilitation

Percent of Homes - Infiltration Rehabilitated	83%	(See Note 4)	
Effectiveness of Infiltration Rehabilitation	75%	(See Note 5)	
Percent of Homes with Inflow Rehabilitated	10%	(See Note 6)	
Homes with Inflow Remaining	42		
Predicted Infiltration Rate from Priv. Prop.	223 gpm	0.32 mgd	
Predicted Inflow Rate From Private Property	368 gpm	0.53 mgd	
	592 gpm	0.85 mgd	
Percent of Public I/I Rehabilitated	83%	(same as % infiltration rehab for homes)	
Effectiveness of Public I/I Removal	50%	(See Note 7)	
Predicted Flow Rate from Public ROW		0.15 mgd	
Predicted Flow from Basin		1.00 mgd	
Flow Rate Exceeding Base Capacity (ie overflow rate)		0.00 mgd	
Overflow Duration		0.0 hours	
Remaining Overflow Volume		**0 gallons**	

Notes:

1 For the KC I/I pilot projects approximately 75% of the flow originated from private property. These were separated basins. A portion of the basin is combined so a higher percentage of flow is assumed to originate from private property

2 Based on a data from a report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010.

3 For typical storms the intensity is likely to range between 0.5 to 1 inches pe hour. With a 1200 sf house and using the Rational formula the peak flow from a single house is between 6 to 12 gpm. The ratio is adjusted tc generate inflow from homes to match this flow rate. The balance of flow is allocated to infiltration sources. (Refer to Figure 2-6 for Seattle IDF curves

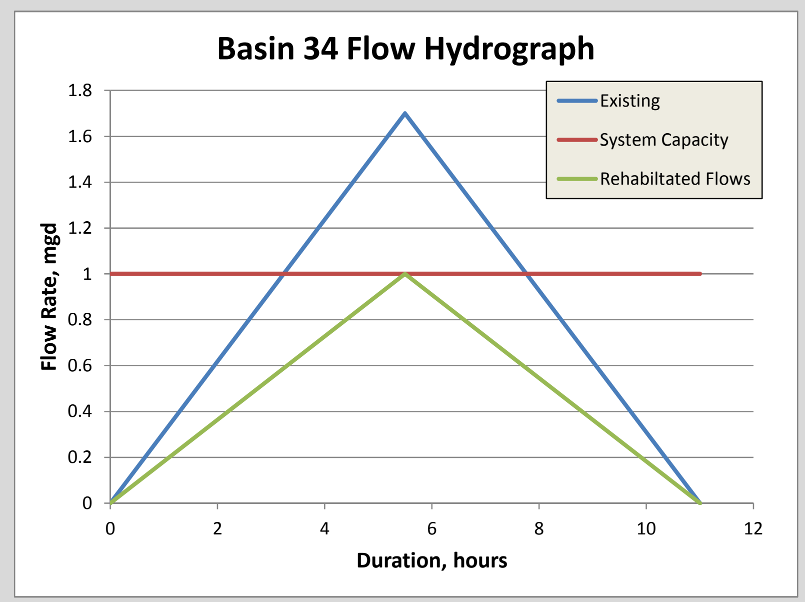
4 This value represents the percent participation needed to obtain CSO compliance

5 King County I/I program found 85% reduction of I/I in the Skyway project; however, this is for a separated basin and if foundation drains or other infiltration sources were found during construction, they were disconnected. A lower effectiveness is expected in the basin

6 Based on a data from a report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010.

7 There is little information to support what reduction that will be achieved by the rehabilitation of sewers in the right-of-way. A value of 50% is assumed. The percent of Public I/I rehabed is the same as the percent of homes rehabilitated.

8 The CSO outfall at NPDES 34 includes flow from both NPDES 34 and NPDES 33. The combined CV at the weir is 200,000 gallons with 66,000 gallons from NPDES 34 and 134,000 from NPDES 33. Bringing NPDES 34 outfall will require reduction in flows from both NPDES 33 and 34.



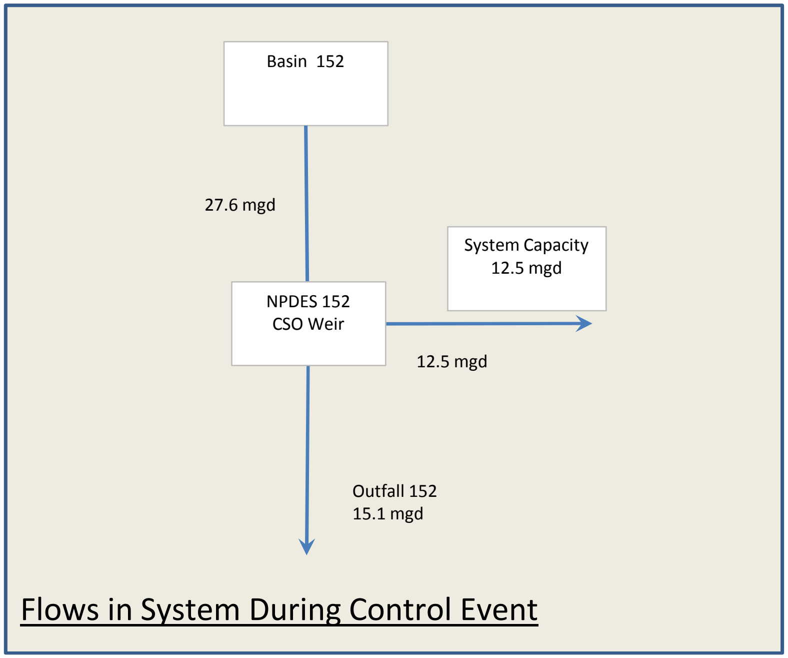
The flow above the System Capacity (red line) represents the overflow from the basin. The Existing (blue line) represents peak basin flows during the control event. The Rehabilitated Flows (green line) represents the remaining flows after the rehabilitation work is completed. Again, the remaining overflow is that portion that is above the red line.

Cost Summary - Refer to Appendix B for detailed Cost Estimate

$15,000	per home for infiltration reduction (includes ROW mainline rehab)
$9,000	per home with only inflow reduction
5	Homes with inflow reduction
112	Homes with infiltration reduction
$45,000	Cost for inflow reduction
$1,680,750	Cost for infiltration reduction
$1,725,750	Construction 'Line Item' Cost

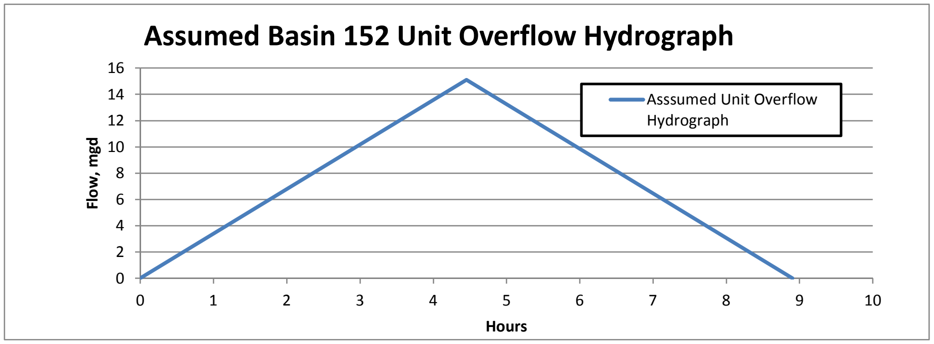
NPDES 152

Based on the Model Approximate Flows in the system are shown below



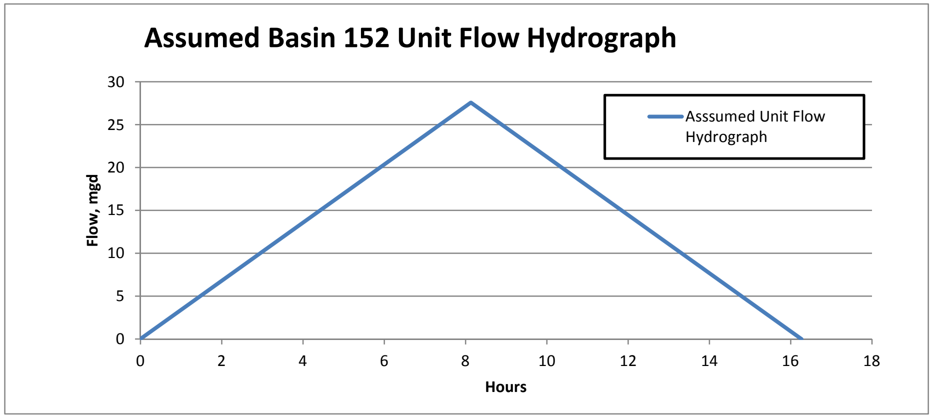
Assumed Control Volume Event Hydrograph

Control Volume	2,800,000	gal
Peak Overflow Rate	15.1	mgd
Calculated Overflow Duration for a triangular Unit Hydrograph	8.9	hrs



Calculated Basin 152 Flow Hydrograph

Peak Basin Flow	27.6	mgd
Event Duration	16.3	hrs



Basin 152
Infiltration Reduction Benefit Model

Existing Base Conditions

Basin Flow Parameters

Peak Wet Weather Flow	27.6 mgd		
Control Volume	2,800,000 gal	(See Note 8)	
Percent of Flow from Private Property	85%	(See Note 1)	
Flow From Private Property	23.46 mgd		
Flow from Public ROW	4.14 mgd		
Base System Capacity	12.50 mgd		
Storm Event Flow Duration	16.3 hours		
Flow Rate Exceeding Base Capacity (ie overflow rate)	15.1 mgd		
Overflow Duration	8.9 hours		

Private Property

Number of Homes	4811		
Homes with Infiltration	4811		
Percentage of Homes with Inflow	31%	(See Note 2)	
Homes with Inflow	1491		
Ratio of Private Inflow to Infiltration	5 :1	(See Note 3)	
Infiltration Flow per Home	1.3 gpm		
Infiltration from Homes	6395 gpm	9.20 mgd	
Inflow per Home for Homes Connected	6.6 gpm		
Inflow from Homes	9910 gpm	14.26 mgd	
	Total	23.46 mgd	

Public Right-of-Way

Flow from ROW	2877 gpm	4.14 mgd	
Total Existing Flow		**27.60 mgd**	

Predicted Conditions Resulting from Rehabilitation

Percent of Homes - Infiltration Rehabilitated	100%	(See Note 4)	
Effectiveness of Infiltration Rehabilitation	75%	(See Note 5)	
Percent of Homes with Inflow Rehabilitated	35%	(See Note 6)	
Homes with Inflow Remaining	969		
Predicted Infiltration Rate from Priv. Prop.	1599 gpm	2.30 mgd	
Predicted Inflow Rate From Private Property	6440 gpm	9.27 mgd	
	8039 gpm	11.57 mgd	
Percent of Public I/I Rehabilitated	100%	(same as % infiltration rehab for homes)	
Effectiveness of Public I/I Removal	50%	(See Note 7)	
Predicted Flow Rate from Public ROW		2.07 mgd	
Predicted Flow from Basin		13.64 mgd	
Flow Rate Exceeding Base Capacity (ie overflow rate)		1.14 mgd	
Overflow Duration		1.4 hours	
Remaining Overflow Volume		**32,000 gallons**	

Notes:

1 For the KC I/I pilot projects approximately 75% of the flow originated from private property. These were separated basins. A portion of the basin is combined so a higher percentage of flow is assumed to originate from private property

2 Based on a data from a report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010.

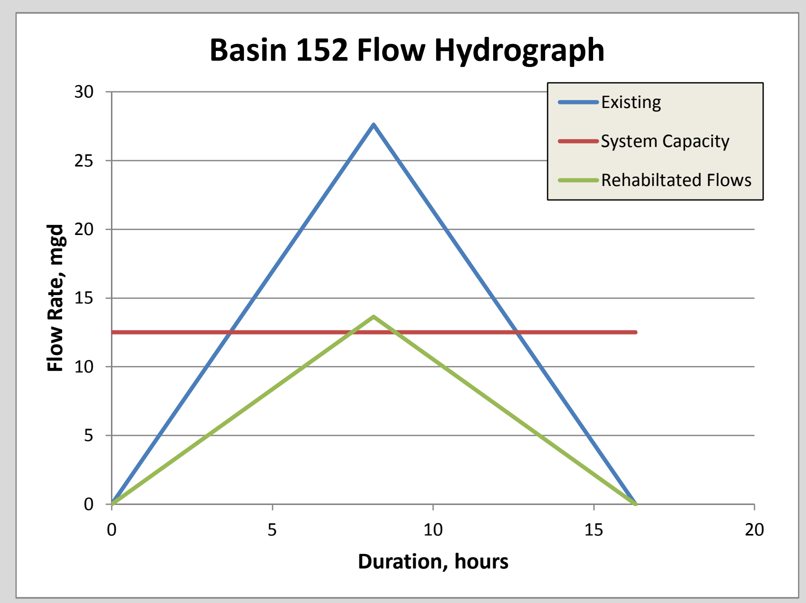
3 For typical storms the intensity is likely to range between 0.5 to 1 inches per hour. With a 1200 sf house and using the Rational formula the peak flow from a single house is between 6 to 12 gpm. The ratio is adjusted to generate inflow from homes to match this flow rate. The balance of flow is allocated to infiltration sources. (Refer to Figure 2-6 for Seattle IDF curves

4 This value represents the percent participation needed to obtain CSO compliance

5 King County I/I program found 85% reduction of I/I in the Skyway project; however, this is for a separated basin and if foundation drains or other infiltration sources were found during construction, they were disconnected. A lower effectiveness is expected in the basin

6 Based on a data from a report entitled "City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation" prepared by SPU and CH2MHill, dated November 2010.

7 There is little information to support what reduction that will be achieved by the rehabilitation of sewers in the right-of-way. A value of 50% is assumed. The percent of Public I/I rehabed is the same as the percent of homes rehabilitated.



The flow above the System Capacity (red line) represents the overflow from the basin. The Existing (blue line) represents peak basin flows during the control event. The Rehabilitated Flows (green line) represents the remaining flows after the rehabilitation work is completed. Again, the remaining overflow is that portion that is above the red line.

Cost Summary - Refer to Appendix B for detailed Cost Estimate

$15,000	per home for infiltration reduction (includes ROW mainline rehab)
$9,000	per home with only inflow reduction
522	Homes with inflow reduction
4,811	Homes with infiltration reduction
$4,698,000	Cost for inflow reduction
$72,165,000	Cost for infiltration reduction
$76,863,000	Construction 'Line Item' Cost

Appendix B: Cost Estimate

LTCP I/I Basin Specific Cost Estimate "Construction Cost"

NPDES 20 Cost Estimate

$	15,000	per home for infiltration reduction (includes ROW mainline rehab)
$	9,000	per home with only inflow reduction
	10	Homes with inflow reduction
	366	Homes with inflitration reduction
$	90,000	Cost for inflow reduction
$	5,490,000	Cost for infiltration reduction
$	5,580,000	Construction 'Line Item' Cost

NPDES 30 Cost Estimate

$	15,000	per home for infiltration reduction (includes ROW mainline rehab)
$	9,000	per home with only inflow reduction
	10	Homes with inflow reduction
	3	Homes with inflitration reduction
$	90,000	Cost for inflow reduction
$	37,950	Cost for infiltration reduction
$	127,950	Construction 'Line Item' Cost

NPDES 34 Cost Estimate

$	15,000	per home for infiltration reduction (includes ROW mainline rehab)
$	9,000	per home with only inflow reduction
	5	Homes with inflow reduction
	112	Homes with inflitration reduction
$	45,000	Cost for inflow reduction
$	1,680,750	Cost for infiltration reduction
$	1,725,750	Construction 'Line Item' Cost

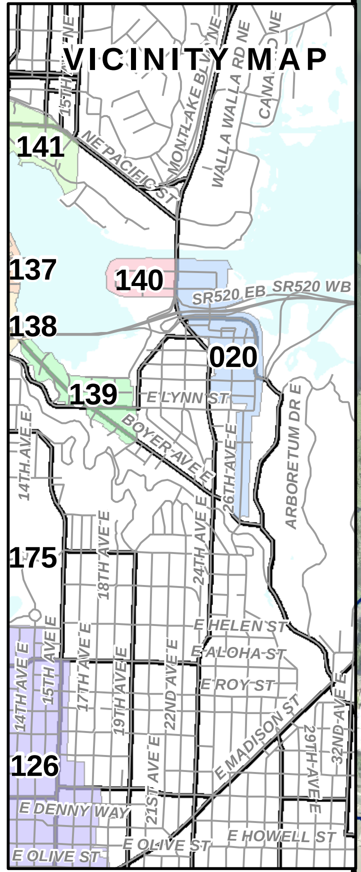
NPDES 152 Cost Estimate

$	15,000	per home for infiltration reduction (includes ROW mainline rehab)
$	9,000	per home with only inflow reduction
	522	Homes with inflow reduction
	4,811	Homes with inflitration reduction
$	4,698,000	Cost for inflow reduction
$	72,165,000	Cost for infiltration reduction
$	76,863,000	Construction 'Line Item' Cost

LTCP I/I Total Project Cost

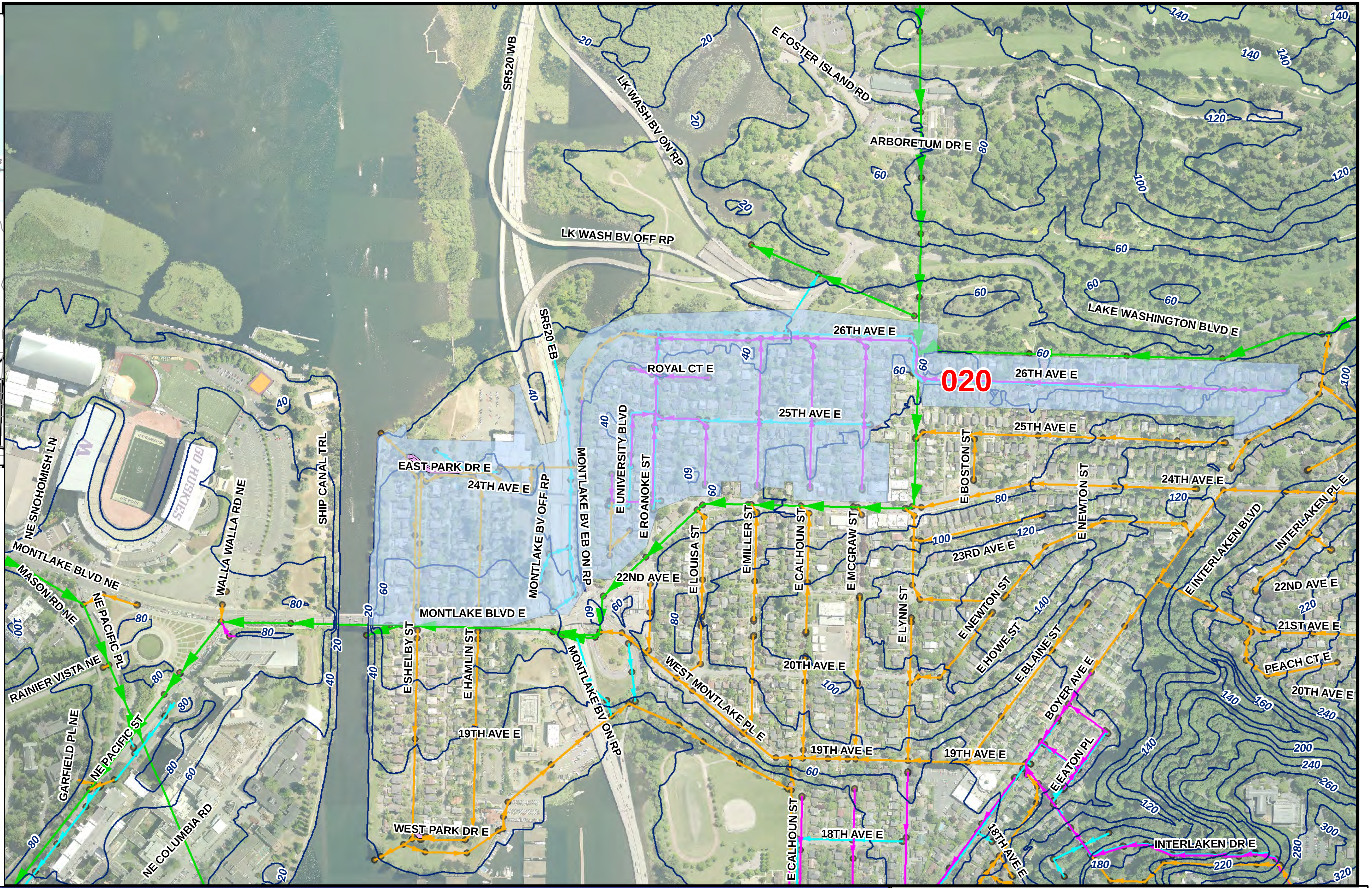
	NPDES 20	NPDES 30	NPDES 34	NPDES 152
	Estimated Cost	**Estimated Cost**	**Estimated Cost**	**Estimated Cost**
	$ 5,580,000	$ 127,950	$ 1,725,750	$ 76,863,000
Construction Line Item Pricing	**$ 5,580,000**	**$ 127,950**	**$ 1,725,750**	**$ 76,863,000**
Adjustment for Market Conditions	0%	0%	0%	0%
Construction Bid Amount	**$ 5,580,000**	**$ 127,950**	**$ 1,725,750**	**$ 76,863,000**
Sales Tax %	9.50%	9.50%	9.50%	9.50%
Construction Contract Amount	**$ 6,110,100**	**$ 140,105**	**$ 1,889,696**	**$ 84,164,985**
Crew Construction Costs	$ 100	$ 100	$ 100	$ 100
Miscellaneous Hard Costs	$ 100	$ 100	$ 100	$ 100
Construction Cost Total	**$ 6,110,300**	**$ 140,305**	**$ 1,889,896**	**$ 84,165,185**
Soft Cost %	30%	30%	30%	30%
Soft Cost	$ 1,833,090	$ 42,092	$ 566,969	$ 25,249,556
Property Acquisition Costs	$ 1,000	$ 1,000	$ 1,000	$ 1,000
Base Cost Total	**$ 7,944,390**	**$ 183,397**	**$ 2,457,865**	**$ 109,415,741**
Contingency Reserve %	10%	10%	10%	10%
Contingency Reserve	$ 794,439	$ 18,340	$ 245,787	$ 10,941,574
Management Reserve %	10%	10%	10%	10%
Management Reserve	$ 794,439	$ 18,340	$ 245,787	$ 10,941,574
Project Reserves	$ 1,588,878	$ 36,679	$ 491,573	$ 21,883,148
Total Cost	**$ 9,533,268**	**$ 220,076**	**$ 2,949,438**	**$ 131,298,889**
Total Cost Projection	**$ 9,647,928**	**$ 222,606**	**$ 2,984,829**	**$ 132,879,607**

Appendix C: Basin Exhibits



LEGEND

- Basin Boundary
- XXX NPDES Basin No.
- SPU Drainage Mainline
- SPU Sanitary Mainline
- SPU Combined Mainline
- King County Mainline
- 20-ft Contour
- Maintenance Hole



Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 20
Basin Map

DECEMBER 2012 | **EXHIBIT 20-1**

LEGEND

XXX	NPDES Basin No.
	SPU Drainage Mainline
	SPU Sanitary Mainline
	SPU Combined Mainline
	King County Mainline
	20-ft Contour
	Maintenance Hole

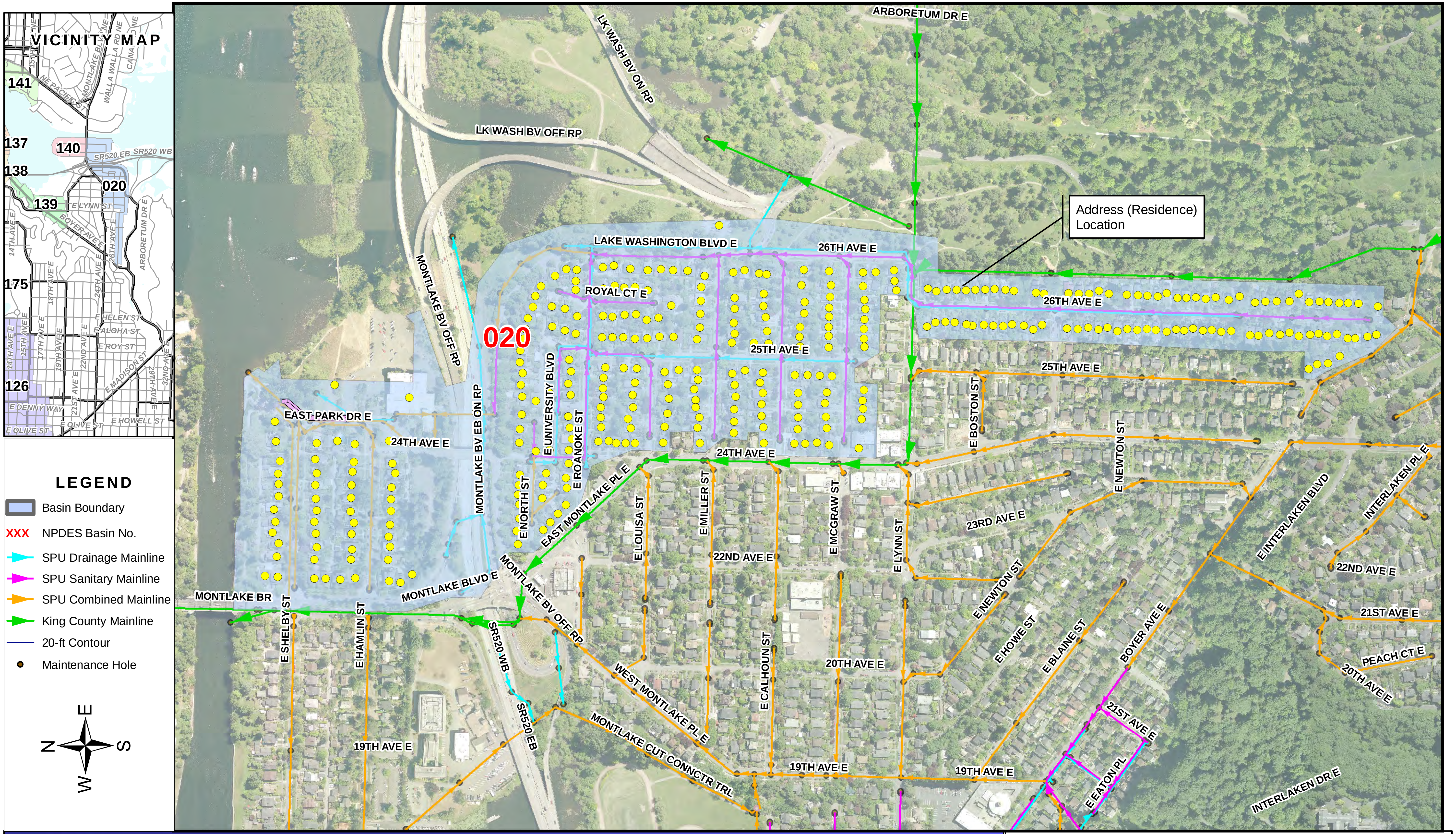
N E S W

Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 20
CSO Outfall - Detail Map

DECEMBER 2012 | **EXHIBIT 20-2**

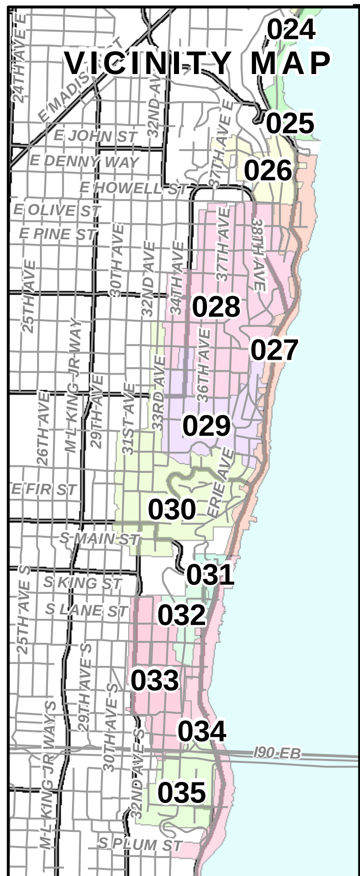


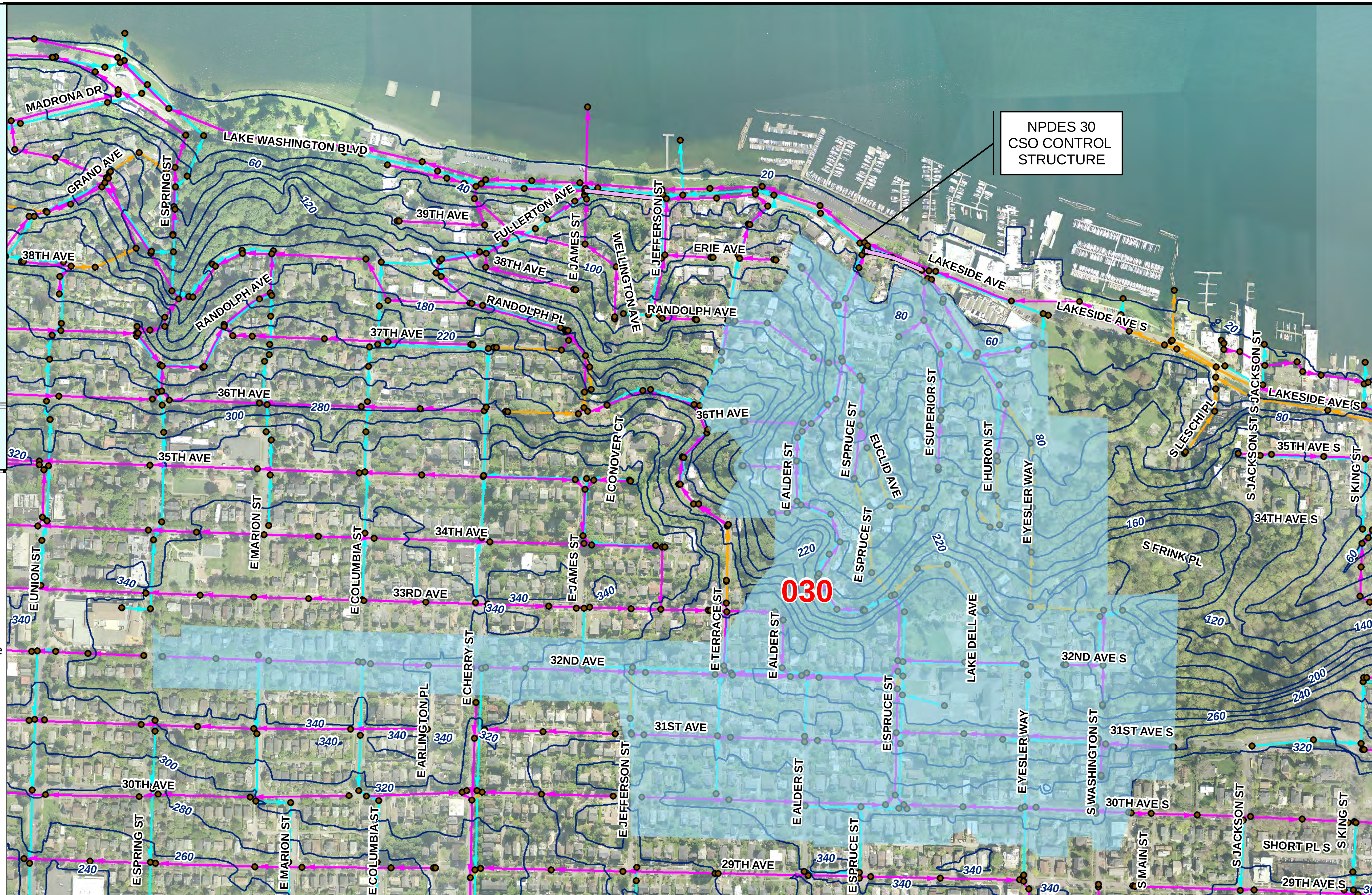
Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 20
Address (Resident) Map

DECEMBER 2012 | **EXHIBIT 20-3**





LEGEND

- Basin Boundary
- XXX NPDES Basin No.
- SPU Drainage Mainline
- SPU Sanitary Mainline
- SPU Combined Mainline
- King County Mainline
- 20-ft Contour
- Maintenance Hole

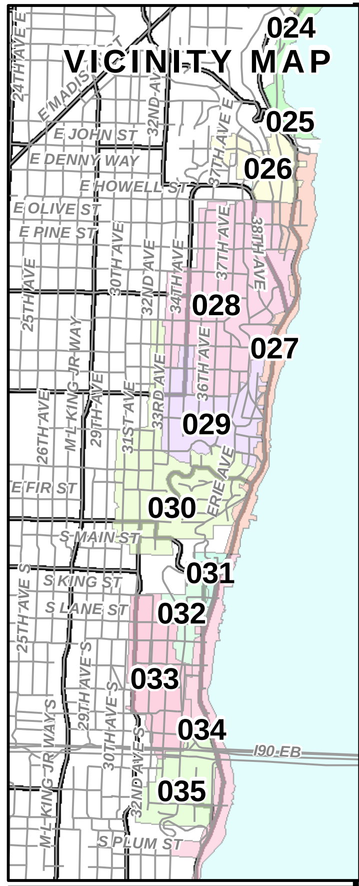
N E S W

Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 30
BASIN MAP

DECEMBER 2012 | **EXHIBIT 30 - 1**



LEGEND

XXX NPDES Basin No.
SPU Drainage Mainline
SPU Sanitary Mainline
SPU Combined Mainline
King County Mainline
20-ft Contour
Maintenance Hole

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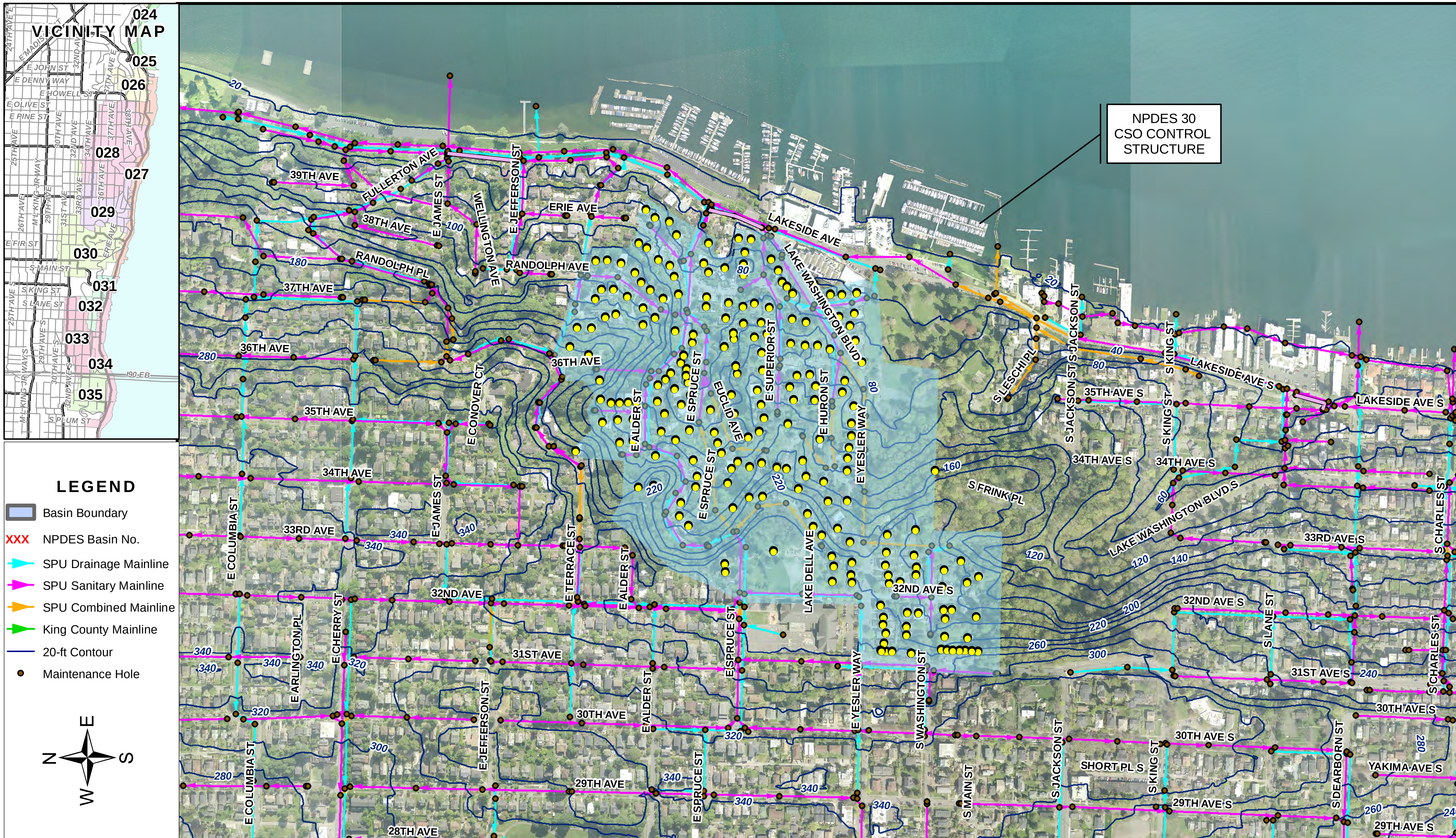
Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 30
CSO OUTFALL - DETAIL MAP

DECEMBER 2012

EXHIBIT 30 - 2

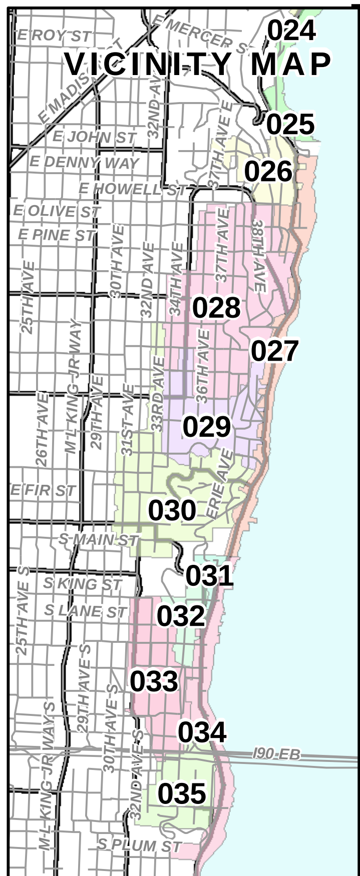


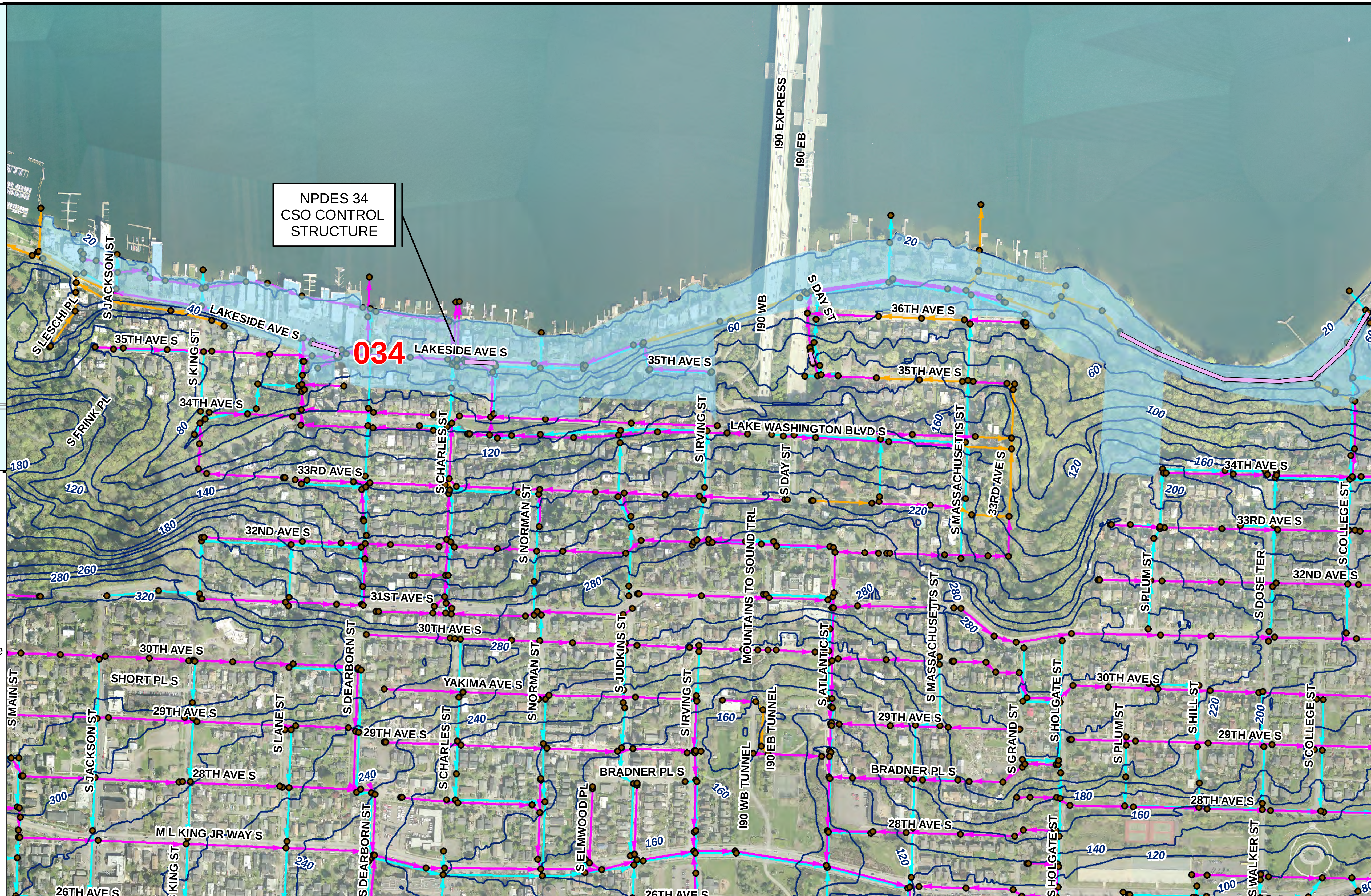
Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 30
ADDRESS (RESIDENT) MAP

DECEMBER 2012 | **EXHIBIT 30 - 3**





LEGEND

- Basin Boundary
- XXX NPDES Basin No.
- SPU Drainage Mainline
- SPU Sanitary Mainline
- SPU Combined Mainline
- King County Mainline
- 20-ft Contour
- Maintenance Hole

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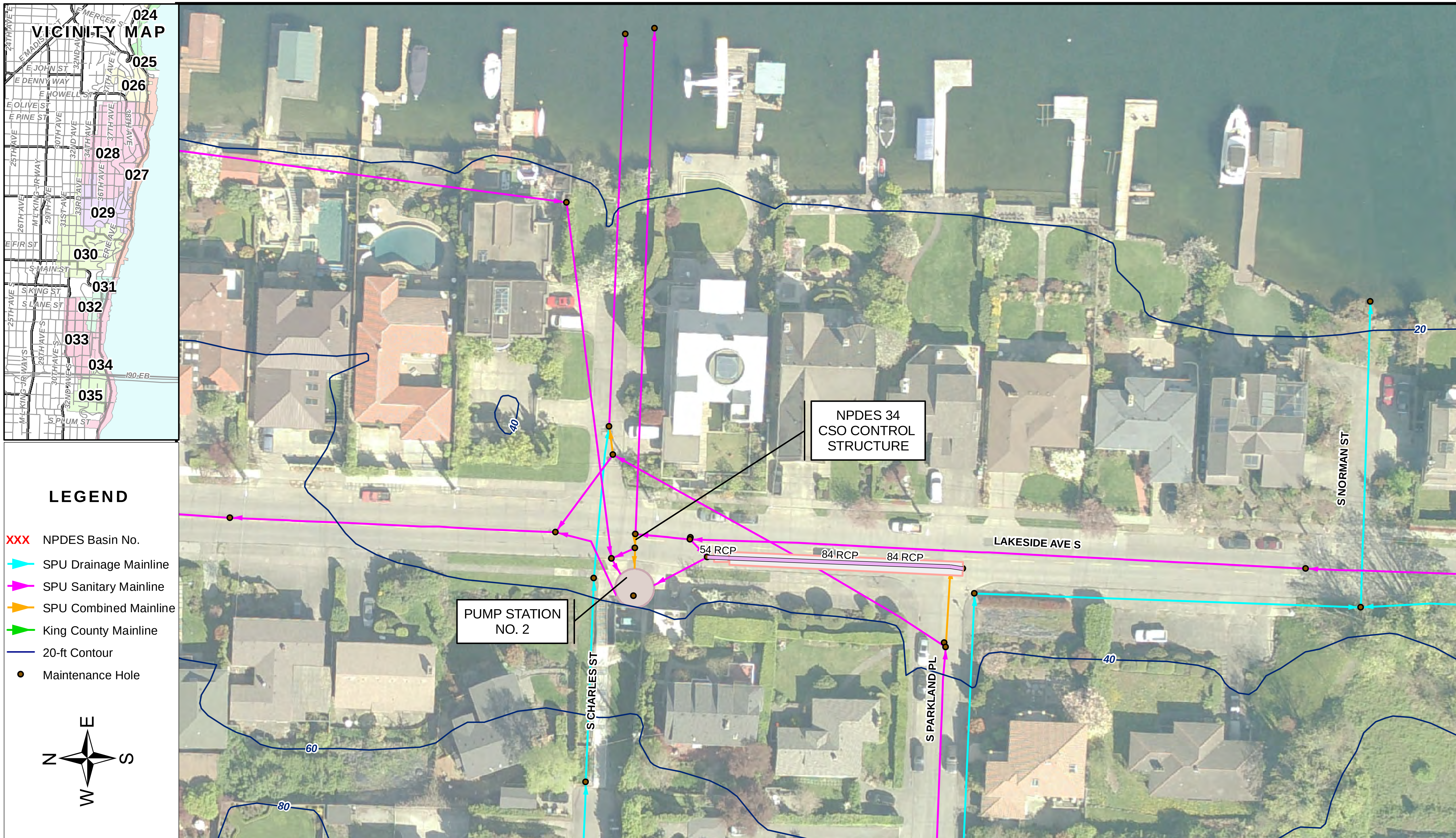
Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 34
BASIN MAP

DECEMBER 2012 | **EXHIBIT 34-1**



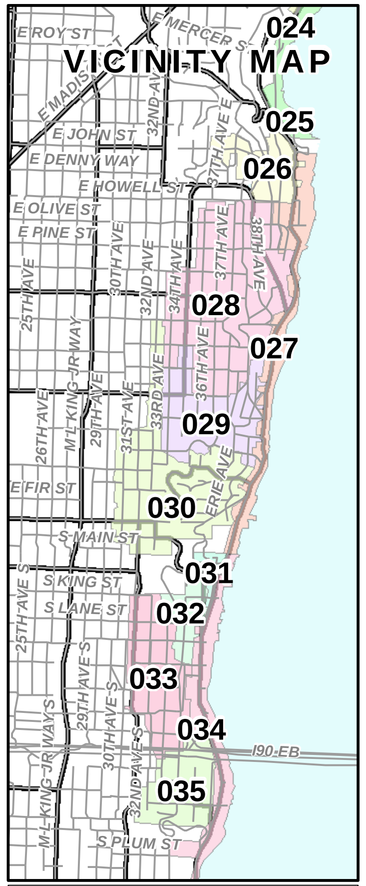
Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 34
CSO OUTFALL - DETAIL MAP

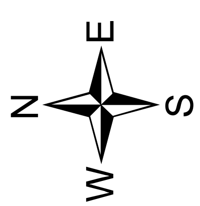
DECEMBER 2012

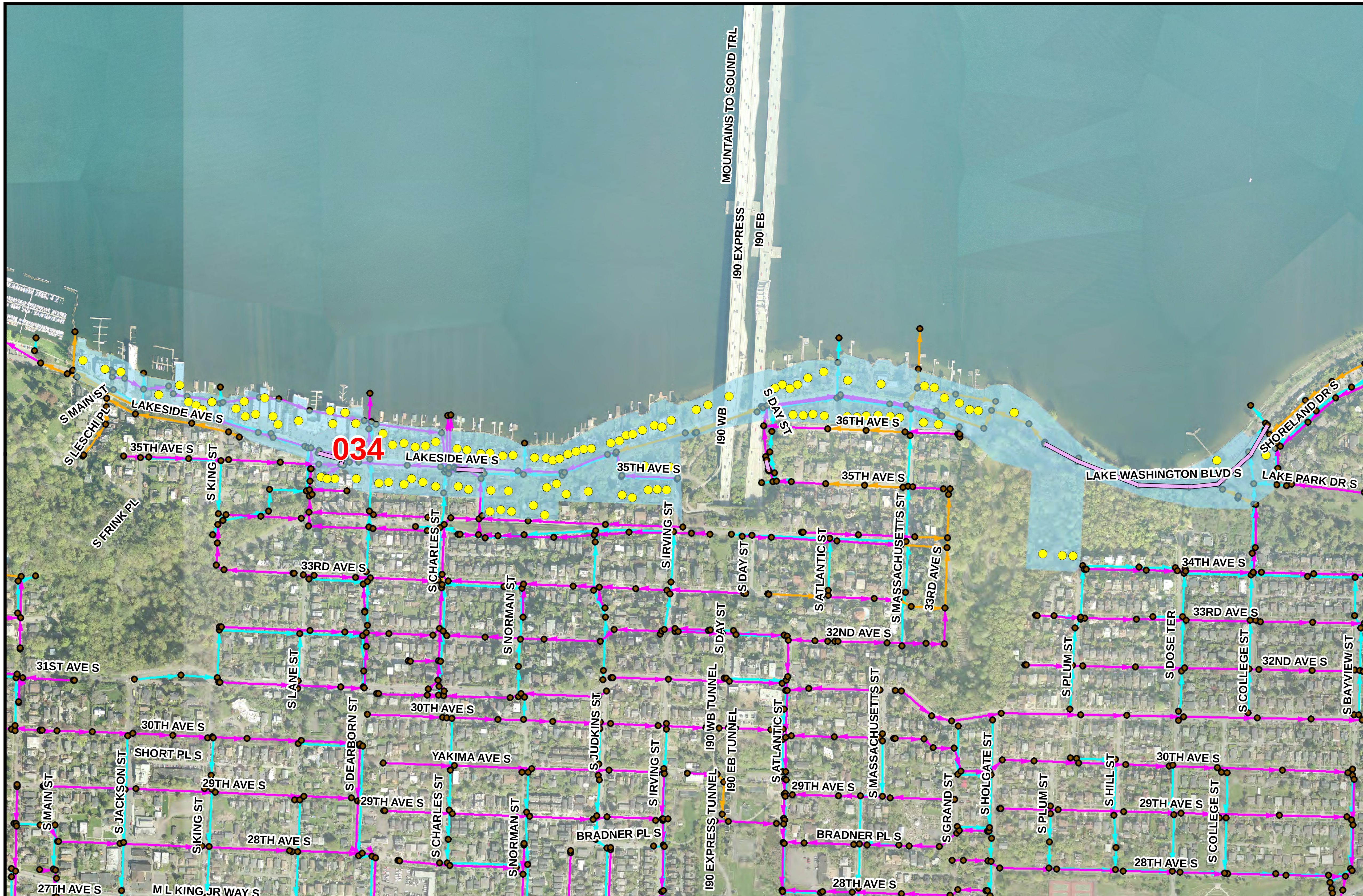
EXHIBIT 34-2



LEGEND

- Basin Boundary
- XXX NPDES Basin No.
- SPU Drainage Mainline
- SPU Sanitary Mainline
- SPU Combined Mainline
- King County Mainline
- 20-ft Contour
- Maintenance Hole



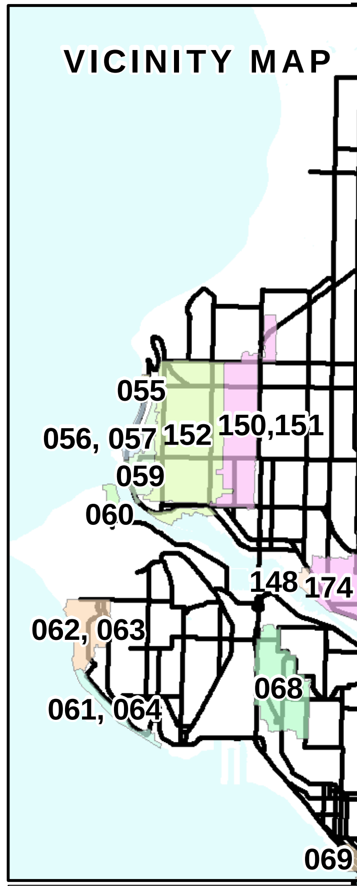


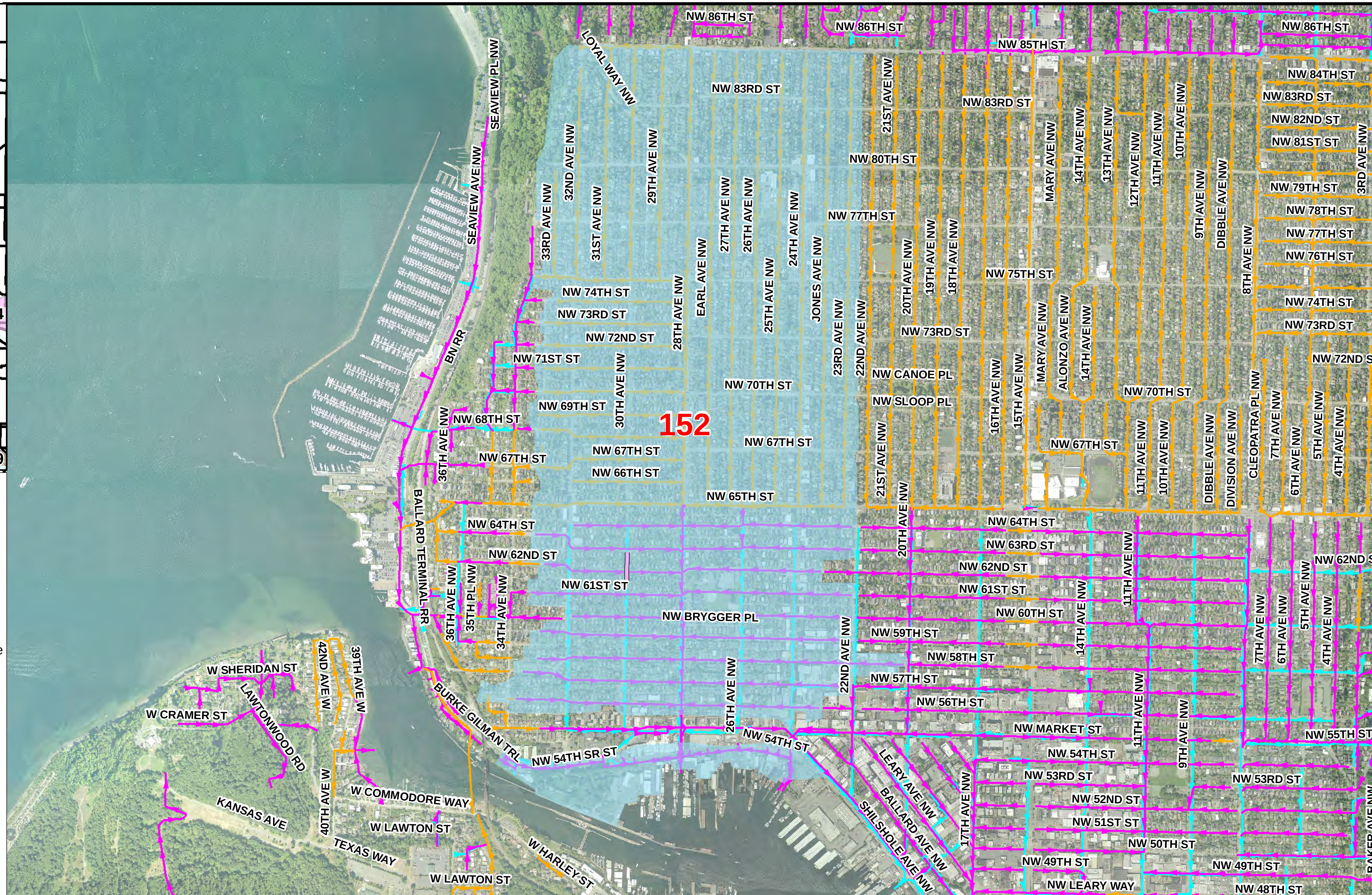
Seattle Public Utilities

Leschi CSO Retrofit Project
Alternative Screening

NPDES 34
ADDRESS (RESIDENT) MAP

DECEMBER 2012 | **FIGURE 34-3**





LEGEND

- Basin Boundary
- XXX NPDES Basin No.
- SPU Drainage Mainline
- SPU Sanitary Mainline
- SPU Combined Mainline
- King County Mainline
- 20-ft Contour
- Maintenance Hole

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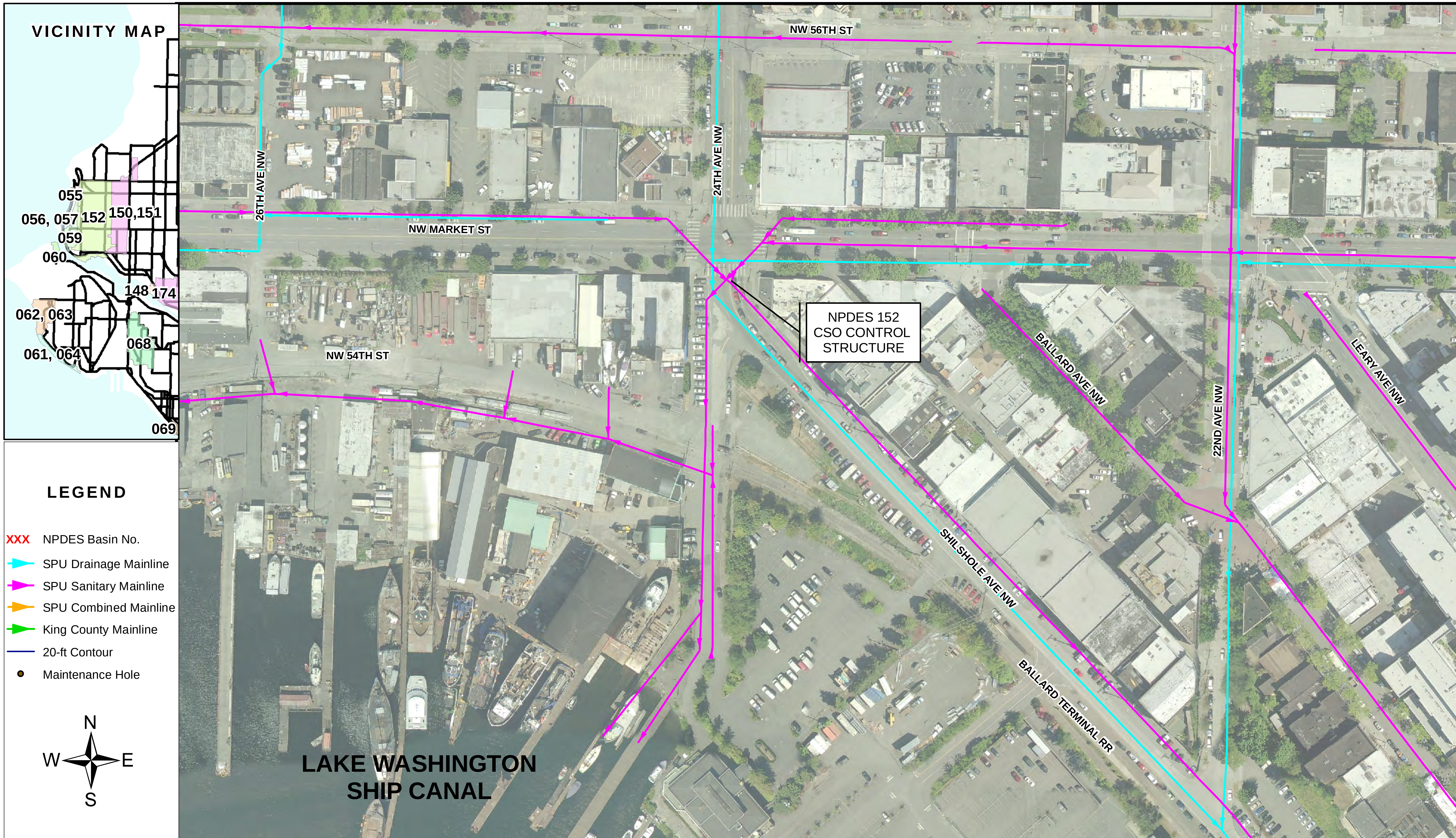
Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 152
BASIN MAP

DECEMBER 2012 | **FIGURE 152-1**

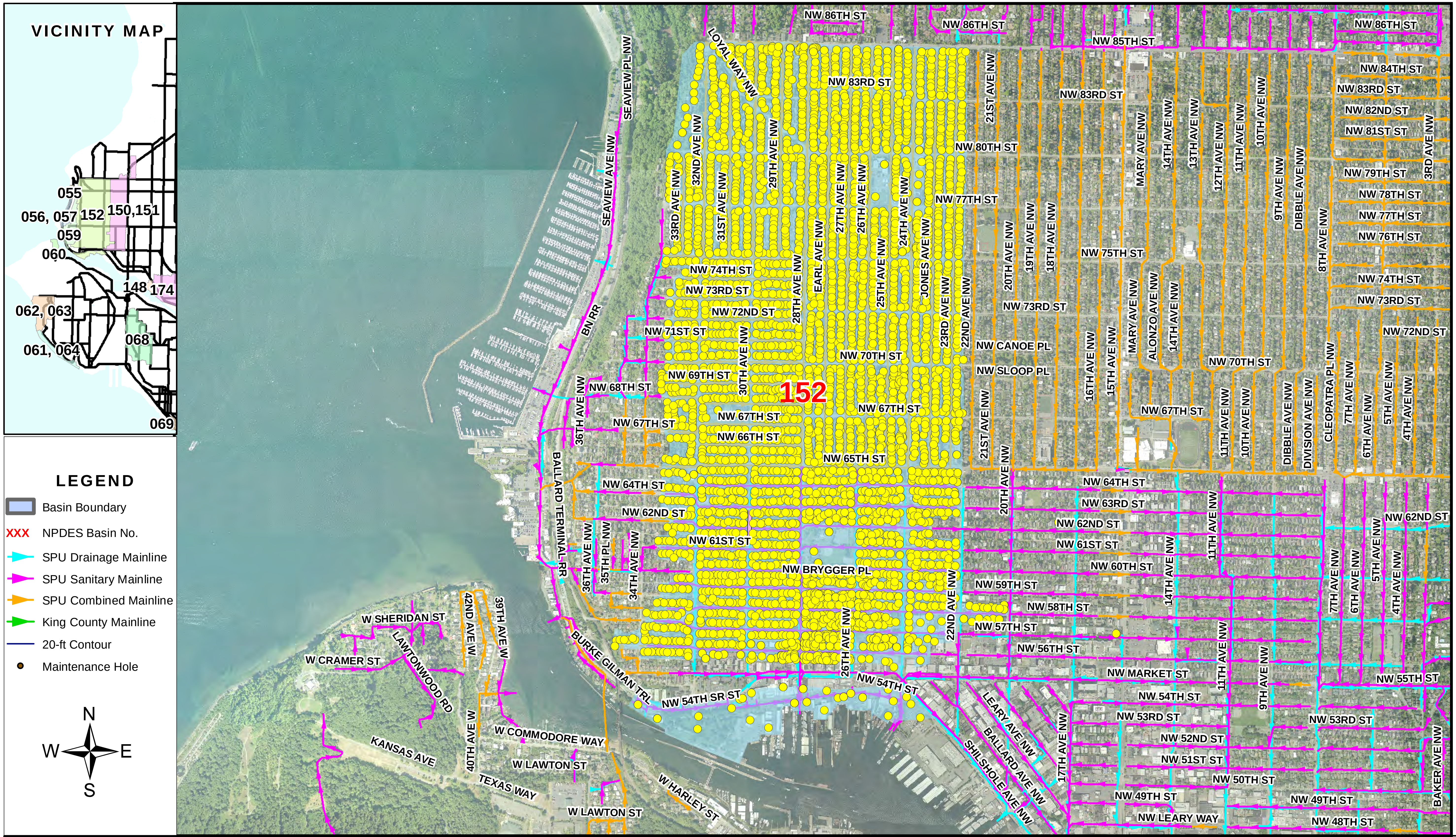


Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 152
CSO OUTFALL - DETAIL MAP

DECEMBER 2012	FIGURE 152-2



Seattle Public Utilities

Long Term Control Plan
Inflow and Infiltration Analysis

NPDES 152
ADDRESS (RESIDENT) MAP

DECEMBER 2012	FIGURE 152-3

Appendix I: GSI Feasibility Analysis Report

Technical Memorandum

Green Infrastructure Conceptual Analysis for CSO Control

Prepared for

Seattle Public Utilities

March 2014

CH2MHILL

Brown AND Caldwell

Technical Memorandum

Green Infrastructure Conceptual Analysis for CSO Control

Submitted to

Seattle Public Utilities

March 2014

Contents

Tables

Figures

Appendices

Acronyms and Abbreviations

The City	The City of Seattle
CSO	combined sewer overflow
GI	Green Infrastructure
GIS	geographic information system
GSI	green stormwater infrastructure
MG	million gallons
NDS	Natural Drainage Systems
NPDES	National Pollutant Discharge Elimination System
ROW	right-of-way
SPU	Seattle Public Utilities

1. Purpose

GI (also GSI) strategies—that infiltrate, evapotranspirate, and/or recycle stormwater runoff—include bioretention (e.g., rain gardens), permeable pavements, vegetated roofs, trees, and rainwater harvesting. GI improves water quality by reducing the occurrence or volume of CSOs. By reducing stormwater runoff, capacity in combined sewer systems is freed up to carry wastewater. This reduces CSO-related pollution from both untreated wastewater and stormwater. In addition to reducing stormwater volume and improving its quality, GI can provide many additional environmental, economic, and human-health benefits, such as increased habitat, improved air quality, and carbon sequestration.

GI is SPU’s preferred lead strategy in attaining control of CSOs. While it may not be technically suitable in specific cases and may not have the capacity to be the sole CSO control technique, it is consistent with the concept of sustainability and is supported by a broad public constituency. GI will be implemented in many of the currently uncontrolled basins at some level in addition to other CSO control solutions.

This summary reports on the results of the evaluation of conceptual GI alternatives for CSO control.

2. Background

SPU's GI program is well situated for incorporation into the CSO reduction strategies. The program has received national attention for the work to date on projects and policies. The GI team executed the retrofit of 232 acres of creek watershed with natural drainage systems, which reconfigure full street ROWs with interconnected bioretention cells in addition to vehicular, pedestrian, and landscape improvements. The Natural Drainage System program received the prestigious Kennedy School of Government’s Innovations in Government Award in 2004. State and federal funding agencies have reinforced the innovation in the program by funding over 40 percent of the $18M in capital project costs with grants or low interest loans. In addition to pilot and capital projects, SPU’s comprehensive GI program includes financial incentives, stormwater regulations, and stormwater fee credits as highlighted in the August 2010 U.S. Environmental Protection Agency (EPA) Green Infrastructure Case Studies (EPA-841-F-10-004, August 2010: http://www.epa.gov). SPU’s design guidance materials are taught as part of the Puget Sound Partnership’s Low Impact Development certification classes. Additional information about SPU’s GI program and projects is available atwww.seattle.gov/util/greeninfrastructure.

3. GI Toolbox

The GI Toolbox varies, depending on the sewer system type. Fully combined portions of the system have a larger suite of GI tools, involving work in the ROW as well as on private property. For the partially separated portions of the system, only the private parcels contribute flows to the combined sewer system.

3.1 Green Infrastructure BMPs Applicable for CSO Reduction in Fully Combined Areas

Fully combined sewer system portions of the service area refer to places where privately-owned parcels and ROWs are both connected to a combined sanitary sewer. These are the portions of the CSO basins where separation projects were not pursued during prior separation programs. The GI strategies for combined CSO basins that already have a formal street cross-section (curb and gutter) are described in Table 1. For this conceptual analysis, all the GI tools are sized to achieve the performance standard of managing the stormwater peaks and volumes generated by a 1-year flood frequency. For infiltration technologies this size correlates to infiltrating 95 percent of the average annual runoff volume from the contributing drainage basin. For detention strategies this size correlates to reducing the 1-year flood frequency by 95 percent.

Table 1. GI Strategies for Fully Combined Sewer Systems				
GI Strategy	**Strategy description**	**Implemented by**	**Owned and maintained by**	**Key strategy elements**
RainWise	RainWise rebates incentivize property owners who mitigate the impacts of impervious roof surfaces on private property by installing properly sized and constructed rain gardens or cisterns. Property owners who install an eligible rain garden or cistern meeting SPU design standards may apply for a rebate for the amount of impervious roof area controlled.	Property owner	Property owner	Homeowners informed of program through media and solicitation by contractors. Homeowners use RainWise Tools Web site for information and to select contractors. SPU will inspect installations and issue reimbursement checks to the homeowners.
Green alleys	Modify existing alleys with permeable pavement. Runoff generated by the impervious portion of the alley as well as run-on from adjacent buildings and yards would enter the permeable pavement area and infiltrate into native soils.[1]	SPU	SDOT (funding mechanism TBD; for analysis assumed to be SPU's cost)	SPU to select and design using standard CIP procedures.
Roadside rain gardens	Roadside rain gardens are bioretention facilities constructed in the public ROW. Two primary designs are used for roadside rain gardens: (1) the curb bulb and (2) the planting strip. The designs include curb cuts that allow the stormwater that runs down the gutter line to be intercepted and enter the cell.	SPU	SPU	SPU screens blocks for technical feasibility. Residents informed of program and eligible streets. Blocks with resident champions requesting and coordinating with neighbors will be prioritized.
Natural drainage systems	Bioretention facilities constructed as part of full street ROW reconstruction. Only applicable on streets that are currently lacking formal street improvements or conveyance systems.	SPU	SPU	

[1] The Green Alley program has been suspended to allow time to address design, capital cost, and operations and maintenance issues through the GI program.

3.2 Green Infrastructure BMPs Applicable for CSO Reduction in Partially Separated Areas

The City of Seattle has undergone extensive retrofit beginning in the 1960s to reduce flow going to the wastewater treatment plants. Large portions of the City's combined sewer systems have had separate stormwater systems installed. As part of these stormwater separation projects, runoff from ROWs was removed from the combined system and directed into a new piped storm drain system. Parcels adjacent to the newly separated streets were not reconnected to the new storm system; it was anticipated that the re-plumbing of parcels would occur through redevelopment. In these partially separated areas CSO reduction can be achieved by reducing the flows entering the combined system from the private parcels. Reduction in flow can occur by detaining or infiltrating flows before discharging back to the combined sewer, or by redirecting the flows to the piped storm drain within the street ROWs. Table 2 summarizes the GI strategies for partially separated areas.

Table 2. GI Strategies for Partially Separated Sewer Systems

GI strategy	Strategy description	Implemented by	Owned and maintained by	Key strategy elements
RainWise	RainWise rebates incentivize property owners who mitigate the impacts of impervious roof surfaces on private property by installing properly sized and constructed rain gardens or cisterns. Property owners who install an eligible rain garden or cistern meeting SPU design standards may apply for a rebate for the amount of impervious roof area controlled.	Property owner	Property owner	Homeowners informed of program through media and solicitation by contractors. Homeowners use RainWise Tools Web site for information and to select contractors. SPU will inspect installations and issue reimbursement checks to the homeowners.

4. Methodology

This section summarizes the steps to define the parameters used for a conceptual feasibility evaluation of GI's potential to reduce or control CSOs for 38 CSO sub-basins (in 12 of the 17 CSO areas presented in the 2010 Plan Amendment) in the City of Seattle. The GI feasibility modeling analysis has been completed for the Ballard and North Union Bay CSO areas, however it is now out of date due to updated LTCP basin wide modeling using SWMM5 v.5.0.022. Updates are in progress as part of the options analysis phases of the Delridge, and Ballard Natural Drainage Systems (NDS) Projects.

The monitoring and modeling efforts performed for the LTCP identified basins for GI evaluation. These basins are either uncontrolled or controlled but upstream of an uncontrolled basin. The conceptual feasibility for implementation of GI in selected basins was then evaluated using the following procedures, further described in the following subsections:

1. Delineation of impervious and pervious surfaces and areas disconnected from the combined sewer system (conducted by CH2M HILL staff).
2. Delineation and identification of areas unsuitable for infiltration. This includes eliminating hazardous areas for infiltration such as steep slopes, landslide-prone areas, contaminated soils areas, areas with high groundwater, etc. (conducted by CH2M HILL staff).
3. Field evaluation (conducted by SPU staff) to estimate the technical feasibility of GI practices areas that are connected to the combined sewer system. Evaluations for approaches include evaluation of type of street, site slope, available space, setbacks, and major obstructions.
4. Evaluation of privately-owned parcels and areas within the ROW to estimate levels of participation (conducted by SPU staff).
5. Calculation of areas eligible and potential impervious area mitigated for individual GI practices for various participation level scenarios (conducted by CH2M HILL staff).
6. Analysis of flow monitoring data to estimate the approximate CSO CV reduction based on various participation levels (conducted by CH2M HILL staff).

The results of this analysis yielded a wide range of potential CV reduction using GI. GI may potentially provide a significant reduction of the CSO CV in some basins (e.g., Montlake and Ballard), including possible full control with best estimate or higher participation assumptions. In other basins, due to technical feasibility, infiltration hazards, or nature of the overflow conditions (e.g., excessive volumes to control), GI has a lower potential benefit toward CV reduction. In all cases, implementation of GI will provide some reduction in overflow volume.

4.1 Delineation of Areas Separated from the Combined Sewer System

The primary target of GI practices is to intercept directly connected impervious areas and reduce runoff before entering the combined sewer system. Therefore, an initial step in this analysis was to identify runoff surfaces that are already disconnected from the combined sewer system. This step was supported by ongoing work by the City to develop computer models of the combined sewer system in each of the CSO areas evaluated in this study. Development of these models started with creating GIS shapefiles for estimating impervious areas draining to the combined sewer system. GIS data was used to delineate the land coverage for input into the models for both parcel and ROW. The impervious surfaces were then screened to identify areas that are likely separated from the combined sewer system, for example, the GIS database shows a drainage lateral or catch basin connected to a separated storm drain. This analysis also identified impervious surfaces that are likely disconnected and drain directly to adjacent pervious areas, for example smaller disconnected buildings such as garages. Appendix B provides further detail on this analysis and the results.

The degree of connection of these areas to the system cannot be determined through GIS alone as roof and paved surfaces may not necessarily be directly connected to the combined system through a variety of conditions. The models will therefore be calibrated using flow monitoring data over multiple seasons to estimate the approximate percent of connected impervious area (relative to the delineated impervious area) that generates simulated runoff that best matches the monitored data. Where system models have been calibrated or manually calibrated, this analysis uses the values developed for those basins to estimate the total directly connected impervious area that may be mitigated through GI to reduce flows to the combined sewer system. Where the models have not been developed to a level sufficient to establish an approximate degree of connectivity, the flow monitoring data was analyzed using hydrograph separation techniques (Figure 1) to estimate the approximate degree of connectivity.

FIGURE 1
Model Delineation of Right-of-Way Sewer Separation

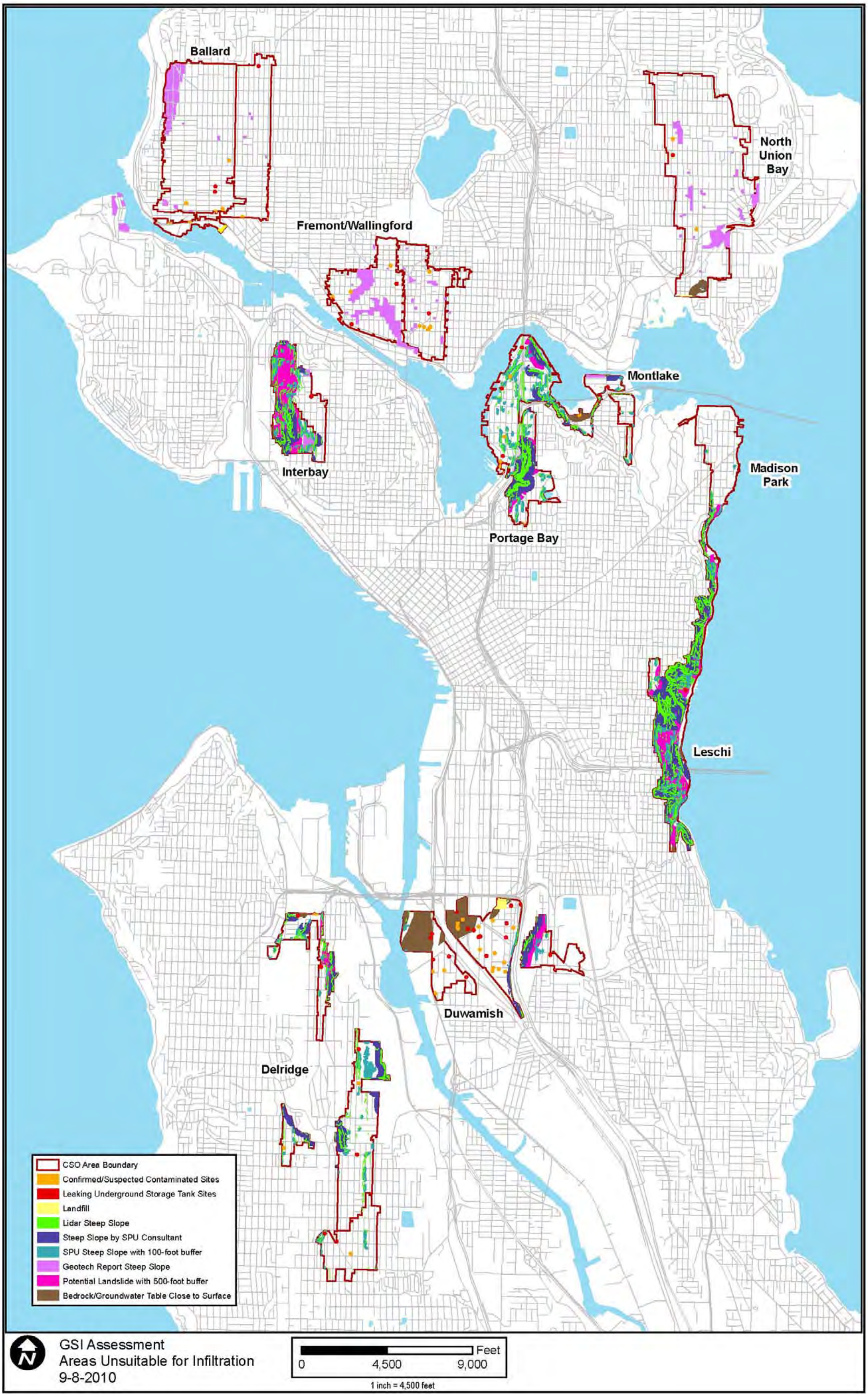
4.2 Evaluation of Areas Unsuitable for Infiltration

Many GI practices, notably rain gardens, green alleys and downspout disconnections, rely on infiltration to reduce runoff. Therefore, the CSO basins were analyzed to identify areas that were unsuitable for infiltration through either impermeable soils or potentially hazardous conditions created by infiltrated runoff. GIS analysis, supported by fieldwork by City geotechnical staff, was used to map areas unsuitable for infiltration and thus identify areas where practices that rely on infiltration are prohibited. In general, areas unsuitable met one or more of the following conditions:

- Areas identified as close to **bedrock.**
- Areas over **high groundwater.**
- In or within a 100-foot uphill setback from **landslide- prone critical areas.**
- In or within an uphill setback from **steep slopes.** Steep slopes are identified as areas exceeding 40 percent slope for 10 feet or greater in height. Setbacks are defined as equal to 10 times the steep slope height with a minimum setback of 100 feet and maximum of 500 feet.
- Within 100 feet of **contaminated sites** or **abandoned landfills.**

Appendix C describes the methods and data sources used in this analysis. Figure 2 shows a map of the areas identified as unsuitable for infiltration within the CSO areas analyzed.

FIGURE 2
Areas Unsuitable for Infiltration



4.3 Field Evaluation of Technical Feasibility and Participation

Even in areas where infiltration is feasible, other physical site constraints can limit the potential implementation of GI practices. The RainWise program is voluntary and the City recognizes the competing uses (e.g. on-street parking) within ROW that may render some GI retrofits infeasible. Therefore, an additional step beyond GIS analysis was performed to field evaluate and verify the potential for GI within each CSO area. SPU staff conducted walking and windshield surveys of the CSO basins to estimate technical feasibility and participation for GI through either ROW retrofits or the RainWise program.

For ROW approaches, SPU staff reviewed each block draining to combined sewer and not identified as unsuitable for infiltration to identify areas where GI retrofits were technically feasible and implementable. For each block, SPU staff identified the potential area mitigated by GI practices within the ROW. The following is a brief summary of the considerations, beyond areas unsuitable for infiltration (AUI), for technical feasibility:

- **Longitudinal slopes** above six percent (for roadside rain gardens) and above five percent (for green alleys) were considered infeasible.
- The **width of the existing planter strip** was used to determine if roadside rain gardens were feasible with or without a curb extension.
- **Use adjacent to the planter strip** was identified and areas in front of public spaces were excluded (e.g. schools, parks, churches, etc.).
- Presence of existing **curb and gutter** was used to determine candidacy for roadside rain gardens or natural drainage systems.
- The extent of **on-street parking use** was incorporated into estimates of the level of implementation of GI within the ROW.

In addition to technical feasibility, a percentage of estimated right-of-way implemented was applied (generally between 60 to 80 percent) based on practical limitations of full implementation.

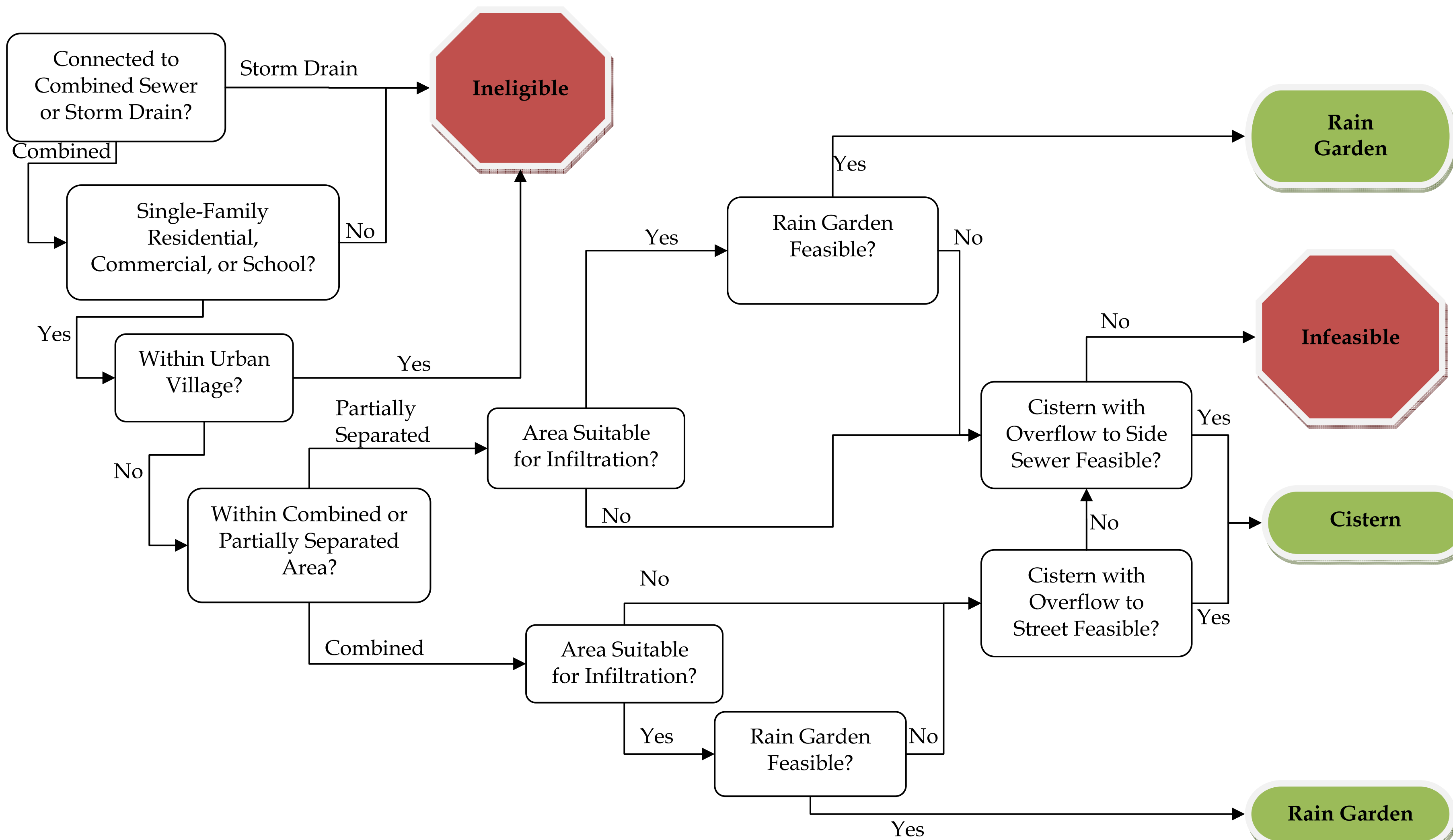
For RainWise, the technical feasibility and participation estimates performed by SPU staff were comprised of most practical (high) and low estimates of technical feasibility (e.g. physical constraints), proportion of building area that could be drained to practices and participation. This analysis was developed for residential areas within each basin and for commercial and school land uses citywide. In addition, Urban Village areas, multi-family residential and industrial land uses are ineligible for the RainWise. The level of participation by residents in the RainWise program was estimated based on staff experience with the Lakewood Rain Catchers program, which was a similar voluntary pilot program in the Genesee CSO area. Experience with constructing rain gardens on private property has shown that it is often technically infeasible (or costly) to drain entire roofs to a single GI rain garden or cistern and homeowners are commonly reluctant to construct multiple practices on their parcels. Therefore, low and high estimates of the roof area that could be drained to GI practices were also provided. Finally, the technical feasibility of individual practices was summarized as a low and high estimated percentage of sites where the practices were considered feasible.

Factors considered in the technical feasibility for individual practices were as follows:

- Setbacks from retaining walls and rockeries equal to two times the height of the feature were excluded as feasible for rain gardens or downspout disconnections.
- Areas for rain gardens or downspout disconnections must slope away from the house, basement, or neighboring basement.
- Available space for rain gardens calculated from the simplified sizing guidelines in the City's Stormwater Management Manual must be available.
- Sites must be able to provide sufficient grade and unobstructed area to drain safely both to the rain gardens from downspouts and from rain garden to either the street or existing side sewer.
- Sites must be able to provide sufficient grade and unobstructed area to safely drain from downspouts to the street for downspout disconnection to be considered feasible.
- Cisterns cannot obstruct ingress/egress from residences (e.g. all windows and doors).
- Sufficient area to site a cistern without blocking walkways, driveways, or landscaping must be available.
- A minimum of 400 feet of roof area is required to drain to cisterns. Costly gutter reconfigurations were considered infeasible to meet this requirement.

Figure 3 provides a decision tree that was applied to estimate the total area mitigated though the RainWise program. Evaluation for single-family residences, schools and commercial parcels were similar, however basin-by-basin estimates of technical feasibility and participation were made only for single-family residences. As there is less variability in technical feasibility and participation for schools and commercial parcels, citywide estimates were applied to those land uses. Appendix D summarizes the results of SPU's field analysis for RainWise feasibility and participation. Appendix E presents field maps developed by SPU to demonstrate the feasibility of GI retrofits within the ROW.

FIGURE 3
Decision Tree for RainWise Eligibility by GI Practice



4.4 Calculation of Potential Impervious Area Mitigated by GI Practices

The results from the steps described above to identify runoff surfaces connected to the combined sewer system, areas unsuitable for infiltration and average technical feasibility and participation were combined to develop estimated ranges of potential impervious area mitigated by GI practices. The total potential impervious mitigated by GI practices was calculated by NPDES Basin for low, high, and maximum participation levels. For ROW, the total area mitigated by GI was summed directly from the field analysis provided by SPU for both low and high participation levels. Where evaluated for maximum potential GI, ROW areas where SPU staff noted partial implementation based on non-technical reasons (e.g. on street parking) were adjusted to include all blocks identified as technically feasible. These calculations were made at a level consistent with the model subcatchments in order that GI implementation may be most easily simulated once calibrated models are available for all basins. Appendix F describes the methods and data sources used in this analysis.

4.4.1 Inclusion of system connectivity in GI control volume feasibility estimate

GI practices slow or remove the flow of storm water into the combined sewer system. The effectiveness of GI practices is thus dependent on the connection of storm water hydrology to the combined sewer system. Initial analysis (described above) was based on preliminary estimates of connectivity. Automated model calibration performed since November 2010 produced calibrated values for system connectivity for each of the calibration basins (City of Seattle, 2011). The calibrated values were used to factor the total area for which GI is slowing or removing flow.

4.5 Estimation of Potential Control Volume Reduction through GI

To evaluate the potential for GI to effectively reduce CSOs or the required volume of conventional CSO control facilities, it is necessary to translate the area mitigated through GI practices to a control volume reduction. Ultimately, the actual volume of CSO reduction provided by GI will be estimated using the computer models currently under development and compared to monitored data from projects such as the Ballard Roadside Rain Garden Project. In the meantime, this study analyzed flow monitoring data collected from 2007 to 2010 to estimate the approximate CSO control volume reduction provided by GI based on representative storms collected during that period. The result of this analysis was to determine an estimated control volume reduction (e.g. gallons) associated with impervious area mitigated.

The actual CSO control volume reduction through GI is dependent on a number of variables, including the nature of the CSO event, hydrologic behavior of the flows in the system, configuration of the combined sewer system and CSO control facilities and the capacity of the downstream system. Different basins can overflow during different hydrologic conditions, for example, systems with minimal to no storage may overflow more frequently during high intensity but relatively short duration storms; during such storms the proportion of the flow associated with directly connected impervious area is larger and thus can be more easily mitigated using GI. However, systems with large amounts of storage can overflow during larger duration storms where wet weather inflow can contribute a larger percentage of the flow and GI practices may be less effective due to saturated conditions.

Where the existing combined sewer system does not contain storage facilities, the CSO reduction associated with GI can be approximated as the amount of runoff from impervious that is reduced throughout the duration of existing overflow. For instance, runoff that is reduced through GI before and following the overflow event has minimal impact on the control volume as that runoff is passed through the system. Where storage exists under existing conditions, the runoff reduction that occurs during the period where storage facilities are being filled can equate to approximate CSO control volume reduction. Finally, the capacity of the system downstream of an overflow location can have an impact on the level of reduction possible using GI. For example, the Basins 147 and 174 in Fremont/Wallingford typically overflow during conditions where the capacity of the downstream trunk system is exceeded; therefore, nearly all flow in the city system upstream of the overflow needs to be stored during a CSO event. In other locations, the capacity of the downstream system is more-or-less fixed, often using a hydraulic restriction device such as a HydroBrake.

These considerations were taken into account when determining an approximate CSO reduction volume per impervious area mitigated by GI using the flow monitoring data, described in detail in Appendix G (last published and updated in 2011). In locations where sufficient monitoring data is not available, an average CSO reduction of 0.5 gallons per square foot of impervious area mitigated was used. This is within the typical range found in the flow monitoring data analysis and used in prior studies.

4.5.1 Modeling of CSO reduction due to GI

Reduction of CSO control volumes due to GI was analyzed by modifying calibrated CSO area SWMM models. The creation and calibration of these base models is described in a series of modeling reports (City of Seattle, 2011). GI practices were added using the LID Controls module that is available in SWMM5 Engine Version 5.0.021 and higher. Three RainWise practices were simulated (rain gardens, cisterns and downspout disconnection), as well as two right-of-way practices (rain gardens and green alleys).

The GI feasibility spreadsheets created for the analysis presented in Section 4.1 through 4.4 were modified to generate input for the SWMM LID Controls module. The feasibility spreadsheets were used to sum the area draining to each of the five GI practices in each model catchment, including factors for system connectivity, site feasibility, technical feasibility and residential participation.

The SWMM parameters used to simulate GI practices are described in Appendix H. A summary of the modeling methodology is included in Appendix I, with detailed documentation of modeling steps included in Appendix J.

5. Results

5.1 Feasibility Results

The total potential control volume reduction using GI was calculated using three levels of participation.

- Low technical feasibility and participation values from SPU's field analysis of RainWise and ROW options were used to establish the **worst-case** estimates of control volume reduction for each basin.
- High technical feasibility and participation values were used to establish the **most practical estimate** of control volume reduction for each basin (Figure 4).
- One hundred percent participation was assumed for both RainWise and ROW options to establish the **maximum potential** control volume reduction for each basin (Figure 5).

The results of this analysis yielded a wide range of potential control volume reduction using GI. GI may potentially provide a significant reduction of the CSO control volume in some basins (e.g. Montlake, Leschi, North Union Bay and Ballard), including possible full control with most practical or higher participation assumptions. In other basins, due to technical feasibility, infiltration hazards, or nature of the overflow conditions (e.g. excessive volumes to control) GI has a lower potential benefit toward control volume reduction. In all cases, some implementation of GI will provide a reduction in overflow volume.

The potential control volume reduction possible through GI for each basin was categorized into one of five potential control levels:

- **Full Control of CSOs through GI per Most Practical Levels of Participation.** These basins are considered the greatest opportunity where GI may be implemented to control CSOs fully through a combination of RainWise and ROW retrofits, potentially eliminating the need for conventional CSO control facilities. Table 3 provides data on this potential control level.
- **Basins with the Potential to Control CSOs Fully through GI with Increased Participation.** These basins have the potential to control CSOs fully through a combination of RainWise and ROW retrofits, if all technically feasible ROW areas are implemented and estimated participation in RainWise can be increased over most practical levels. The estimated level of participation in RainWise to meet the control volume is calculated for each of these basins. Table 4 provides data on this potential control level.
- **Basins with Moderate Potential to Reduce CSO Control Volumes through GI.** These basins are unlikely to control CSOs fully through a combination of RainWise and ROW retrofits, even with full participation. However, implementation of GI in these basins may reduce the required volume of conventional CSO facilities (over 15 percent reduction or greater with full participation). The maximum control volume is calculated

for each of these basins. Table 5 provides data on this potential control level with most practical participation. Table 6 provides data on basins with the potential to meet this control level with increased participation.

- **Basins with Limited Potential to Reduce CSO Control Volumes through GI.** These basins are unlikely to control CSOs fully through a combination of RainWise and ROW retrofits even with full participation. In addition, implementation of GI in these basins may have limited benefit in reducing the required volume of conventional CSO facilities (under 15 percent reduction or greater with full participation). The maximum control volume is calculated for each of these basins. Table 7 provides data on this potential control level.
- **Controlled Basins.** These basins are currently considered to be controlled. Although not specifically analyzed in this analysis, flow reduction through GI in these basins may have additional benefits for reducing control volumes in adjunct basins (e.g. uncontrolled basins that drain to the same system) and as a collaborative alternative for reducing volumes to King County's combined system downstream. Table 8 provides data on this potential control level.

Table 9 provides data on the GI potential in basins to be controlled by the Early Action Projects defined by the July 2013 Consent Decree.

FIGURE 4
CSO Reduction Potential of GI for Most Practical Implementation Level (Including Updated Model Results for North Union Bay and Ballard)

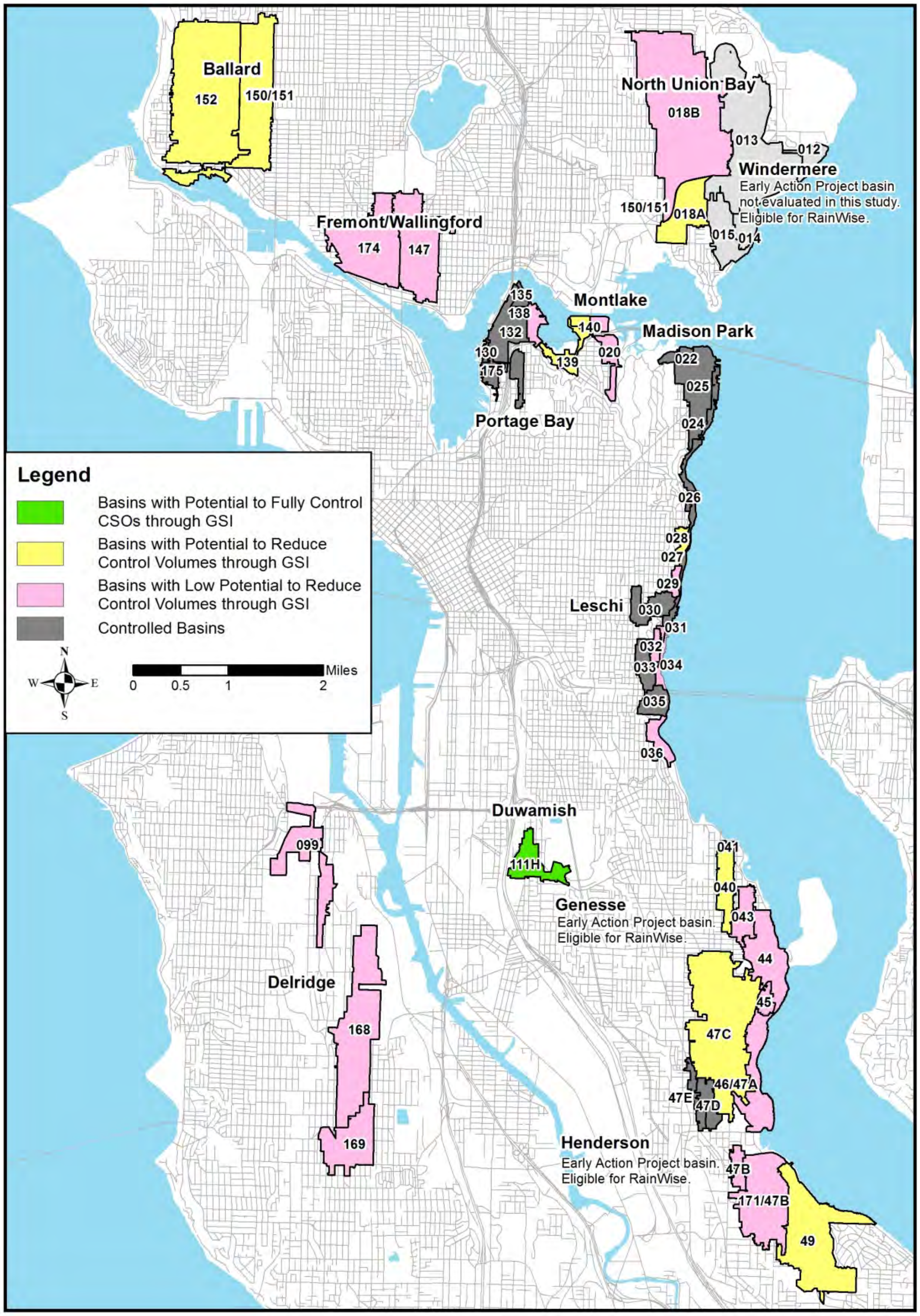


FIGURE 5
CSO Reduction Potential of GI for Maximum Implementation Level

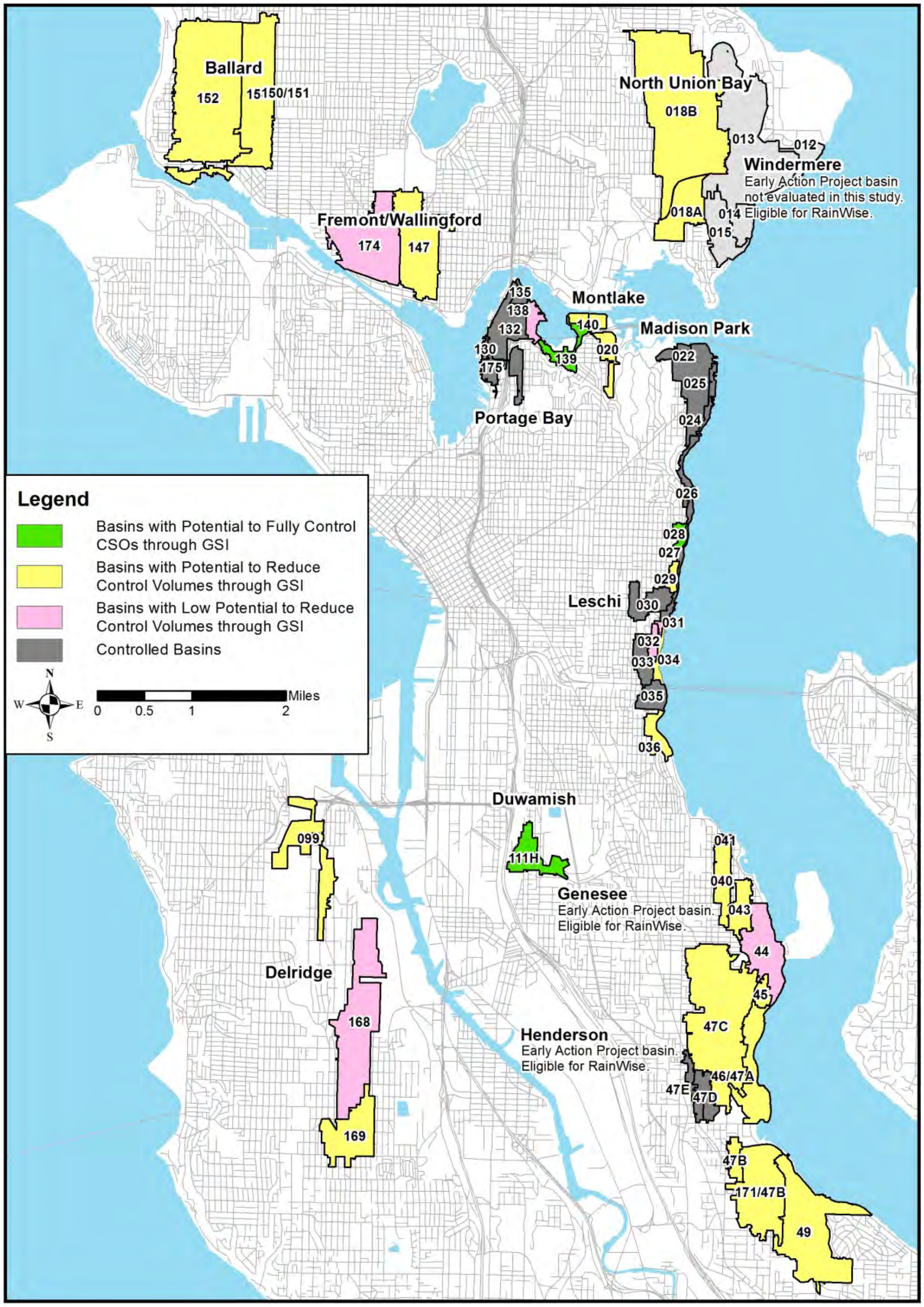


TABLE 3
Basins with Potential to Fully Control CSOs through GI per Most Practical Participation

Basin	Overflow	LTCP Control Volume (MG)	Most Practical Control Volume Reduction through GI (MG)	Most Practical of Control Volume Possible through GI	Estimated RainWise Most Practical Participation	Estimated ROW Implementation	Maximum Control Volume Reduction with 100% Participation[1] (MG)
Duwamish	111H	0.01	0.016	164%	25%	80%	0.052

1 Includes full participation in RainWise and implementation ROW GI where technically feasible.

MG million gallons

TABLE 4
Basins with Potential to Fully Control CSOs through GI with Increased Participation

Basin	Overflow	LTCP Control Volume (MG)	Most Practical Control Volume Reduction through GI (MG)	Most Practical of Control Volume Possible through GI	RainWise Most Practical Participation	Estimated ROW Implementation	Maximum Control Volume Reduction with 100% Participation[1] (MG)	Minimum Participation to Meet Control Volume through GI[2]
Leschi	28	<0.01	0.002	19%	10%	80%	0.015	67%
Montlake	139	<0.01	0.006	63%	20%	80%	0.025	40%

1 Includes full participation in RainWise and implementation ROW GI where technically feasible

2 Minimum participation in RainWise. Assumes full implementation of GI in the ROW where technically feasible.

3 Achievable through 100% implementation of GI in ROW without RainWise.

TABLE 5
Basins with Moderate Potential to Reduce CSO Control Volumes through GI

Basin	Overflow	LTCP Control Volume (MG)	Most Practical Control Volume Reduction through GI (MG)	Most Practical % of Control Volume Possible through GI	RainWise Most Practical Participation	Estimated ROW Implementation	Maximum Control Volume Reduction with 100% Participation[1] (MG)	Maximum % of Control Volume Possible through GI[1]
N. Union Bay[2]	18A	0.26	0.085	33%	30%	80%	0.162	62%
N. Union Bay[2]	18B	1.37	0.365	27%	30%	80%	0.628	46%
Montlake	140	0.05	0.019	37%	20%	80%	0.026	53%
Ballard[2]	150/151	0.62	0.172	28%	35%	60%	0.273	44%
Ballard[2]	152	5.38	1.070	20%	35%	60%	1.718	32%

1 Includes full participation in RainWise and implementation ROW GI where technically feasible.

2 See subsequent section for updated modeling results.

TABLE 6
Basins with Moderate Potential to Reduce CSO Control Volumes through GI with Increased Participation

Basin	Overflow	LTCP Control Volume (MG)	Most Practical Control Volume Reduction through GI (MG)	Most Practical % of Control Volume Possible through GI	RainWise Most Practical Participation	Estimated ROW Implementation	Maximum Control Volume Reduction with 100% Participation* (MG)	Maximum % of Control Volume Possible through GI*
Montlake	20	0.16	0.021	13%	5%	80%	0.066	41%
Leschi	29	0.02	0.001	5%	10%	80%	0.008	38%
Leschi	34	0.03	0.0007	2%	10%	80%	0.005	17%
Leschi	36	0.03	0.001	5%	10%	80%	0.011	36%
Fre/Wall	147	2.15	0.020	1%	35%	80%	0.484	23%
Delridge	99	0.17	0.017	10%	30%	80%	0.043	25%
Delridge	169	1.19	0.152	13%	30%	80%	0.192	16%

* Includes full participation in RainWise and implementation ROW GI, where technically feasible.

TABLE 7
Basins with Limited Potential to Reduce CSO Control Volumes through GI

Basin	Overflow	LTCP Control Volume (MG)	Most Practical Control Volume Reduction through GI (MG)	Most Practical of Control Volume Possible through GI (MG)	RainWise Most Practical Participation	Estimated ROW Implementation	Maximum Control Volume Reduction with 100% Participation* (MG)	Maximum % of Control Volume Possible through GI
Leschi	31	0.31	0.0004	0%	10%	80%	0.003	1%
Leschi	32	0.08	0.001	2%	10%	80%	0.010	13%
Portage Bay	138	0.11	0.007	6%	30%	80%	0.011	10%
Delridge	168	2.00	0.1619	8%	30%	80%	0.266	13%
Fre/Wall	174	1.06	0.054	5%	35%	80%	0.122	12%

* Includes full participation in RainWise and implementation ROW GI, where technically feasible.

TABLE 8
GI Potential in Controlled Basins

Basin	Overflow	LTCP Control Volume (MG)	Most Practical Control Volume Reduction through GI (MG)	RainWise Most Practical Participation	Estimated ROW Implementation	Maximum Control Volume Reduction with 100% Participation* (MG)
Mad Park	22	0	0.001	15%	80%	0.007
Mad Park	24	0	0.002	15%	80%	0.006
Mad Park	25	0	0.012	15%	80%	0.057
Leschi	26	0	0.001	10%	80%	0.011
Leschi	27	0	0.0005	10%	80%	0.004
Leschi	30	0	0.002	10%	80%	0.017
Leschi	33	0	0.005	10%	80%	0.039
Leschi	35	0	0.002	10%	80%	0.017
Portage Bay	130	0	0.0001	0%	0%	0.0001
Portage Bay	132	0	0.000	0%	0%	0.000
Portage Bay	135	0	0.000	0%	0%	0.000
Portage Bay	175	0	0.000	0%	0%	0.000
Henderson	47D	0	0.003	30%	0%	0.008
Henderson	47E	0	0.001	30%	0%	0.003

* Includes full participation in RainWise and implementation ROW GI, where technically feasible.

TABLE 9
GI Potential in Early Action Projects Basins

Basin	Overflow	LTCP Control Volume (MG)	Practical CV Reduction through GI (MG)	Practical % of CV Possible through GI (MG)	Est. RainWise Participation	Est. ROW Implementation	Maximum CV Reduction with 100% Participation	Max. % of CV Possible through GI
Genesee	40	0.177	0.034	19%	35%	0%	0.075	42%
Genesee	41	0.194	0.001	0%	35%	0%	0.001	1%
Genesee	43	0.18	0.021	12%	30%	0%	0.052	29%
Henderson	44	1.7	0.074	4%	35%	0%	0.153	9%
Henderson	45	0.14	0.011	8%	35%	0%	0.024	17%
Henderson	46	0.185	0.011	6%	20%	0%	0.034	18%
Henderson	47B	0.112	0.008	7%	30%	0%	0.020	18%
Henderson	47C	0.136	0.054	40%	30%	0%	0.141	104%
Henderson	49	0.108	0.037	34%	30%	0%	0.091	85%
Henderson	171	0.105	0.011	10%	20%	0%	0.043	41%

5.2 Modeling Results

Modeling for GI for the Ballard and North Union Bay basins was performed using SWMM5 version 5.0.021 and prior to the update of the LTCP for Control Volumes resulting from SWMM5 version 5.0.022. Thus, this section compares the GI modeling results against previous LTCP Control Volumes resulting from modeling using SWMM5 version 5.0.018. Further modeling is to be conducted at the options analysis phase of the individual GI projects; updates to modeling are in progress for the Delridge and Ballard Natural Drainage Systems (NDS) Projects.

Due to differences in model results using SWMM5 version 5.0.018 and 5.0.021 and the availability of the LID module in version 5.0.021 and not SWMM5 version 5.0.018, results from GI modeling are presented in Table 10 as a percent reduction of the LTCP Control Volumes from SWMM5 version 5.0.018.

Note that the LTCP Control Volumes presented in Tables 3 through 9 are results from SWMM5 version 5.0.022. More detailed GI modeling results can be found in Appendix K.

TABLE 10

Modeled Control Volume Reduction due to GI

Basin	Overflow	Feasibility Analysis Control Volume Reduction (%)[1]	Modeled Control Volume Reduction (%)[1]
Ballard	150	37%	26%
Ballard	152	26%	19%
North Union Bay	18A	49%	70%
North Union Bay	18B	20%	13%

1. Using Most Practical implementation of GI. Comparison between LTCP Control Volumes resulting from SWMM5 version 5.0.018 and GI modeling performed with SWMM5 version 5.0.021. Subsequent to modeling, the LTCP control volumes have been updated to reflect results from basin wide modeling using SWMM5 version 5.0.022.

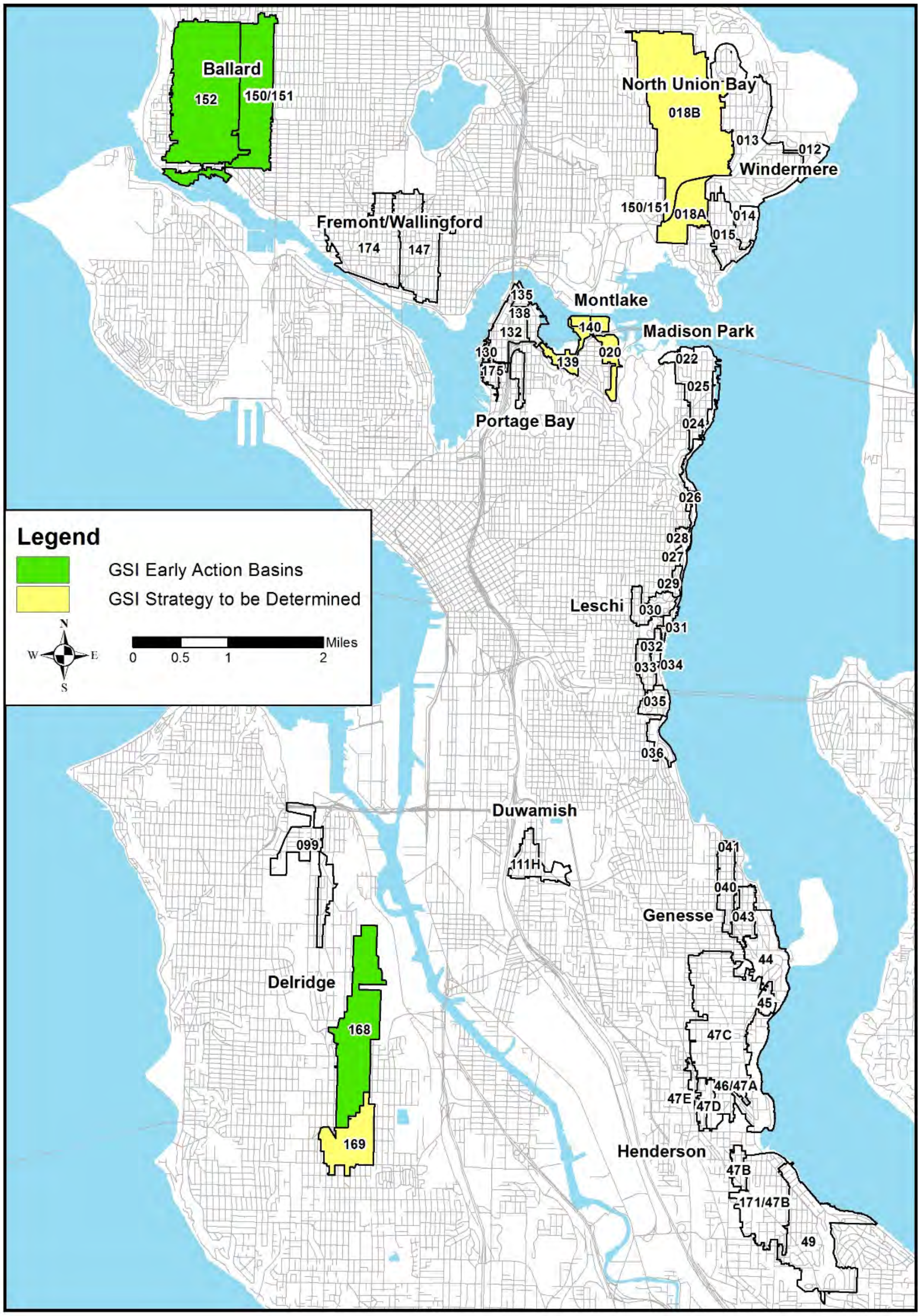
6. Conclusion

GI alternatives are within the same cost range as the traditional/gray alternatives. GI alternatives also offer multiple secondary benefits. The reduction in total volume of combined sewage reduces pumping and treatment cost, helping to lower the carbon footprint of the overall system. The green space associated with roadside rain gardens allows the city to have more park-like settings to encourage walking and biking. The vegetation provides shading of streets in summertime, helping offset urban heat island effects, sequester carbon, and provide habitat for avian species. The RainWise program engages parcels owners as part of the environmental solution. Shifting of high-impact behaviors such as over-fertilization and dumping toxic materials down drains could potentially be an added benefit of the program's associated education and outreach. The program undoubtedly offers the multiple benefits of the aesthetic improvements to the city landscapes, as well as a "green" job market. The use of cisterns also will help the City in water conservation goals.

The City has adopted a policy of leading with green and has a robust Green Infrastructure Program. The 2010 Plan Amendment evaluated () and recommended a number of GI techniques in several CSO areas. GI evaluation through the LTCP development has further refined the GI strategies within Seattle's CSO basins. Significant right-of-way GI opportunities do not exist in many of the CSO basins, largely due to prior efforts that have separated the stormwater runoff from the right-of-way. SPU will continue to implement concurrent GI programs retrofitting rights-of-way and private parcels, in addition to implementation of GI projects via the stormwater code (which has significant GI requirements for new and redevelopment project with 2,000 square feet or more of new and replaced impervious area). RainWise currently is offered in all of SPU's uncontrolled CSO basins.

SPU is implementing an early action GI capital program consisting of retrofitting rights-of-way with bioretention in the Ballard (150 and 151) and Delridge (168) basins. In the future, it is anticipated that the GI approach in several CSO basins will be incorporated into the preliminary engineering of storage facilities to evaluate and potentially implement size and scope reduction for those gray facilities, including the Ballard (150/151, 152), Delridge (168, 169), Montlake (20, 139 and 140) and North Union Bay (18) CSO Basins, see Figure 6. These future evaluations will quantify the CSO reduction in an Engineering Report and as appropriate green approaches may be proposed to substitute gray within the projects engineering report.

FIGURE 6
GI Plan for CSO Control (2014)l



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Appendix A
SPU GSI Feasibility for CSO Mitigation Protocol

City of Seattle's Green Stormwater Infrastructure Feasibility Assessment for CSO Mitigation

Protocol Memo

To: Tracy Tackett, Seattle Public Utilities

From: April Mills, Seattle Public Utilities

With edits by: CH2MHill

11/4/2010

GREEN STORMWATER INFRASTRUCTURE FEASIBILITY ASSESSMENT FOR CSO MITIGATION

This protocol outlines the process for estimating the feasibility of green stormwater infrastructure in the City of Seattle for CSO mitigation. It includes the planning steps for determining scenarios for removing (or delaying) runoff from impervious surfaces to the CSO.

BACKGROUND

Green stormwater infrastructure (GSI) is a decentralized approach for reducing runoff from development using infiltration, evapotranspiration, or stormwater reuse. GSI can be a tool to complement traditional means for managing CSOs, and in this case, contributing to reducing the CSO events in each uncontrolled Seattle basin to no more than one per year. The GSI toolbox currently being used by Seattle Public Utiltity for CSO mitigation includes Natural Drainage Systems (SEAStreets), Roadside Raingardens (similar to curb bulbs added to existing curb and gutter streets), Permeable Pavement Alleys, RainWise Raingardens and RainWise Cisterns. In fully combined basins (or portions of basins), all of the GSI facilities listed above apply. In partially separated basins where streets are already separated, only RainWise strategies apply. In partially separated areas, RainWise could be a program for downspout disconnections only, or it could coupled with smaller raingardens or cisterns for extra benefits. RainWise is a SPU program to promote GSI and will be used to offer financial incentives to parcel owners to participate in these GSI options. RainWise will be combined with SPU-initiated projects in the rights-of-way and alleys to reduce contributions of stormwater to the CSO.

METHODOLOGY

This document presents an assessment method overview for determining the maximum amount of GSI that can feasibly be installed in a CSO basin. This planning level assessment consists of the following steps for each GSI technique:

(1) Identify areas connected to the combined sewer system (CSS).
(2) Initial GIS screening to eliminate areas unsuitable for infiltration, including hazardous and undesirable locations.
(3) More detailed GIS analysis of a finer resolution to identify highly desirable, potentially feasible, and undesirable locations.
(4) Field analysis to validate GIS information and refine results.
(5) Translation and summary of field information in GIS and spreadsheets.
(6) Estimate any additional constraints.
(7) Estimate total impervious surface in square feet removed from the control volume given the effectiveness of the respective GSI facility.

These steps will be applied to each GSI technique, summarized as follows:

General Steps for All GSI Techniques

Step 1: Determine areas that drain to combined sewer

Identify roof and right-of-way sections that are indicated in GIS to drain to the combined sewer. Use GIS shape files from the CSO Long Term Control Plan modelers.	CSO_Basins_Final.shp parcel.shp dwumnl.shp dwulat.shp dwulatpt.shp contour.shp cbgps.shp cbasin.shp others depending on method

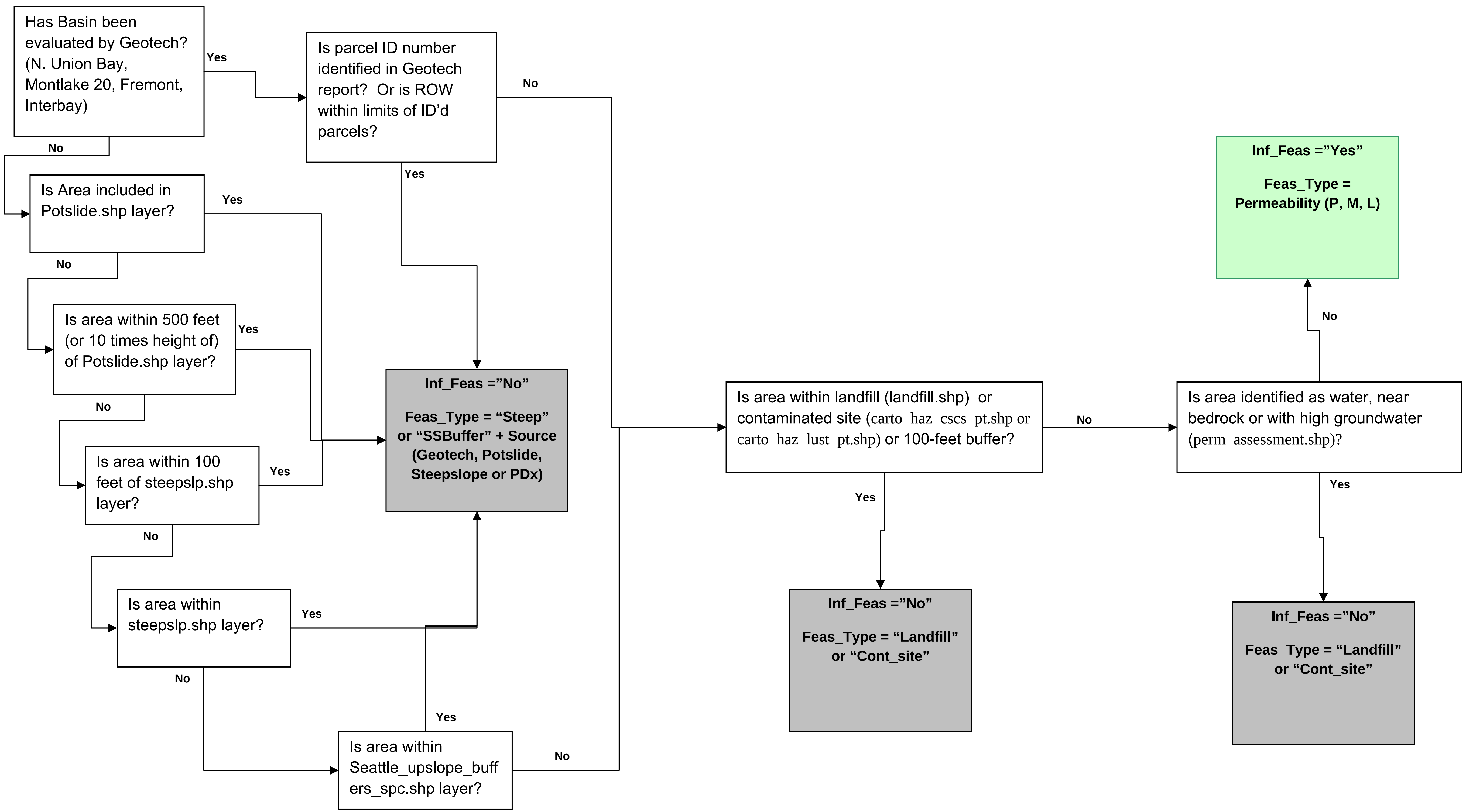
Eliminate all roofs and right-of-way sections shown to be connected to a storm drain from further consideration.

Step 2: Determine Areas Unsuitable for Infiltration

Option 1 [Magnolia, Fremont/Wallingford, Montlake 140, North Union Bay, Interbay]. Use GSI_Geotech_Feas.shp developed from Green Stormwater Infrastructure, Steep Slope Evaluation Technical Memorandum by Seattle Public Utilities dated May 10, 2010 to identify areas not suitable for infiltration due to slope. The Ballard CSO basins were also evaluated by a SPU geotechnical engineer, but were not included in the above mentioned technical memorandum. Ballard steep slope results are summarized in "Ballard CSO – Steep slopes.pdf".	GSI_Geotech_Feas Ballard CSO-Steep slopes.pdf
Option 2 [All other basins]. Parcels and Right-of-way are not suitable for infiltration if **within** the uphill setback for a Steep Slope Critical Area (SMC 25.09.020), as defined per the following criteria: 1. Use Landslide Prone areas (potslide.shp) with a 500-ft uphill buffer. 2. Use steep slopes designated as critical areas by the "steepslp" shapefile with a 100-ft uphill buffer. 3. Other areas as defined by the steep slope and buffer in Seattle_upslope_buffers.spc.shp 4. Use all areas defined by "SteepSlope_Lidar.shp".	steepslp.shp potslide.shp Seattle_upslope_buffers_spc.shp SteepSlope_Lidar.shp
Not within 100 feet of contaminated sites or abandoned landfills. For right-of-way sections, identify sites meeting all other screening criteria but	carto_haz_cscs_pt.shp carto_haz_lust_pt.shp

are within 500-feet of contaminated sites or abandoned landfills as low potential and would require as needing further assessment.	landfill.shp
Not in areas defined as close to bedrock or with high groundwater.	Perm_Assessment.shp

Eliminate all right-of-way sections identified in areas unsuitable for infiltration. For parcels identified in areas unsuitable for infiltration, proceed to Step 3 of RainWise Section for production of cistern only parcel/roof candidates.


Has Basin been evaluated by Geotech? (N. Union Bay, Montlake 20, Fremont, Interbay)
Yes
No
Is parcel ID number identified in Geotech report? Or is ROW within limits of ID'd parcels?
No
Yes
Is Area included in Potslide.shp layer?
Yes
No
Is area within 500 feet (or 10 times height of) of Potslide.shp layer?
Yes
No
Is area within 100 feet of steepslp.shp layer?
Yes
No
Is area within steepslp.shp layer?
Yes
No
Is area within Seattle_upslope_buffers_spc.shp layer?
Yes
No
Inf_Feas ="No"
Feas_Type = "Steep" or "SSBuffer" + Source (Geotech, Potslide, Steepslope or PDx)
Is area within landfill (landfill.shp) or contaminated site (carto_haz_cscs_pt.shp or carto_haz_lust_pt.shp) or 100-feet buffer?
No
Yes
Inf_Feas ="No"
Feas_Type = "Landfill" or "Cont_site"
Is area identified as water, near bedrock or with high groundwater (perm_assessment.shp)?
No
Yes
Inf_Feas ="Yes"
Feas_Type = Permeability (P, M, L)
Inf_Feas ="No"
Feas_Type = "Landfill" or "Cont_site"

GREEN STORMWATER INFRASTRUCTURE TECHNIQUES FOR RIGHT-OF-WAY

ROADSIDE RAINGARDENS AND NATURAL DRAINAGE SYSTEMS
(Note all references to right-of-way (ROW) length refer to the length of ROW in front of the adjacent parcels, not intersection to intersection.)

For larger basins with more right-of-way opportunity, the following steps 3-6 were used for any streets identified with potential per steps 1 and 2. This includes the CSO basins: Ballard, North Union Bay, and Montlake.

Step 3: Evaluate space constraints for Roadside Raingardens and Natural Drainage Systems [Completed by SPU Staff].

Step	Shapefile
Not if frontage strip (planting strip) < 1.0' (or 4.0' for block needing check dam – greater than 2% longitudinal slope).	cortho2005.sid CAD
Not areas where frontage strip used for angle parking for school, church, community school, commercial, ballfield, etc.	cortho2005.sid
If right-of-way section is in an Urban Village zone, label the area as a candidate for the Drainage and Wastewater Partnering Program.	cenvill.shp
Not if longitudinal slopes greater than 6%.	contour.shp

Step 4: Field analysis [To Be Completed by SPU Staff].
Conduct only on blocks identified as potential candidates per step 1 above.

Step	Equipment
Note whether section has curb and gutter (Roadside Raingarden candidate) or ditch and culvert (Natural Drainage System (NDS) candidate). If road section is ditch and culvert, then evaluate in field street potential for NDS candidacy.	
Double-check sample longitudinal slopes using field level.	Level
Identify large conifer trees and mark on map. Avoid placement of Roadside Raingardens in those frontages.	
Validate other GIS information and take relevant field notes.	

Step 5: Calculate total area mitigated with Roadside Raingardens [To Be Completed by SPU Staff].

Step	Shapefile
Create spreadsheet with one block per row [see sample attached]. Use GIS to: ▪ identify if ROW has curb/gutter (Roadside Raingarden) ▪ identify if ROW is an arterial[1]	cortho2005.sid contour.shp snd.shp [feacode for

[1] Designate right-of-ways as arterial versus non-principal streets. Non-principal streets are non-arterial classifications plus collector arterials. Arterials can only be used for Roadside raingardens. Non-arterials can be used for roadside

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- calculate ROW width
- calculate ROW length
- enter longitudinal slope as: <2%= **F** (flat); 2%-4%=**M** (medium); 4%-6%=**MS** (medium steep); >6%=**S** (steep)
- calculate pavement width
- calculate planting strip width (north and south or east and west)
- number of driveways (N/S or E/W)
- number of properties (N/S or E/W)
- identify if the planting strip is available (no large conifers) (not available=1; yes available=0)
- include other relevant notes from field and from criteria listed above

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<td>primary arterials is 5]
parcel.shp</td>
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Calculate the catchment area for each side of the ROW per block.

Catchment Area (upstream) =
[(Pavement width)/2]*ROW length + # Driveways (north) *10 *((ROW width – Full pavement width)/2)

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Calculate raingarden bottom area for each side of block:

RG Bottom Area = Catchment area*4.6%

<u>Assumptions:</u>
Infiltration rate: 0.5”/hr
Ponding: 6”
Sizing factor: 4.6%
Planting strip cross-slope: 2%
Pavement cross-slope: 2%
Planting strip (Flat): Min 9.5’ existing strip necessary Planting strip (M-S): Min 12.5’ exist. strip nec.
5’ Curb Extension (Flat): Min 1.0’ existing strip nec. 5’ Curb Extension (M-S): Min 4.0’ exist. strip
If planting strip < 5’, concrete walk included in impervious area for sizing purposes (not included in CSO volume mitigation).

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Calculate raingarden bottom length required for each design-type.

What length is needed for a planting strip design (each side of block) to meet catchment area requirements?

1. If slope is flat, is planting strip width at least 9.5’? If slope is M/S, is planting strip width at least 12.5’? If no, mark N to design option.

2. If yes to #1, calculate for each side:

   RG Bottom Length Required for Planting strip design =

   RG Bottom Area/[1 + (Planting strip width) - (Planting strip width required given ROW slope)]

What length is needed for a 5’curb extension design (each side of block) to meet catchment area requirements?

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raingardens or natural drainage systems (depending on curb and gutter vs. ditch and culvert). Collector arterials could be roadside raingardens or only a partial natural drainage system.

1. If slope is flat, is planting strip width at least 1.0? If slope is M/S, is planting strip width at least 4.0? If no, mark N to design option. 2. If yes to #1, calculate for each side: **RG Bottom Length Required for 5' curb extension design =** RG Bottom Area/[1 + (Planting strip width) - (Planting strip width required given ROW slope)]
What frontage is available per block per side? Once the lengths for the different raingarden design possibilities are calculated, determine whether sufficient frontage length is available per each side of block: **Frontage available (upstream) =** ROW lngth – Pavemnt wdth/2 - # Drivways*14 – (ROW lngth-Pavemnt width/2)/# Prop.*Plant strip not available ▪ # Driveways*14 removes 10 feet plus 2 feet on each side for visibility per driveway ▪ All components to the right of "14" in the equation will only be included if there is a conifer and the "Planting strip not available = 1"
For block sides that cannot be mitigated due to site constraints, evaluate adjacent blocks to see whether they could receive flow. If yes, add flow to that receiving block catchment area and add comment field to clarify.
Code each block and side of block as (optional): Red (cell) = Area not possible to mitigate for one side of the block Mauve (cell) = Area mitigated in another block for one side of the block Orange (row) = Entire block not suitable for raingarden (due to slope, contamination, buffer, etc.) Yellow (row) = Block partially not suitable for raingarden
Sum total area mitigated with Roadside Raingardens.
Sum total area mitigated with Natural Drainage Systems.

Step 6: Estimate Participation Estimates based on field experience [To Be Completed by SPU Staff].

Calculations through Step 3 will produce the area that could be mitigated with Roadside Raingardens given site constraints. Since this program is voluntary, we are adding a participation constraint estimated as 45%.

For all other CSO basins, the following steps 3A-4A are used.

Step 3A: Field analysis [To Be Completed by SPU Staff].

Conduct only on blocks identified as potential candidates per step 1 & 2 above.

Step	Equipment
Note whether section has curb and gutter (Roadside Raingarden candidate) or ditch and culvert (Natural Drainage System (NDS) candidate). If road section is ditch and culvert, then evaluate in field street potential for NDS candidacy.	
Evaluate slope.	

Evaluate space constraints.	
Evaluate parking use and adjacent land use.	
Estimate Roadside Raingarden potential.	

Step 4A: Estimate Participation Estimates based on field experience [To Be Completed by SPU Staff].

Participation estimates for the remaining basins were conducted in the field based on previous experience. For values, see Appendix E.

GREEN ALLEYS (PERMEABLE PAVEMENT FACILITIES)

Alleys that are unimproved may be improved by installing permeable pavement when the alley is used as a driving surface. For improved alleys, usually designed with standard concrete V-shaped alleyways, permeable pavement concept design is a strip of permeable pavement down the center of the alley with checkdams in the subbase. The purpose of this portion of the analysis is to identify those alleys that should be excluded from consideration (red); alleys that are good candidates for retrofitting with permeable pavement (green); and alleys that could be retrofitted, but may require more costly design (orange).

For CSO basins with green alley opportunities, Steps 3-7 were evaluated: namely, Ballard and Montlake. A slightly modified version was used for Interbay.

Step 3: Evaluate Alley Sections [To Be Completed by SPU Staff].

Step 4: Field analysis [To Be Completed by SPU Staff].

Step	Equipment
Evaluate alley widths, longitudinal slopes and alley lengths for representative sample.	Level, measuring tape, and roadrunner
Note condition, material (dirt, concrete), and shape (V, slanted) of each alley and determine if alley continues through the entire block.	
Estimate existing run-on area from current disconnected downspouts and impervious surfaces such as sheds, houses, and driveways. Sample at least four improved alleys and note which driveways/sheds/etc. drain directly onto the alleyway. Gather length, width, and slope data for these sample alleys.	Level, measuring tape, roadrunner, and ortho map
Unimproved alleys can be retrofitted with a full permeable pavement alley surface. Evaluate whether or not this retrofit will result in a decrease in flow to the CSO for each unimproved alley.	
Not if longitudinal slopes greater than 6%.	contour.shp

Step 5: Use GIS to process lengths, widths, and slopes for remaining alleys not surveyed. Test to ensure GIS to field error is acceptable [To Be Completed by SPU Staff].

Step	Equipment
Compare GIS derived widths, lengths, and permeable pavement lengths (derived from using contours to determine where slopes are less than or equal to 5 feet) with field measurements for a representative sample. If error is acceptable, proceed with obtaining width, length, and permeable pavement lengths (length of alley less than or equal to 5%) using GIS.	cortho2005.sid contour.shp

Step 6: Sort alleys into two retrofit classes based on percentage of alley run-on [To Be Completed by SPU Staff].

Step	Shapefile
For each of your run-on area field samples, calculate the contributing area of the sheds, houses, and driveways that are already disconnected and draining to the alley [RUNON_AREA].	cortho2005.sid
For each sample, calculate the total alley area [TOT_AREA] and the alley area less than 5% slope, i.e., candidate for permeable pavement [PP_AREA].	
For each sample, calculate the ratio of RUNON_AREA to TOT_AREA [RATIO_RUNONTOT].	
For each sample, calculate the ratio of all the impervious surface area providing run-on to the permeable pavement assuming a 4 foot wide permeable pavement strip [RATIO_IMP2PP]. This impervious surface run-on area will include RUNON_AREA, alley width – 4 ft for permeable pavement area, and any alley area with a slope greater than 5%.	
Plot y-axis percent PP length of TOTAL alley length against x-axis RATIO_IMP2PP. If for all y-values, x-values are equal to or less than 5, then all alleys remaining alleys can be included in the low estimate or “green” category. If there are some y-values that show x-values greater than 5%, estimate the threshold value for y. You may have to use professional judgment depending on the strength of the correlation between x and y and the size of your sample/variability. For example in Ballard, we assumed if less than 80% of an alley length was available for permeable pavement retrofit then it would not be in the “green” category.	
Sort your alley data [post-step1] by percent permeable pavement length of Total alley length in descending order. Create the “green” or low estimate [easy and most cost effective] alleys category based on your cut-off value established in the previous sub-step and the “orange” category [add to green for the high estimate.]	
Also add to the “green” category any unimproved alleys that were evaluated in step 2 as benefitting CSO if fully retrofitted. Consider impact of run-on areas.	

Step 7: Estimate average impervious surface run-on area to improved “green” alleys. Calculate total impervious area that could be mitigated with green alleys (low and high estimate) [To Be Completed by SPU Staff].

Step	Shapefile
For your samples with a RATIO_IMP2PP < or = 5:1, **average** the percentage of RUNON_AREA to TOT_AREA. Assume this percentage of RUNON_AREA to TOT_AREA for all other alleys classified as “green”. For each alley classified as “green”, calculate the total amount of impervious surface estimated to run onto the permeable pavement strip [SUM_IMPSFTOT] by summing the components: (1) alley area > 5% slope; (2) alley area on either side of the 4 foot wide permeable pavement strip; and (3) sheds/driveways/roof run-on area estimated from method above.	

For alleys in the “orange” category, use the same run-on area to total area percentage estimate and calculate the total amount of impervious surface estimated to run onto a permeable pavement strip using the same method as above. Other permeable pavement features will need to be added in design to mitigate these higher flows.
For the low estimate of square feet impervious surface removed from the CSO by permeable pavement alleys: use SUM_IMPSFTOT for the “green” category of alleys and add unimproved alleys that were evaluated as suitable for full improvement. For a high estimate add to this sum the SUM_IMPSFTOT value for the “orange” category of alleys.

RAINWISE FOR PARCELS

The purpose of the parcel analysis is to first identify where GIS can be used to determine whether sites draining to the combined sewer are candidates for onsite raingardens, downspout disconnection or cisterns through our voluntary RainWise incentive program. These steps include evaluating factors such as whether the site can drain to a storm drain or is within fully combined system. Next, field analysis is necessary to estimate constraint factors for site feasibility and an estimation of participation. Finally, these constraints are applied and the sum roof area removed from the CSO through onsite raingarden, downspout disconnection and cisterns is calculated.

Roofs Connected to the Combined Sewer

ROOF RUNOFF TO RAINGARDENS (CANDIDATES FOR INFILTRATION)

Identify parcels/buildings that are candidates for infiltration and are connected to the combined sewer.

Step 3: Produce a shapefile with parcel/roof candidates suitable for raingardens and sum roof square footage. These sums are created for buildings connected to the combined (Step 1) that are <u>approved</u> for infiltration (Step 2).

Step	Shapefile
Create shapefiles of parcels that are candidates for raingardens for land uses: (1) single family residential; (2) commercial; and (3) schools. Note that these parcels would also be candidates for cisterns, but that analysis will be accounted for in later steps. Calculate the sum roof square footage and number of roofs (BLD for each unique PIN) from Step 1. Be aware of parcel artifacts at the edge of the basin boundary that may distort the results. One method to create a clean parcel clip within the CSO boundary is to use the Select by location function in ArcGIS and select parcels when their centroid is within the basin boundary. In the square footage calculations, be sure to only include roof areas (not shacks – those roofs less than 200 square feet). I will refer to the shapefiles from this step as: FEASIBLE_RG_SFR; FEASIBLE_RG_COMM; and FEASIBLE_RG_SCHOOLS.	bldg.shp parcel.shp current CSO boundary

Step 4: Field analysis [to be conducted by SPU RainWise staff].

Perform a sample walking/windshield survey of the basin (extent depends on time appropriate for this step and size and variability of basin). Output is "SiteFeas_RG" constraint estimate.

Step
Estimate a low and high *average* site feasibility for installation of raingardens given site constraints such as: ▪ Setback of 2 times the height of any rockery or retaining wall, including the concrete, bunker-style driveways ▪ Grade level or sloping away from the house/basement towards safe discharge point (i.e., curb). Not towards neighbor's basement. ▪ Evaluating a sample of sites to evaluate whether **sufficient area** is available for raingardens can be achieved by first calculating the size the raingarden, on average, will need to be for that basin. This value can be calculated by using the GSI calculator developed for the new Seattle Stormwater Manual. Use half or one-quarter (high and low estimates) of the average/median roof area (SF) per land use in the basin being evaluated. You can use the assumptions for 0.5"/hr infiltration rate and 6" ponding. ▪ Sufficient grade and unobstructed area must be available for conveyance to the raingarden from the downspout and from the overflow point of the raingarden to a safe discharge point. If slopes are suitable for overflow conveyance furrough and feasibility of overflowing back into the side-sewer.

Step 5: Estimate other constraints.

Develop additional constraint estimates per basin for:

Constraint	Description	Low	High
Participation [Part]	These estimates include follow-through to actual installation of one raingarden or cistern.	See Appendix D in "Green Stormwater Infrastructure Conceptual Feasibility Evaluation" CH2MHill 2010	See Appendix D in "Green Stormwater Infrastructure Conceptual Feasibility Evaluation" CH2MHill 2010
Proportion of roof sent to cistern [Prop]	While a parcel owner may be willing to participate and their site may allow all of the roof runoff to be sent to a cistern or raingarden, in our experience, we have found that few people want more than one.[2]	Determine the median roof size per land use and calculate the percentage that sends ≥400 SF to 1 cistern. 400sf is our minimum for participation in the program.	See Appendix D in "Green Stormwater Infrastructure Conceptual Feasibility Evaluation" CH2MHill 2010
Functional connectivity of roofs to the combined	Modeling calibration efforts will produce an estimate of the actual % of roof area connected to		

[2] Hopefully, this constraint will decrease over time as people become more aware of the program. We will also update our estimates as we move forward with more basins.

[Connect]	the combined sewer.		

ROOF RUNOFF TO CISTERNS ONLY (NOT CANDIDATES FOR INFILTRATION)

Parcel sites that are excluded from consideration for RainWise raingardens because of site feasibility issues are candidates for RainWise cisterns that can then be plumbed back into the combined sewer system. For example, these cisterns could be placed on steep slopes or in contaminated areas.

Step 3: Produce cistern-only parcel/roof candidates shapefile and sum roof square footage. These sums are created for buildings connected to the combined (Step 1) that are <u>not approved</u> for infiltration (Step 2).

Step	Shapefile
Create shapefiles of parcels that are candidates for cisterns only for land uses: (1) single family residential; (2) commercial; and (3) schools. Calculate the sum roof square footage and number of roofs (BLD for each unique PIN) from Step 1. Be aware of parcel artifacts at the edge of the basin boundary that may distort the results. One method to create a clean parcel clip within the CSO boundary is to use the Select by location function in ArcGIS and select parcels when their centroid is within the basin boundary. In the square footage calculations, be sure to only include roof areas (not garages/shacks – those roofs less than 200 square feet). I will refer to the shapefile output of this step as CISTERN_ONLY_SFR, CISTERN_ONLY_COMM, and CISTERN_ONLY_SCHOOL.	bldg.shp parcel.shp current CSO boundary

Step 4: Field analysis [To Be Completed by SPU Staff].
Perform a sample walking/windshield survey of the basin (extent depends on time appropriate for this step and size and variability of basin). Output is "SiteFeas_Cistern" constraint estimate.

Step
Estimate a low and high *average* site feasibility for installation of cisterns given site constraints such as: ▪ Egress/ingress (unblocked access to all windows/doors) ▪ Area available (walkways, driveways, and landscaping doesn't block) ▪ Aesthetic considerations likely to be taken by homeowner ▪ We will only give incentives to those who can send at least 400 square feet of their roof runoff to a 200 gallon cistern. This requirement impacts all of the above in addition to potentially requiring gutter work for those gutters that would need to be connected to collect the minimum runoff quantity and are not easily funneled into one cistern without costly gutter reconfigurations (due to slope, gutter damage, etc.).

Roofs Connected to the Partially Separated Sewer

DOWNSPOUT DISCONNECTIONS (CANDIDATES FOR INFILTRATION)

Sites that are located in partially separated basins are candidates for downspout disconnections where runoff can either be routed to the street/curb if sufficient site conditions allow for safe conveyance or, if safe conveyance is not available or the site is in a no infiltration zone, the downspout can be routed through a cistern, then returned to the combined sewer.

Step 3A: Produce shapefiles with parcel/roof candidates for downspout disconnections suitable for conveyance to the curb and sum roof square footage. These sums are created for buildings not connected to the combined where a storm drain is available in the adjacent street (Step 1) that are approved for infiltration (Step 2).

Step	Shapefile
Create shapefiles of parcels that are candidates for downspout disconnections conveyed to the curb for land uses: (1) single family residential; (2) commercial; and (3) schools. Create a shapefile of SFR, commercial, and schools parcels, respectively, that are candidates for downspout disconnection incentives. Calculate the sum roof square footage and number of houses (BLD for each unique PIN) from Step 1. Be aware of parcel artifacts at the edge of the basin boundary that may distort the results. One method to create a clean parcel clip within the CSO boundary is to use the Select by location function in ArcGIS and select parcels when their centroid is within the basin boundary. In the square footage calculations, be sure to only include roof areas (not garages/shacks – those roofs less than 200 square feet. I will refer to the shapefiles from this step as: CURB_DD_SFR; CURB_DD_COMM; and CURB_DD_SCHOOLS.	bldg.shp parcel.shp current CSO boundary

Step 3B: Produce shapefiles with parcel/roof candidates for downspout disconnections not suitable for conveyance to the curb and sum roof square footage. These roofs will only be eligible for disconnection to a cistern, then replumbing to the combined sewer. These sums are created for buildings not connected to the combined where a storm drain is available in the adjacent street (Step 1) that are not approved for infiltration (Step 2).

Step	Shapefile
Create shapefiles of parcels that are candidates for downspout disconnections sent to a cistern then back to the combined sewer for land uses: (1) single family residential; (2) commercial; and (3) schools. Create a shapefile of SFR,	bldg.shp parcel.shp current CSO boundary

commercial, and schools parcels, respectively, that are candidates for downspout disconnection incentives. Calculate the sum roof square footage and number of houses (BLD for each unique PIN) from Step 1. Be aware of parcel artifacts at the edge of the basin boundary that may distort the results. One method to create a clean parcel clip within the CSO boundary is to use the Select by location function in ArcGIS and select parcels when their centroid is within the basin boundary. In the square footage calculations, be sure to only include roof areas (not garages/shacks – those roofs less than 200 square feet. I will refer to the shapefiles from this step as: CISTERN_DD_SFR; CISTERN_DD_COMM; and CISTERN_DD_SCHOOLS.	

Step 4A: Field analysis [to be conducted by SPU RainWise staff].

Perform a sample walking/windshield survey of the basin (extent depends on time appropriate for this step and size and variability of basin). Output is "SiteFeas_DD_curb" constraint estimate.

Step
Estimate a low and high *average* site feasibility for installation of raingardens given site constraints such as: ▪ Setback of 2 times the height of any rockery or retaining wall, including the concrete, bunker-style driveways ▪ Grade level or sloping away from the house/basement towards safe discharge point (i.e., curb). Not towards neighbor's basement. ▪ Sufficient grade and unobstructed area must be available for conveyance to a safe discharge point. If slopes are suitable for overflow conveyance furrough and feasibility of overflowing back into the sidesewer.

Step 4B: Estimate for all basins the site feasibility for a downspout disconnection to cistern then plumbed back to the combined sewer [to be conducted by SPU RainWise staff]. Output is "SiteFeas_DD_cistern" constraint estimate.

Currently estimated as 90%.

Calculate Sum Impervious Area Removed From CSO: Parcel GSI

We prefer raingardens in areas where it is feasible because they are more efficient at achieving our GSI goals, but site feasibility is typically more constraining. For planning level analysis, we will estimate raingardens on properties where they can be applied and will use cisterns in areas where raingardens are infeasible, taking into account all other relevant constraints.

1. For each land use (SFR, commercial, schools), multiply roof square footage available for cistern-only roofs by all relevant constraint percentages. Multiply roof square footage available for raingardens by all relevant constraint percentages (midpoint between high and low). For roof

area excluded by raingarden site feasibility constraint, apply cistern site feasibility constraint and remaining relevant constraints. For the equations below, we use the midpoint estimate rather than illustrating both high and low calculations. Also, for the equations below, perform them for single family residential, commercial, and schools. The illustration will be for single family residential only. Note that while we assign unique site feasibility and participation constraint estimates per basin for single family residential, we have typically assigned only Citywide site constraints for commercial and school land uses, respectively.

Roofs connected to the combined sewer

FEASIBLE_RG_SFR * SiteFeas_RG * Part * Prop * Connect = **RG_SFR**

Note: For FEASIBLE_RG_SFR that is excluded due to site constraints (FEASIBLE_RG_SFR – (FEASIBLE_RG_SFR * SiteFeas_RG)), add the ineligible square footage to the Cistern calculation below.

CISTERN_ONLY_SFR + (FEASIBLE_RG_SFR-(FEASIBLE_RG_SFR * SiteFeas_RG)) * SiteFeas_Cistern * Part * Prop * Connect = **CISTERN_SFR**

Roofs connected to the partially separated sewer

CURB_DD_SFR * SiteFeas_DD_curb * Part * Prop * Connect = **DD_CURB_SFR**

Note: For CURB_DD_SFR that is excluded due to site constraints (CURB_DD_SFR – (CURB_DD_SFR * SiteFeas_DD_curb)), add the ineligible square footage to the Cistern calculation below.

CISTERN_DD_SFR + (CURB_DD_SFR – (CURB_DD_SFR * SiteFeas_DD_curb)) * SiteFeas_DD_cistern * Part * Prop * Connect = **CISTERN_DD_SFR**

2. Use the "Pre-Sized Approach" from the Seattle Stormwater Code to calculate the square footage impervious surface mitigated by each BMP (raingarden and cistern, respectively.) based on GSI to MEF sizing. For raingardens, assume an infiltration rate of 0.5 in/hr and 6" ponding depth; corresponding sizing factor is 4.6%.

For cisterns assume the following sizing and effectiveness:

Simplified Cistern (based on cistern shown in details). Credits based on system overflowing to side-sewer or to conveyance channel			
	(200 gallons, with 160 gallons being live storage with 3' of head. ID = 35", bottom area = 6.68')		
	Contributing Area	**Number cisterns**	**GSI Credit**
	401-1000	1	64%

3. Multiply the BMP effectiveness by the square footage remaining for each BMP and sewer type: **RG_SFR, CISTERN_SFR, DD_CURB_SFR, CISTERN_DD_SFR.**

Reporting Data

1. Summary table of all GSI approaches by CSO NPDES Basin #.
2. Report both Low and High estimates of impervious area mitigated.
3. Provide data in maps 1”=1000’ identifying
    a. Roadways candidates – color coded Red/yellow/green
    b. Natural Drainage system candidates – code all as yellow
    c. Green alley candidates -- color coded Red/yellow/green
    d. RainWise Candidates for Cisterns only
    e. RainWise Candidates for Cisterns or Raingardens
    f. RainWise Candidates for Downspout Disconnections

Appendix B
Delineation of Combined Sewer Connectivity

Appendix B: Delineation of Combined Sewer Connectivity

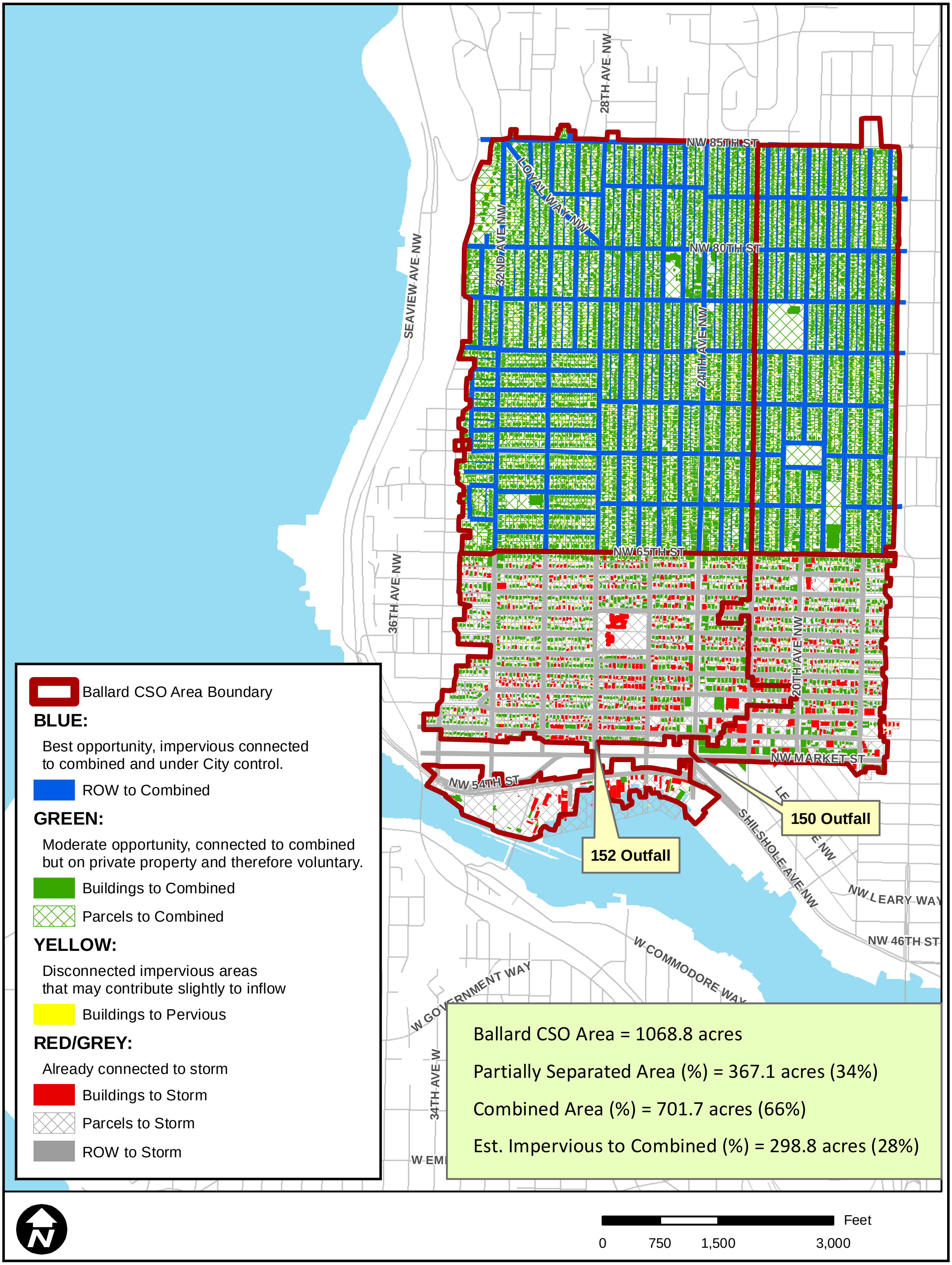
Combined sewer connectivity was delineated in support of the green stormwater infrastructure (GSI) assessment for combined sewer overflow (CSO) mitigation. GSI is a decentralized approach for reducing runoff from development using infiltration, evapotranspiration, or stormwater reuse. GSI can be a tool to complement traditional means for managing CSOs.

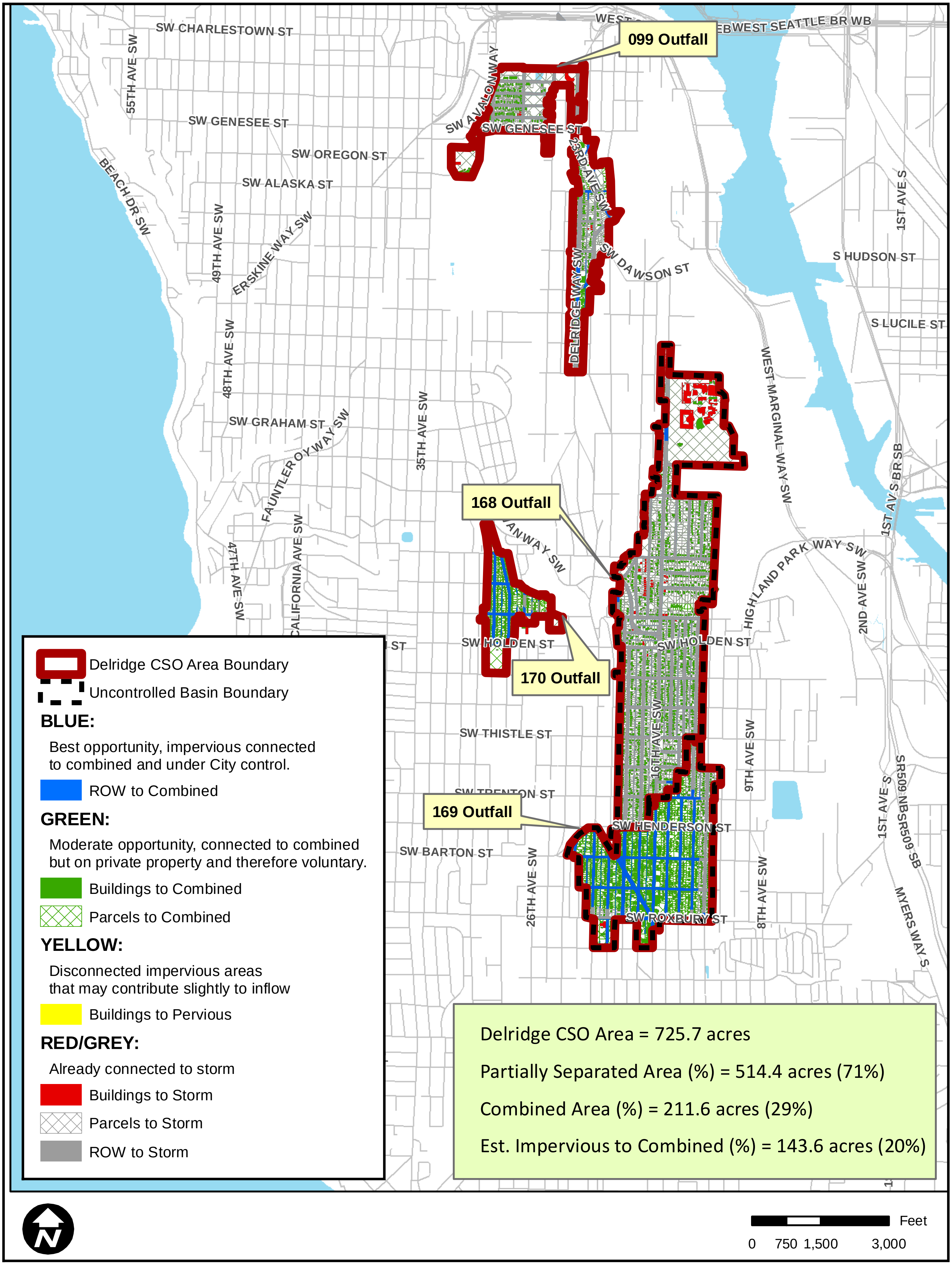
The combined sewer connectivity was provided in GIS data format by CSO modelers for each basin. There was no standard for the GIS data provided, so data attributes describing sewer connectivity varied for each CSO basin. Therefore, delineation of combined sewer connectivity relied heavily on the CSO modelers to describe how GIS data attributes related to modeled land surface (e.g. as connected to combined sewer or not).

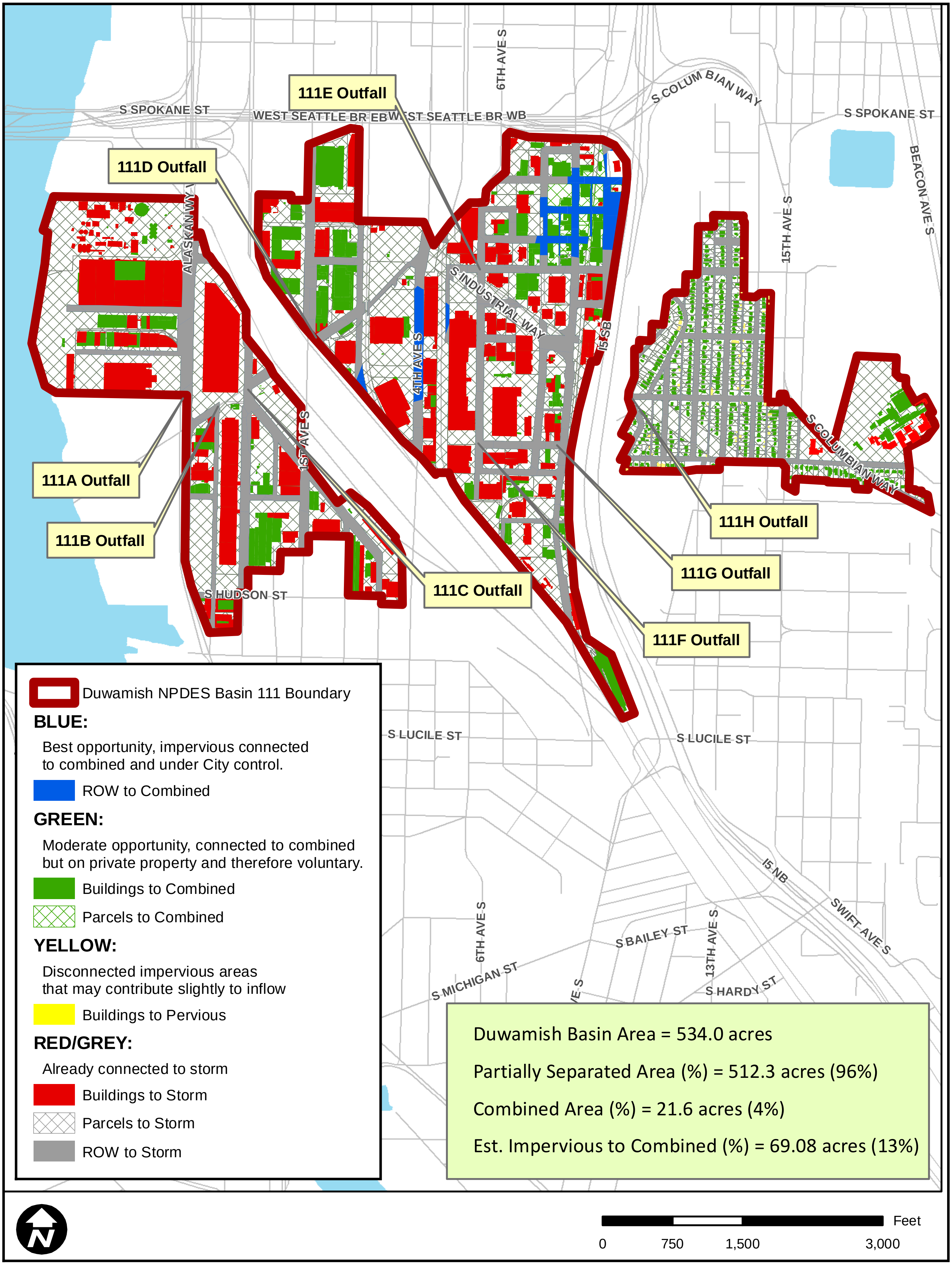
Land surface was identified in GIS data as parcels, right of way, or buildings and was assigned to drain to either combined or storm sewers. The combination of land surface and sewer type resulted in categories of connectivity. For example, *buildings draining to combined sewer* is a connectivity category. The GIS data (i.e. "feature class") used to delineate each connectivity category are provided in the table below. The table also indicates the attribute(s) and value(s) used to identify the connectivity category.

Area estimates of partially separated and combined sewer connectivity were also included in this analysis. The area estimate for partially separated connectivity (for each basin) consisted of the sum of parcel and right of way areas connected to partially separated sewers. Note: building area was not included in the area estimate; therefore, the partially separated area estimate includes area of buildings connected to combined sewer located on parcels connected to partially separated sewer. The area estimate for combined connectivity (for each basin) was determined by subtracting the estimated partially separated connectivity area from the basin area.

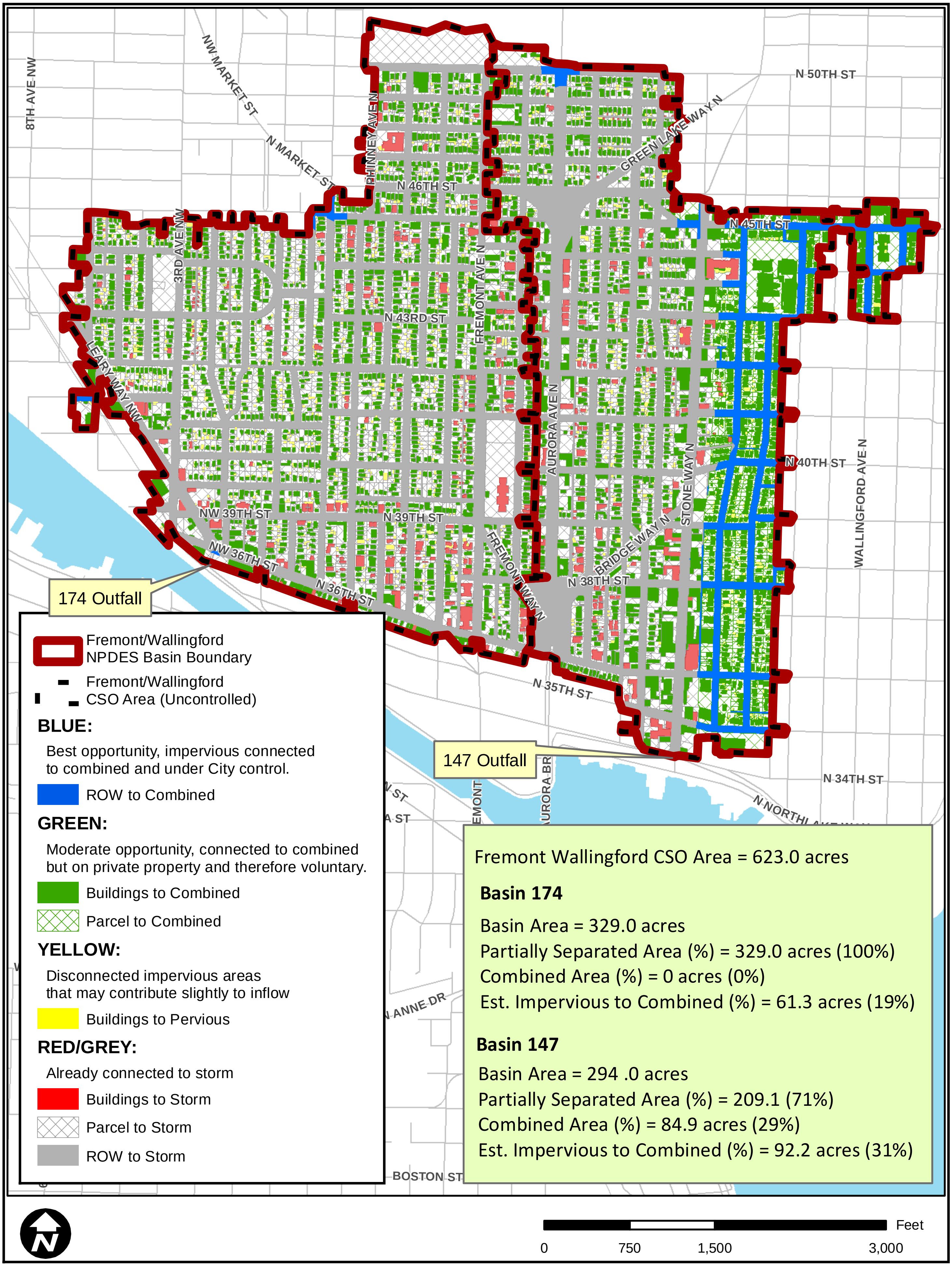
CSO BASIN		SEWER CONNECTIVITY DELINEATION						
		Right of Way to Combined Sewer	Buildings to Combined Sewer	Parcels to Combined Sewer	Buildings to Pervious (Inflow)	Right of Way to Storm Sewer	Buildings to Storm Sewer	Parcels to Storm Sewer
Ballard	Feature Class Name	Ballard_ROW_combined	bldg_ballard_mh_v3_model	ballard_prcls_combined	bldg_ballard_mh_v3_model	Ballard_ROW_storm	bldg_ballard_mh_v3_model	ballard_prcls_storm
	Attribute/value		[DRAINAGE = "IMP --> Sewer" OR DRAINAGE = "Street --> Combined"]		[DRAINAGE = "Pervious"]		[DRAINAGE = "Street --> Storm"]	
Delridge	Feature Class Name	ROW_Del_subcatchment	bldg_DEL_v3_drain_to_sewer	parcel_DEL_subcatchments_v2_r1	N/A	ROW_Del_subcatchment	bldg_DEL_v3_drain_to_storm	parcel_DEL_subcatchments_v2_r1
	Attribute/value	[Surface <> "storm"]		[Surface_1 <> "storm"]		[Surface = "storm"]		[Surface_1 = "storm"]
Duwamish	Feature Class Name	ROW_DUH_Subcatchments_v2	bldg_DUW_v3	parcel_DUW_v3	bldg_DUW_v3	ROW_DUH_Subcatchments_v2	bldg_DUW_v3	parcel_DUW_v3
	Attribute/value	[Surface <> "storm"]	[S_IMSIDR <> "storm"] AND NOT Buildings to Pervious	[Outlet_Suf <> "storm"]	Note: the CSO modeler for the Duwamish basin selected 50 buildings draining to pervious. This data is available as a "selection" of the GIS feature class "bldg_DUW_v3".	[Surface = "storm"]	[S_IMSIDr = "storm"] AND NOT Buildings to Pervious	[Outlet_Suf = "storm"]
Fremont/Wallingford	Feature Class Name	FreWall_ROW_prcl_Clip	bldg_FreWallv5_Clip	FreWall_ROW_prcl_Clip	bldg_FreWallv5_Clip	FreWall_ROW_prcl_Clip	bldg_FreWallv5_Clip	FreWall_ROW_prcl_Clip
	Attribute/value	[Source, Location = "ROW, Combined"]	[IMP, S_IMSIDr2 <> "IMP, storm"] AND NOT Buildings to Pervious	[Source, Location = "Parcel, Combined"]	[IMP, TYPE = "PERV","UNK" OR IMP, TYPE = "PERV","MSC" OR IMP, TYPE = "PERV","OBS" OR IMP, TYPE = "PERV","GAR" OR IMP, TYPE = "PERV","DEK" OR IMP, TYPE = "PERV","BLD" OR IMP, TYPE = "IMP","PAT"]	[Source, Location = "ROW, Partially Separated"]	[IMP, S_IMSIDr2 = "IMP, storm"] AND NOT Buildings to Pervious	[Source, Location = "Parcel, Partially Separated"]
Leschi	Feature Class Name	ROW_Leschi_toMH_Dissolve	Bldg_Leschi_imp_s&c	Par_Leschi_subctchmnts_v2	Bldg_Leschi_imp_s&c	ROW_Leschi_toMH_Dissolve	Bldg_Leschi_imp_s&c	Par_Leschi_subctchmnts_v2
	Attribute/value	[Surface <> "storm"]	[S_IMSIDR1 <> "storm" AND S_IMSIDR1 <> "LW"] AND NOT Buildings to Pervious	[Srf_SMID <> "storm"]	[IMP, TYPE = "PERV","UNK" OR IMP, TYPE = "PERV","PAT" OR IMP, TYPE = "PERV","OBS" OR IMP, TYPE = "PERV","GAR" OR IMP, TYPE = "PERV","DEK" OR IMP, TYPE = "PERV","BLD" OR IMP, TYPE = "IMP","PAT"]	[Surface = "storm"]	[S_IMSIDR1 = "storm" OR S_IMSIDR1 = "LW"] AND NOT Buildings to Pervious	[Srf_SMID = "storm"]
Madison Park	Feature Class Name	ROW_Madison_toMHv2	Bldg_Madison_v2	Parcels_Madison_v2	Bldg_Madison	ROW_Madison_toMHv2	Bldg_Madison_v2	Parcels_Madison_v2
	Attribute/value	[Surface <> "STORM"]	[S_IMSIDr <> "STORM" AND S_IMSIDr <> "LAKE"] AND NOT Buildings to Pervious	[Surface <> "STORM" AND Surface <> "LAKE"]	[IMP, TYPE = "PERV","UNK" OR IMP, TYPE = "PERV","PAT" OR IMP, TYPE = "PERV","OBS" OR IMP, TYPE = "PERV","GAR" OR IMP, TYPE = "PERV","DEK" OR IMP, TYPE = "PERV","BLD" OR IMP, TYPE = "IMP","PAT"]	[Surface = "STORM"]	[S_IMSIDr = "STORM" OR S_IMSIDr = "LAKE"] AND NOT Buildings to Pervious	[Surface = "STORM" OR Surface = "LAKE"]
Montlake	Feature Class Name	ROW_Catchments_Montlake	Building_Catchments	Montlake_Parcels_Catchments	Bldg_montlake_perv	ROW_Catchments_Montlake	Building_Catchments	Montlake_Parcels_Catchments
	Attribute/value	[Surface <> " "]	[S_IMSIDR1 <> "STORM"] AND NOT Buildings to Pervious	[Surface <> "STORM"]		[Surface = " "]	[S_IMSIDR1 = "STORM"] AND NOT Buildings to Pervious	[Surface = "STORM"]
North Union Bay	Feature Class Name	ROW_NUB_Subcatchments_v2	bldg_NUB_v3_imp_s&c	parcels_NUB_Subcatchments_v3	N/A	ROW_NUB_Subcatchments_v2	bldg_NUB_v3_imp_s&c	parcels_NUB_Subcatchments_v3
	Attribute/value	[Surface <> "storm"]	[S_IMSIDr2 <> "STORM"]	[Surf <> "STORM" AND Surf <> "D025-016"]		[Surface = "storm"]	[S_IMSIDr2 = "STORM"]	[Surf = "STORM" OR Surf = "D025-016"]
Portage Bay	Feature Class Name	Thiessen_ROW_Intersect_v2_Dis I5_SR520ROW_Clip	bldg_PB_v2	Parcels_PB_subcatchments_v3	bldg_PB_v2	Thiessen_ROW_Intersect_v2_Dis I5_SR520ROW_Clip	bldg_PB_v2	Parcels_PB_subcatchments_v3
	Attribute/value	(from "Thiessen_ROW_Intersect_v2_Dis") [S_IMSIDr1 <> "storm" OR S_IMSIDr1 <> "PortBay"] AND NOT "I5_SR520ROW_Clip"	[S_IMSIDr1 <> "storm" OR S_IMSIDr1 <> "PortBay"] AND NOT Buildings to Pervious	[S_IMSIDr2 <> "PortBay"]	[IMP, TYPE = "PERV","UNK" OR IMP, TYPE = "PERV","OBS" OR IMP, TYPE = "PERV","GAR" OR IMP, TYPE = "PERV","DEK" OR IMP, TYPE = "PERV","BLD" OR IMP, TYPE = "IMP","PAT"]	(from "Thiessen_ROW_Intersect_v2_Dis") [S_IMSIDr1 = "storm" OR S_IMSIDr1 = "PortBay"] AND "I5_SR520ROW_Clip"	[S_IMSIDr1 = "storm" OR S_IMSIDr1 = "PortBay"] AND NOT Buildings to Pervious	[S_IMSIDr2 = "PortBay"]

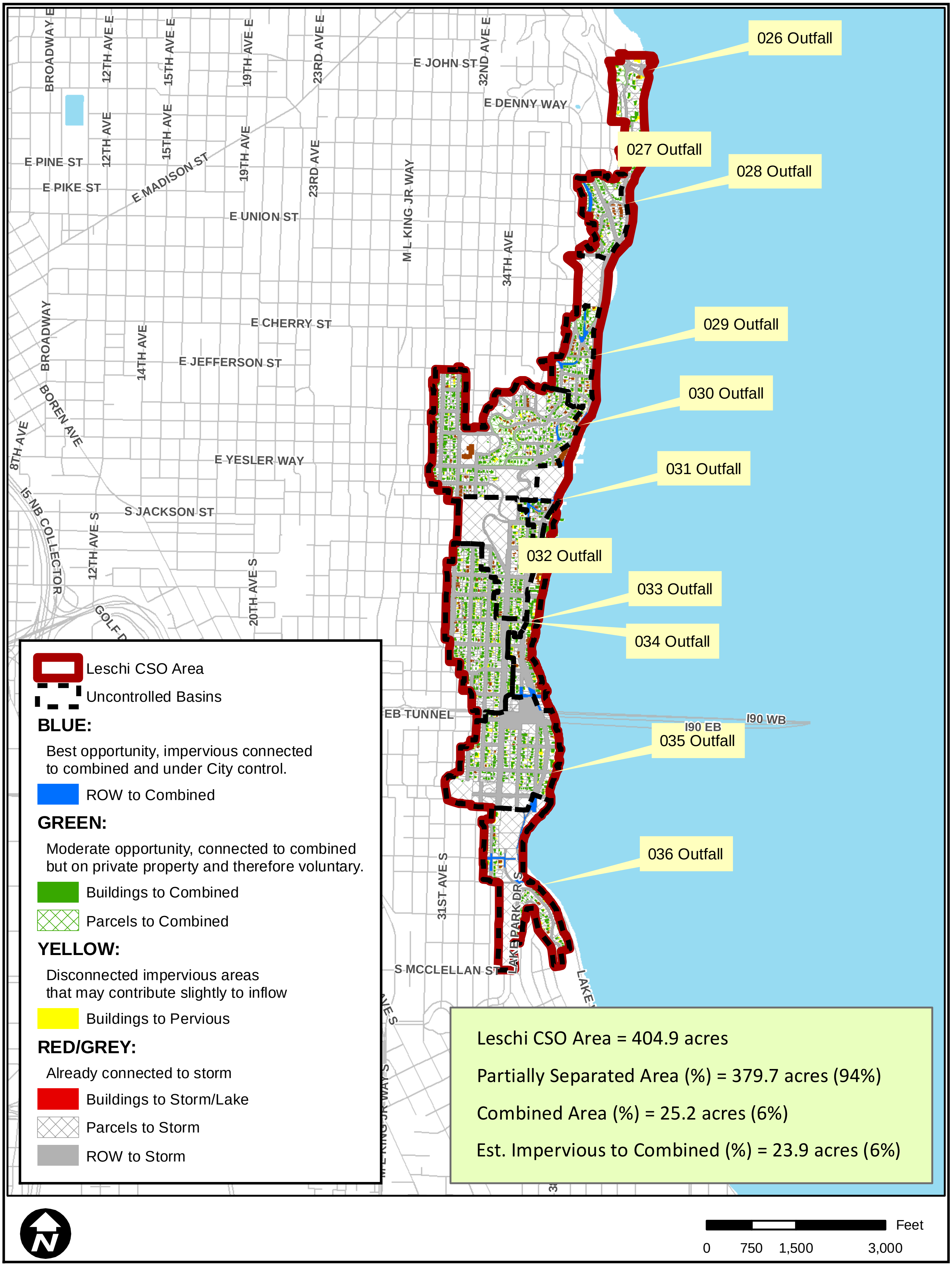

Ballard CSO Area Boundary
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm
ROW to Storm
Ballard CSO Area = 1068.8 acres
Partially Separated Area (%) = 367.1 acres (34%)
Combined Area (%) = 701.7 acres (66%)
Est. Impervious to Combined (%) = 298.8 acres (28%)
152 Outfall
150 Outfall
NW 85TH ST
NW 80TH ST
NW 65TH ST
NW MARKET ST
NW 54TH ST
LOYAL WAY NW
28TH AVE NW
32ND AVE NW
24TH AVE NW
20TH AVE NW
36TH AVE NW
SEAVIEW AVE NW
SHILSHOLE AVE NW
NW LEARY WAY
NW 46TH ST
W COMMODORE WAY
W GOVERNMENT WAY
34TH AVE W
Feet
0
750
1,500
3,000

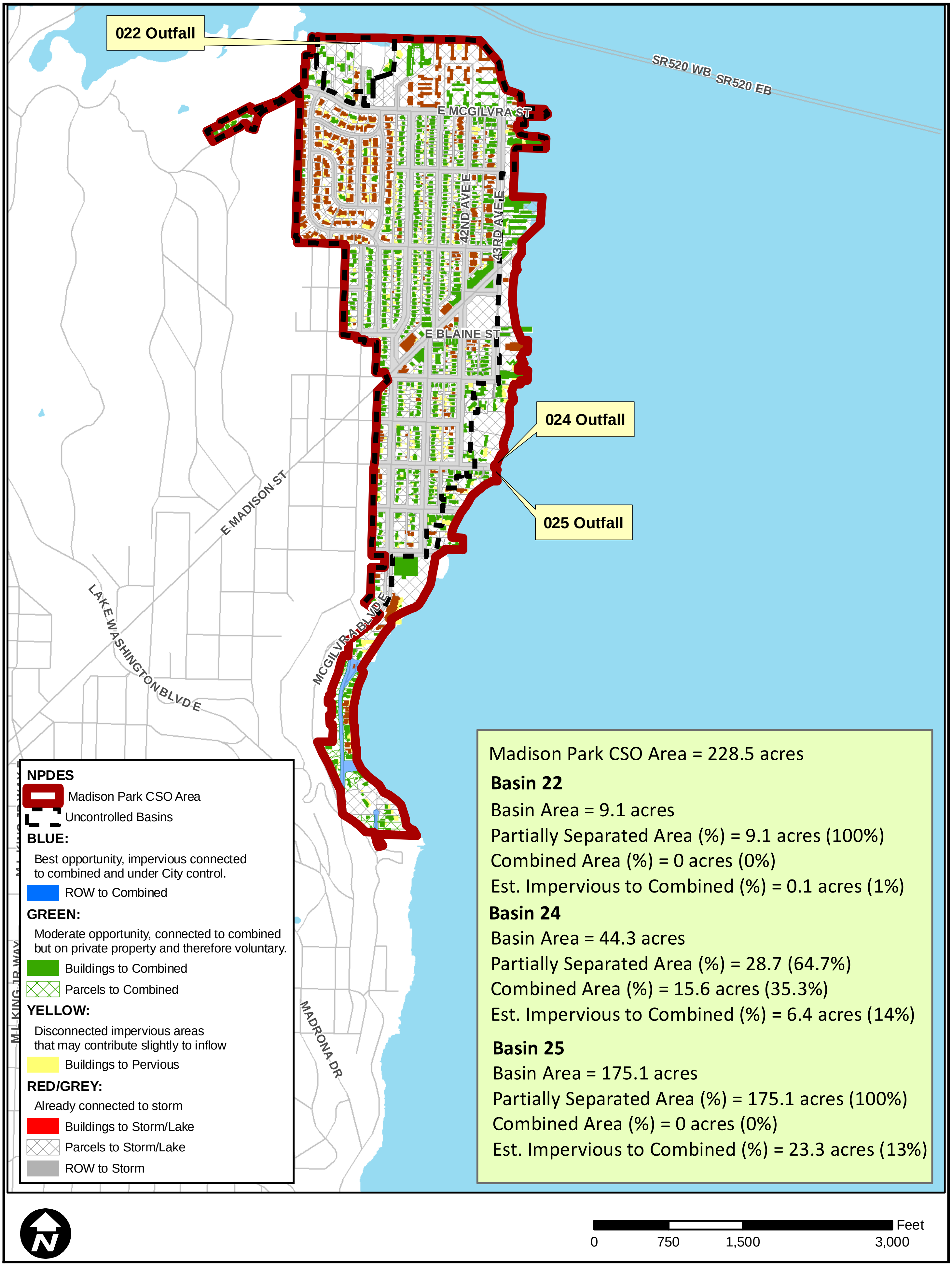

099 Outfall
168 Outfall
170 Outfall
169 Outfall
SW CHARLESTOWN ST
SW GENESEE ST
SW OREGON ST
SW ALASKA ST
55TH AVE SW
BEACH DR SW
49TH AVE SW
ERSKINE WAY SW
48TH AVE SW
SW GRAHAM ST
FAUNTLEROY WAY SW
35TH AVE SW
47TH AVE SW
CALIFORNIA AVE SW
SW AVALON WAY
23RD AVE SW
SW DAWSON ST
DELRIDGE WAY SW
WEST SEATTLE BR WB
1ST AVE S
S HUDSON ST
S LUCILE ST
WEST MARGINAL WAY SW
1ST AV S BR SB
HIGHLAND PARK WAY SW
2ND AVE SW
SW HOLDEN ST
SW THISTLE ST
SW TRENTON ST
16TH AVE SW
9TH AVE SW
SW BARTON ST
SW HENDERSON ST
26TH AVE SW
SW ROXBURY ST
8TH AVE SW
SR509 NBSR509 SB
MYERS WAY S
Delridge CSO Area Boundary
Uncontrolled Basin Boundary
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm
ROW to Storm
Delridge CSO Area = 725.7 acres
Partially Separated Area (%) = 514.4 acres (71%)
Combined Area (%) = 211.6 acres (29%)
Est. Impervious to Combined (%) = 143.6 acres (20%)
N
Feet
0 750 1,500 3,000



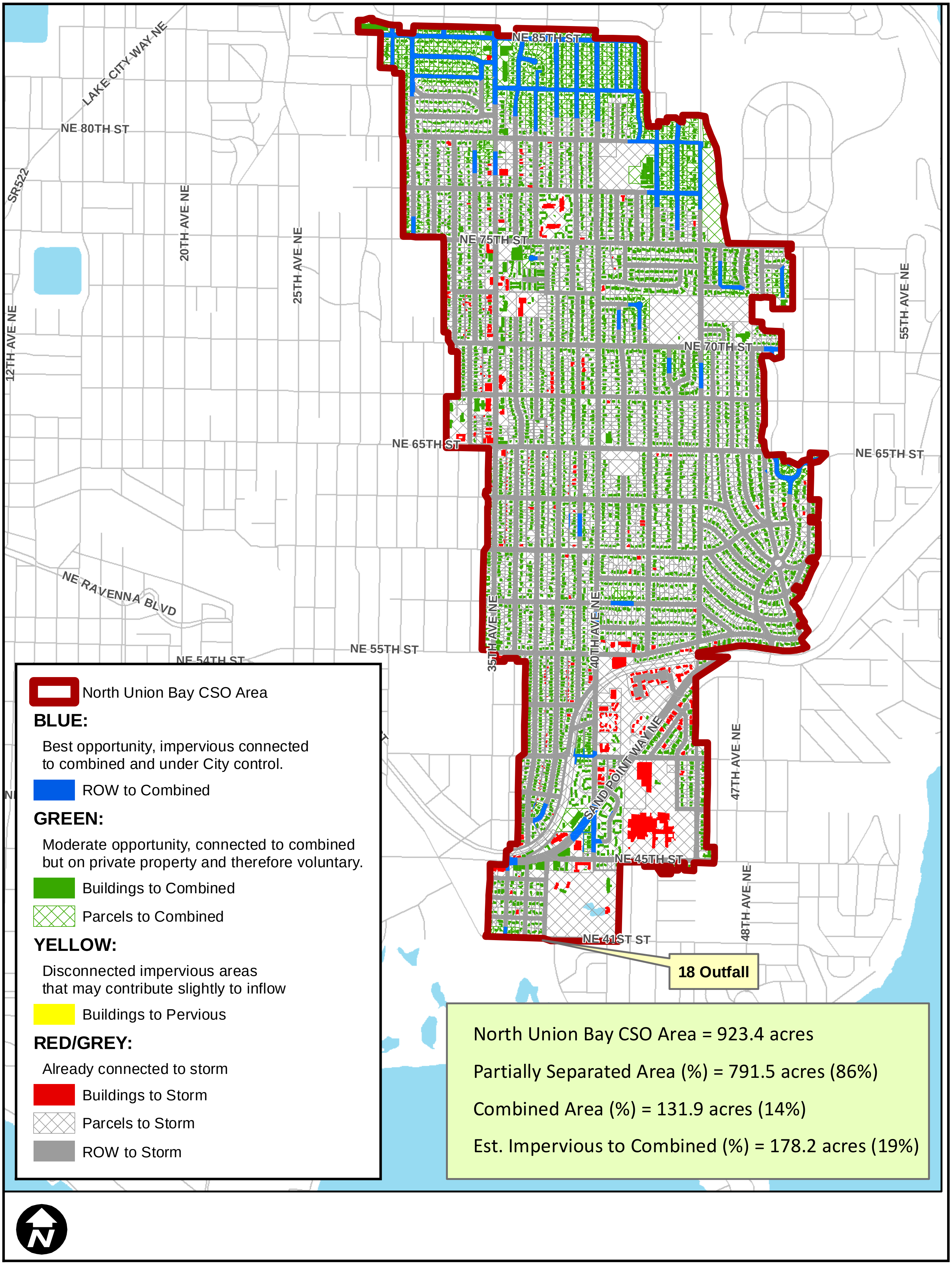
111E Outfall
111D Outfall
111A Outfall
111B Outfall
111C Outfall
111H Outfall
111G Outfall
111F Outfall
S SPOKANE ST
WEST SEATTLE BR EB
WEST SEATTLE BR WB
6TH AVE S
S COLUMBIAN WAY
15TH AVE S
BEACON AVE S
ALASKAN WY
S INDUSTRIAL WAY
4TH AVE S
1ST AVE S
I5 SB
S HUDSON ST
S LUCILE ST
I5 NB
SWIFT AVE S
S BAILEY ST
13TH AVE S
S HARDY ST
S MICHIGAN ST
Duwamish NPDES Basin 111 Boundary
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm
ROW to Storm
Duwamish Basin Area = 534.0 acres
Partially Separated Area (%) = 512.3 acres (96%)
Combined Area (%) = 21.6 acres (4%)
Est. Impervious to Combined (%) = 69.08 acres (13%)
Feet
0
750
1,500
3,000
N

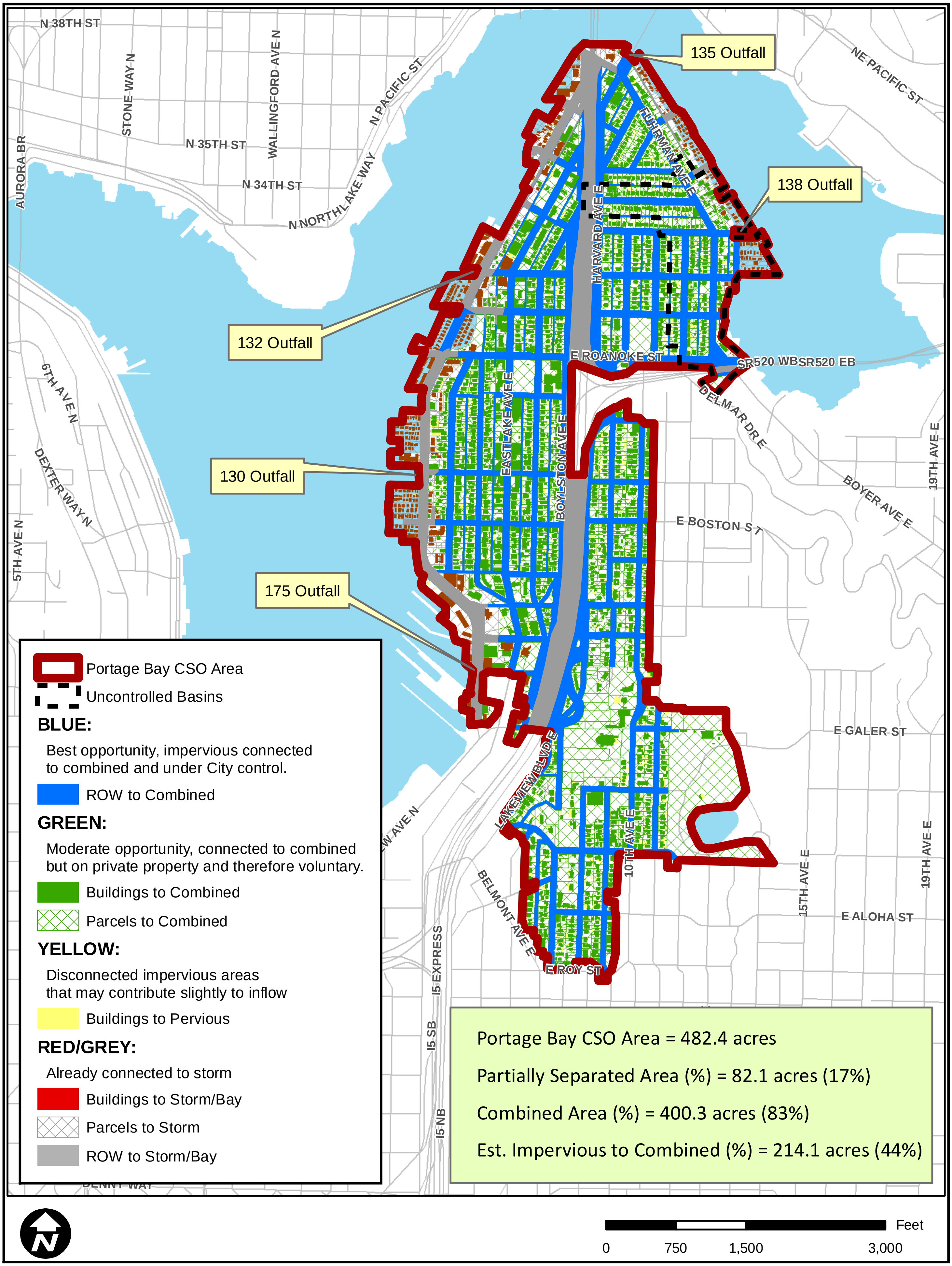

8TH AVE NW
NW MARKET ST
N MARKET ST
PHINNEY AVE N
N 46TH ST
N 50TH ST
GREEN LAKE WAY N
N 45TH ST
3RD AVE NW
N 43RD ST
FREMONT AVE N
LEARY WAY NW
AURORA AVE N
STONE WAY N
N 40TH ST
WALLINGFORD AVE N
NW 39TH ST
N 39TH ST
NW 36TH ST
N 36TH ST
FREMONT WAY N
BRIDGE WAY N
N 38TH ST
N 35TH ST
N 34TH ST
AURORA BR
ANNE DR
BOSTON ST
174 Outfall
147 Outfall
Fremont/Wallingford NPDES Basin Boundary
Fremont/Wallingford CSO Area (Uncontrolled)
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcel to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcel to Storm
ROW to Storm
Fremont Wallingford CSO Area = 623.0 acres
Basin 174
Basin Area = 329.0 acres
Partially Separated Area (%) = 329.0 acres (100%)
Combined Area (%) = 0 acres (0%)
Est. Impervious to Combined (%) = 61.3 acres (19%)
Basin 147
Basin Area = 294 .0 acres
Partially Separated Area (%) = 209.1 (71%)
Combined Area (%) = 84.9 acres (29%)
Est. Impervious to Combined (%) = 92.2 acres (31%)
Feet
0
750
1,500
3,000
N


026 Outfall
027 Outfall
028 Outfall
029 Outfall
030 Outfall
031 Outfall
032 Outfall
033 Outfall
034 Outfall
035 Outfall
036 Outfall
BROADWAY E
12TH AVE E
15TH AVE E
19TH AVE E
23RD AVE E
E JOHN ST
32ND AVE E
E DENNY WAY
12TH AVE
15TH AVE
19TH AVE
23RD AVE
E PINE ST
E PIKE ST
E MADISON ST
E UNION ST
M L KING JR WAY
34TH AVE
E CHERRY ST
BROADWAY
14TH AVE
E JEFFERSON ST
BOREN AVE
8TH AVE
E YESLER WAY
S JACKSON ST
I5 NB COLLECTOR
12TH AVE S
20TH AVE S
EB TUNNEL
I90 EB
I90 WB
31ST AVE S
LAKE PARK DR S
S MCCLELLAN ST
Leschi CSO Area
Uncontrolled Basins
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm/Lake
Parcels to Storm
ROW to Storm
Leschi CSO Area = 404.9 acres
Partially Separated Area (%) = 379.7 acres (94%)
Combined Area (%) = 25.2 acres (6%)
Est. Impervious to Combined (%) = 23.9 acres (6%)
Feet
0 750 1,500 3,000
N


022 Outfall
024 Outfall
025 Outfall
SR520 WB
SR520 EB
E MCGILVRA ST
42ND AVE E
43RD AVE E
E BLAINE ST
E MADISON ST
LAKE WASHINGTON BLVD E
MCGILVRA BLVD E
MADRONA DR
M L KING JR WAY
NPDES
Madison Park CSO Area
Uncontrolled Basins
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm/Lake
Parcels to Storm/Lake
ROW to Storm
Madison Park CSO Area = 228.5 acres
Basin 22
Basin Area = 9.1 acres
Partially Separated Area (%) = 9.1 acres (100%)
Combined Area (%) = 0 acres (0%)
Est. Impervious to Combined (%) = 0.1 acres (1%)
Basin 24
Basin Area = 44.3 acres
Partially Separated Area (%) = 28.7 (64.7%)
Combined Area (%) = 15.6 acres (35.3%)
Est. Impervious to Combined (%) = 6.4 acres (14%)
Basin 25
Basin Area = 175.1 acres
Partially Separated Area (%) = 175.1 acres (100%)
Combined Area (%) = 0 acres (0%)
Est. Impervious to Combined (%) = 23.3 acres (13%)
N
Feet
0
750
1,500
3,000


140 Outfall
020 Outfall
139 Outfall
E SHELBY ST
E HAMLIN ST
19TH AVE E
24TH AVE E
E UNIVERSITY BLVD
E ROANOKE ST
E LOUISA ST
25TH AVE E
26TH AVE E
EVERETT AVE E
14TH AVE E
E MCGRAW ST
E LYNN ST
BOYER AVE E
Montlake CSO Area
Uncontroled Basins
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm or Lake
ROW to Storm
Montlake CSO Area = 120.8 acres
Partially Separated Area (%) = 84.5 acres (70%)
Combined Area (%) = 36.3 acres (30%)
Est. Impervious to Combined (%) = 29.4 acres (24%)
N
Feet
0
750
1,500
3,000


NE 85TH ST
LAKE CITY WAY NE
NE 80TH ST
SR522
20TH AVE NE
25TH AVE NE
12TH AVE NE
NE 75TH ST
NE 70TH ST
55TH AVE NE
NE 65TH ST
NE 65TH ST
NE RAVENNA BLVD
NE 55TH ST
NE 54TH ST
35TH AVE NE
40TH AVE NE
SAND POINT WAY NE
47TH AVE NE
NE 45TH ST
48TH AVE NE
NE 41ST ST
18 Outfall
North Union Bay CSO Area
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm
ROW to Storm
North Union Bay CSO Area = 923.4 acres
Partially Separated Area (%) = 791.5 acres (86%)
Combined Area (%) = 131.9 acres (14%)
Est. Impervious to Combined (%) = 178.2 acres (19%)

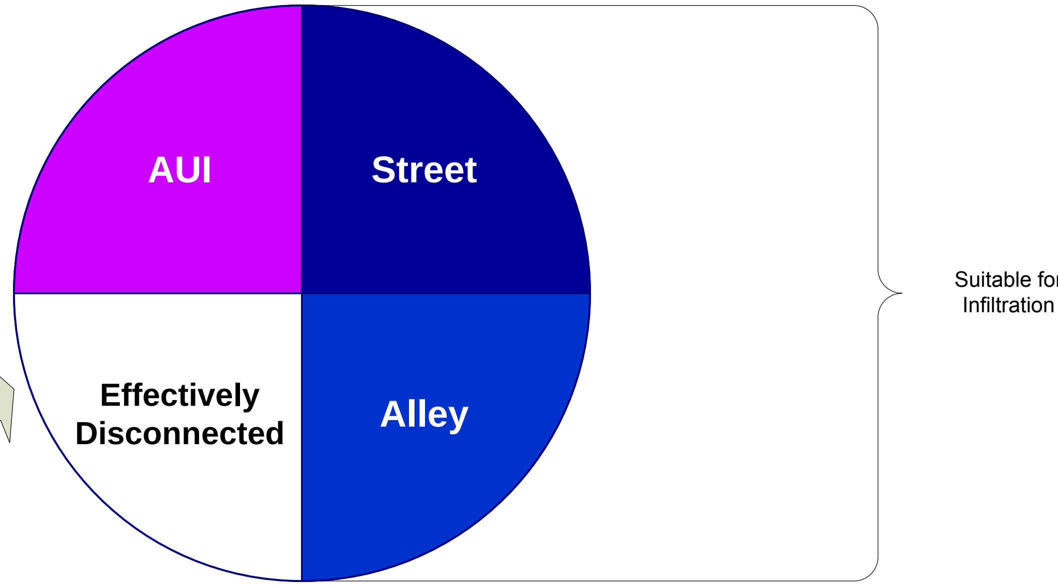

N 38TH ST
STONE WAY N
WALLINGFORD AVE N
N PACIFIC ST
N 35TH ST
N 34TH ST
N NORTHLAKE WAY
AURORA BR
NE PACIFIC ST
135 Outfall
138 Outfall
132 Outfall
130 Outfall
175 Outfall
FUHRMAN AVE E
HARVARD AVE E
E ROANOKE ST
SR520 WB
SR520 EB
DELMAR DR E
EASTLAKE AVE E
BOYLSTON AVE E
BOYER AVE E
19TH AVE E
E BOSTON ST
6TH AVE N
DEXTER WAY N
5TH AVE N
E GALER ST
LAKEVIEW BLVD E
10TH AVE E
BELMONT AVE E
15TH AVE E
E ALOHA ST
E ROY ST
I5 EXPRESS
I5 SB
I5 NB
DENNY WAY
Portage Bay CSO Area
Uncontrolled Basins
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm/Bay
Parcels to Storm
ROW to Storm/Bay
Portage Bay CSO Area = 482.4 acres
Partially Separated Area (%) = 82.1 acres (17%)
Combined Area (%) = 400.3 acres (83%)
Est. Impervious to Combined (%) = 214.1 acres (44%)
N
Feet
0
750
1,500
3,000

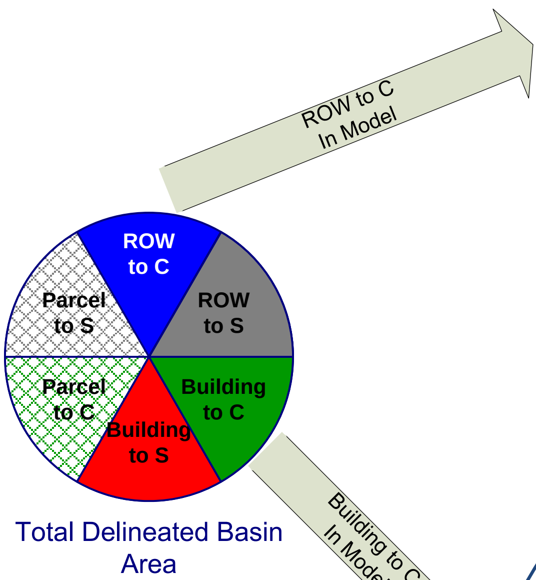
Appendix C
Evaluation of Areas Unsuitable for Infiltration

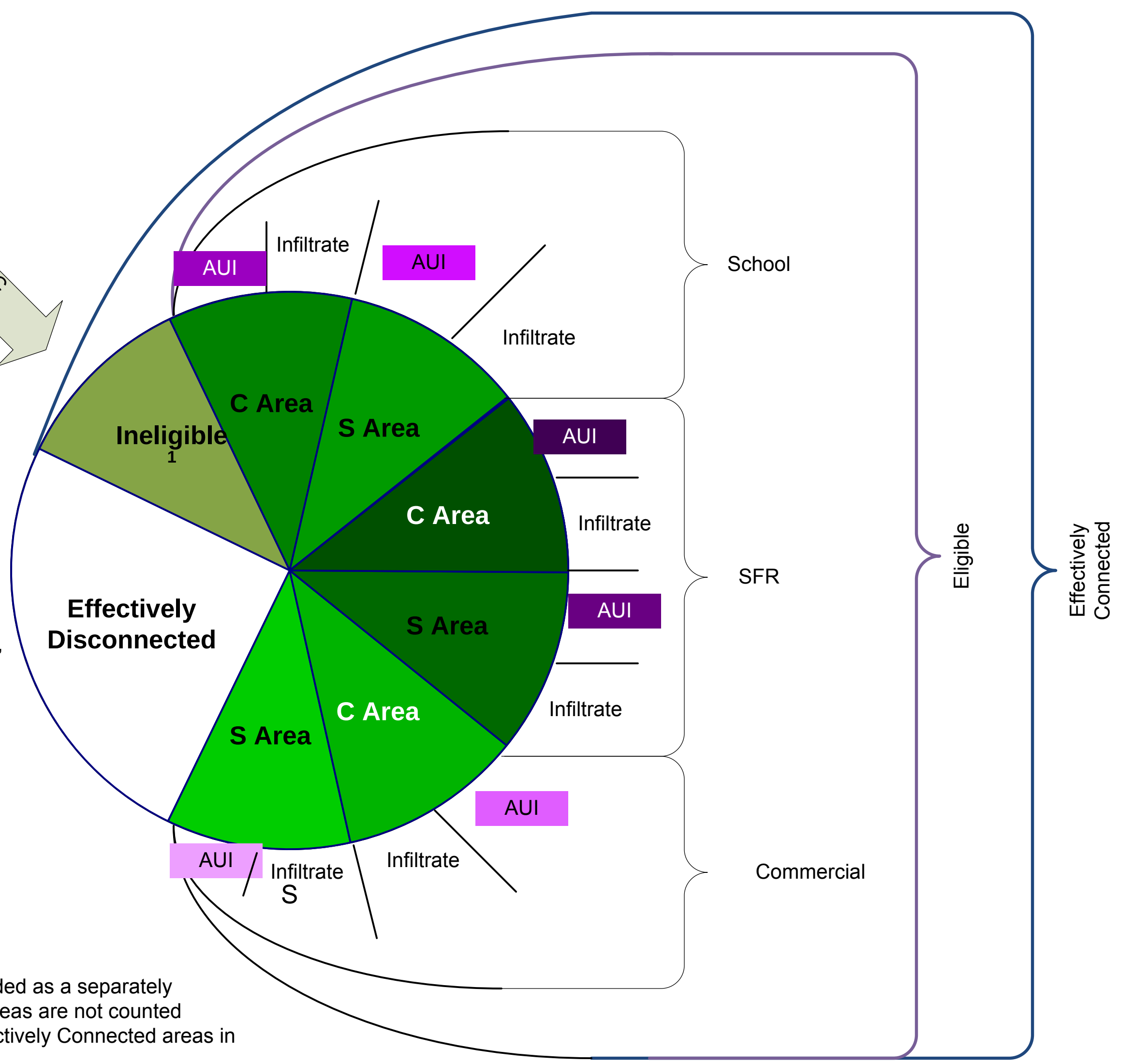
City of Seattle LTCP Basin Areas
Pie Chart Key

Draft. Revised 9.2.2011

This "key" is meant to help interpret the series of pie charts made for individual NPDES Basins. Pie slice sizes are schematic only, and are not to scale. Colors used in the key are identical to those in the actual pie charts.





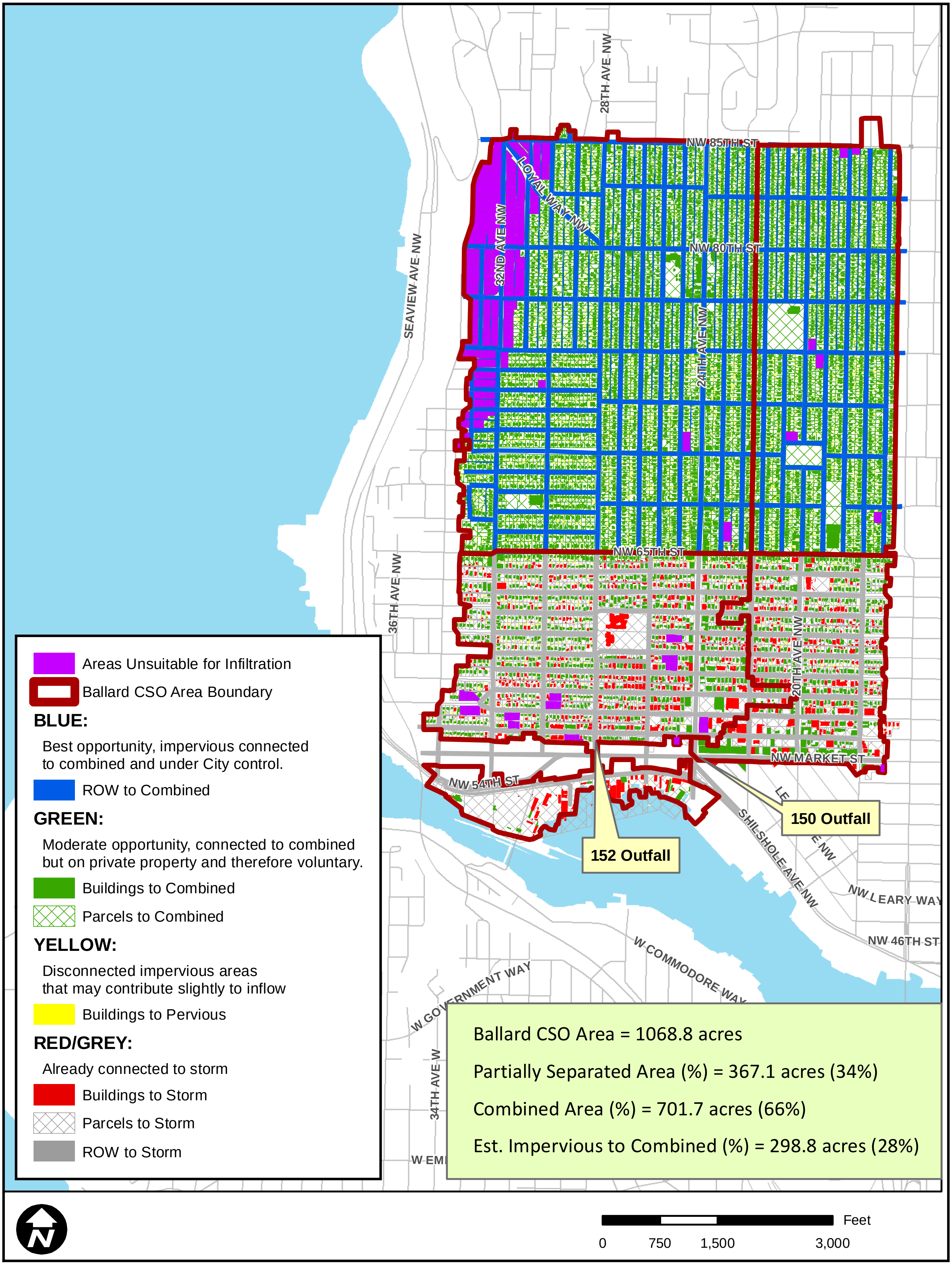


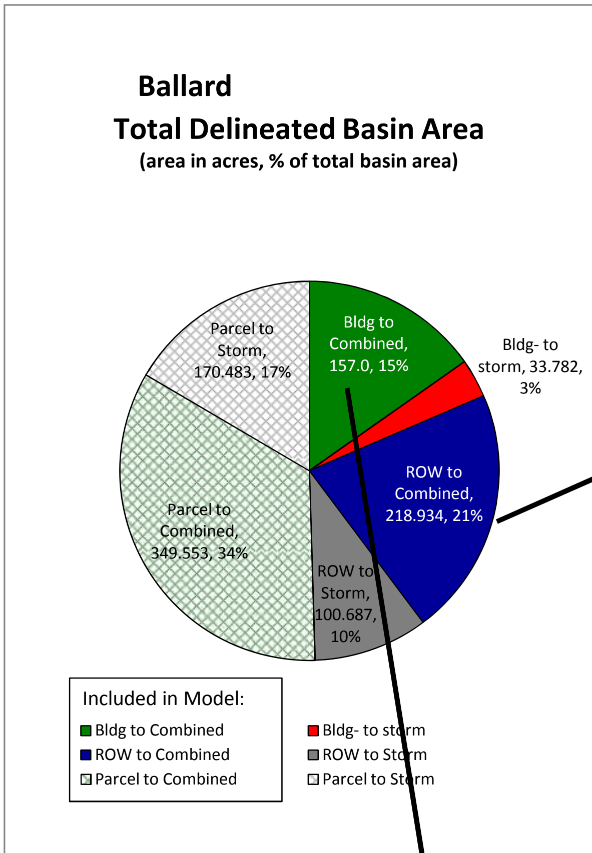
Notes
1. Ineligible buildings include: urban villages; buildings with "Type" = "" (blank), "Industrial", "Multi-Family", "Other Housing", "Parking", "Terminal/ Warehouse", "Utility", "Vacant".

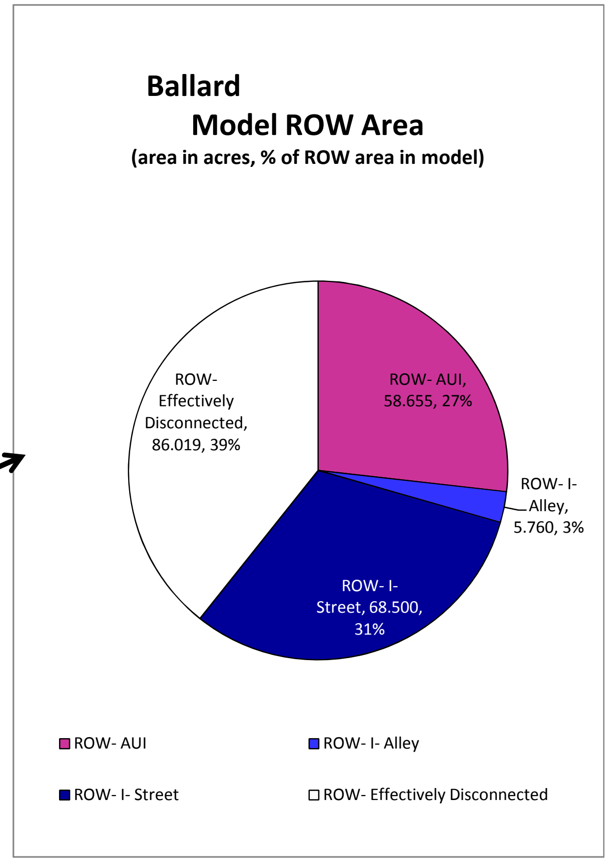
"C Area" = building in a combined area
"S Area" = building in a partially separated area

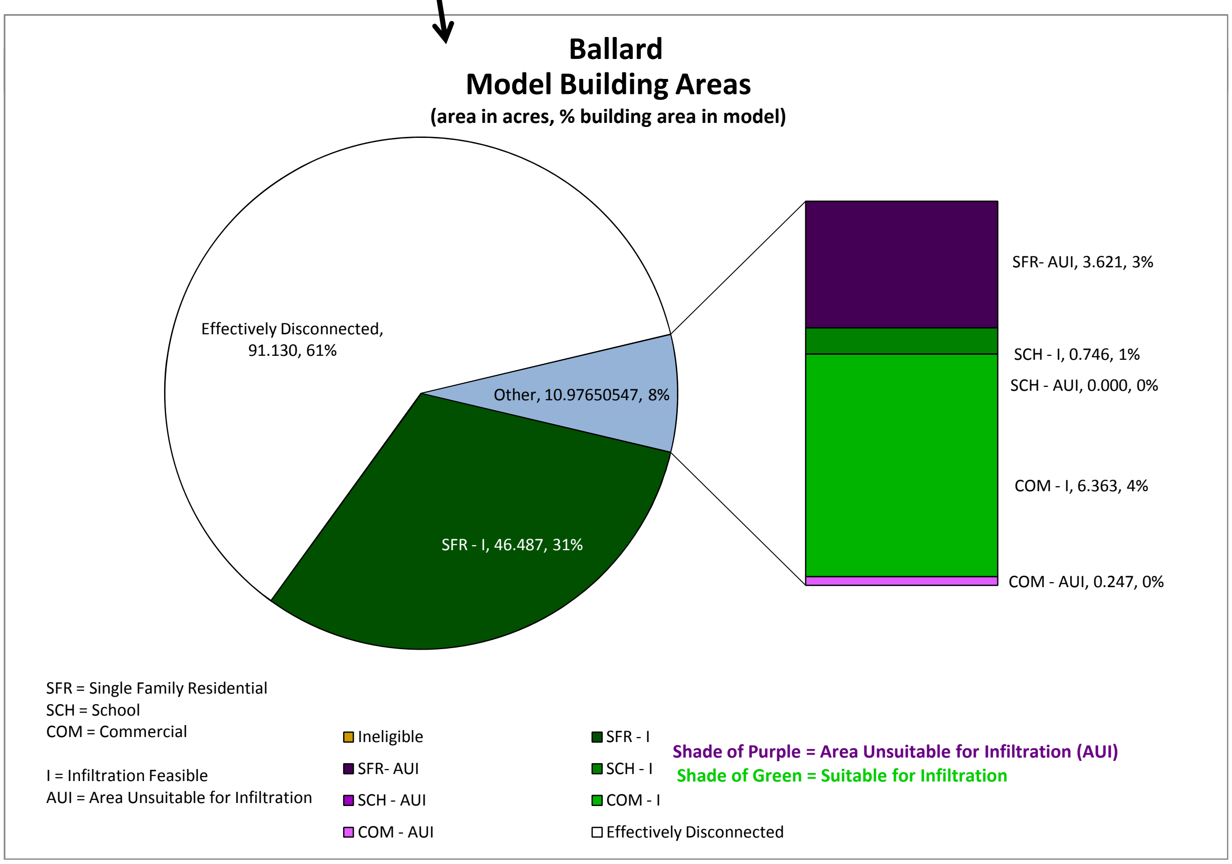
"Infiltrate" = Area Suitable for Infiltration
"AUI" = Area Unsuitable for Infiltration

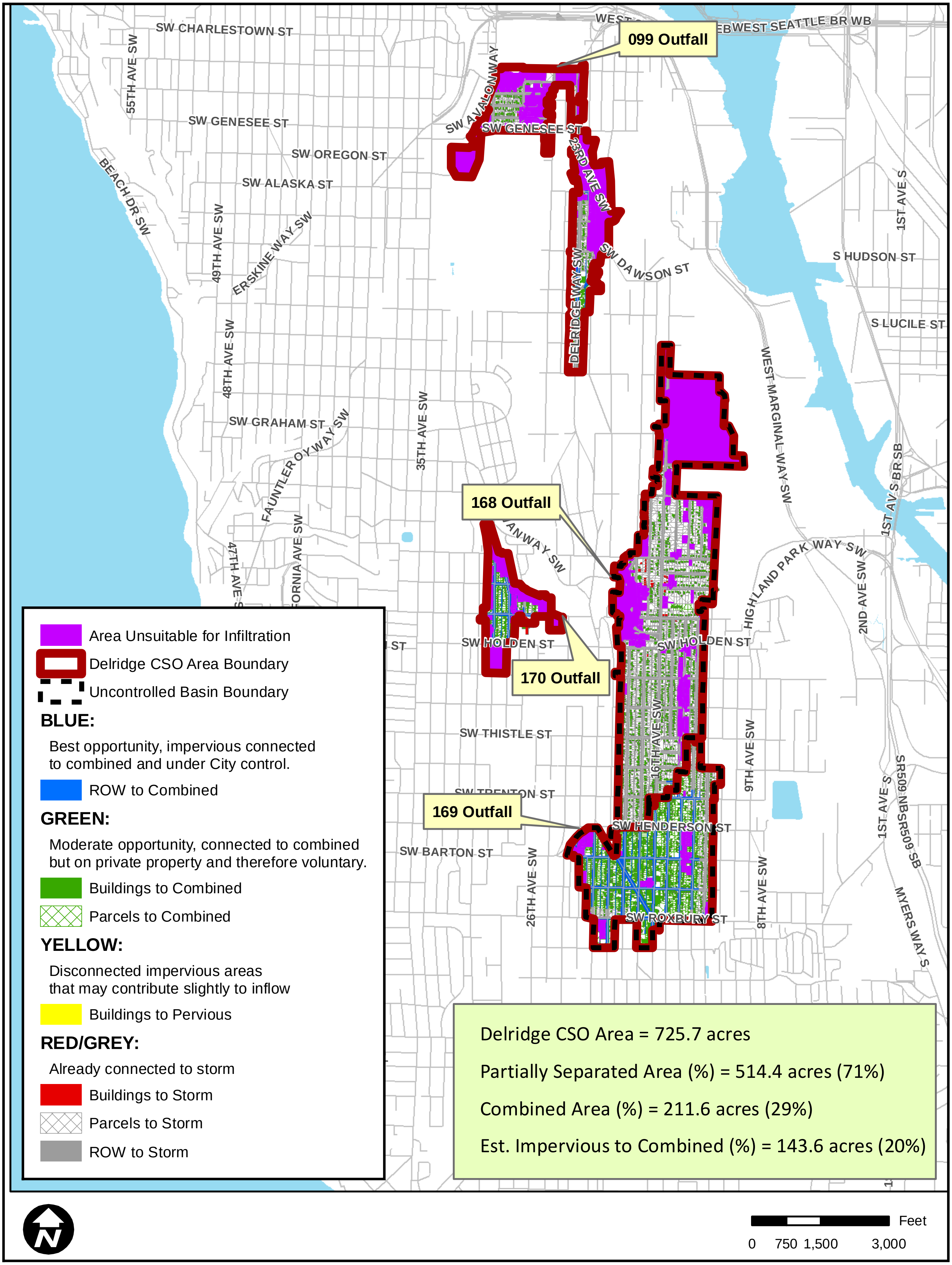
Building Count:
All pie slivers with distinct colors are included as a separately counted item. Effectively Disconnected areas are not counted separately, and are included with the Effectively Connected areas in the building count.


28TH AVE NW
NW 85TH ST
LOYAL WAY NW
32ND AVE NW
NW 80TH ST
SEAVIEW AVE NW
24TH AVE NW
NW 65TH ST
36TH AVE NW
20TH AVE NW
NW MARKET ST
NW 54TH ST
150 Outfall
152 Outfall
SHILSHOLE AVE NW
NW LEARY WAY
NW 46TH ST
W COMMODORE WAY
W GOVERNMENT WAY
34TH AVE W
Areas Unsuitable for Infiltration
Ballard CSO Area Boundary
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm
ROW to Storm
Ballard CSO Area = 1068.8 acres
Partially Separated Area (%) = 367.1 acres (34%)
Combined Area (%) = 701.7 acres (66%)
Est. Impervious to Combined (%) = 298.8 acres (28%)
Feet
0
750
1,500
3,000

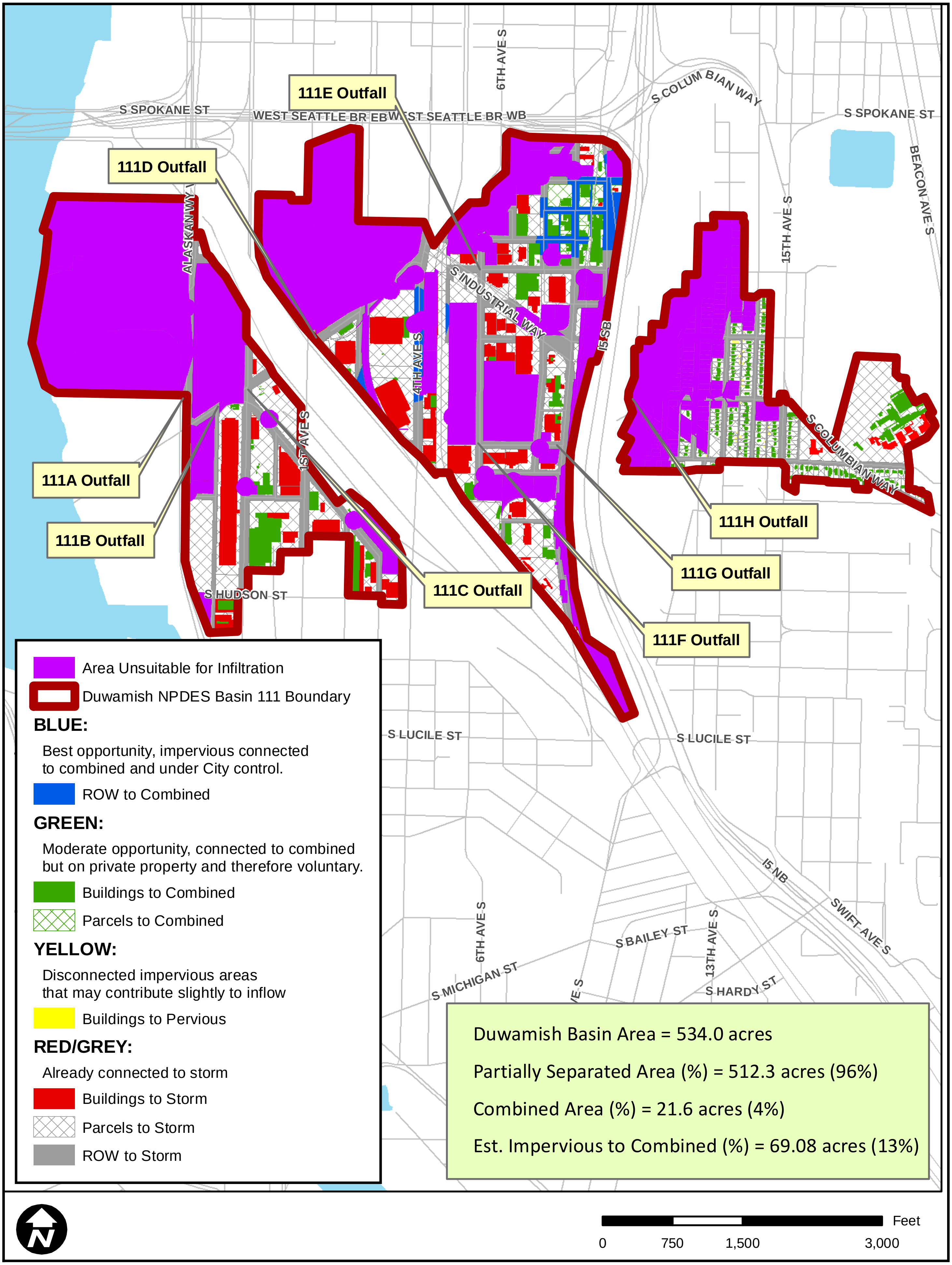

Ballard
Total Delineated Basin Area
(area in acres, % of total basin area)
Bldg to Combined, 157.0, 15%
Bldg- to storm, 33.782, 3%
ROW to Combined, 218.934, 21%
ROW to Storm, 100.687, 10%
Parcel to Combined, 349.553, 34%
Parcel to Storm, 170.483, 17%
Included in Model:
Bldg to Combined
ROW to Combined
Parcel to Combined
Bldg- to storm
ROW to Storm
Parcel to Storm

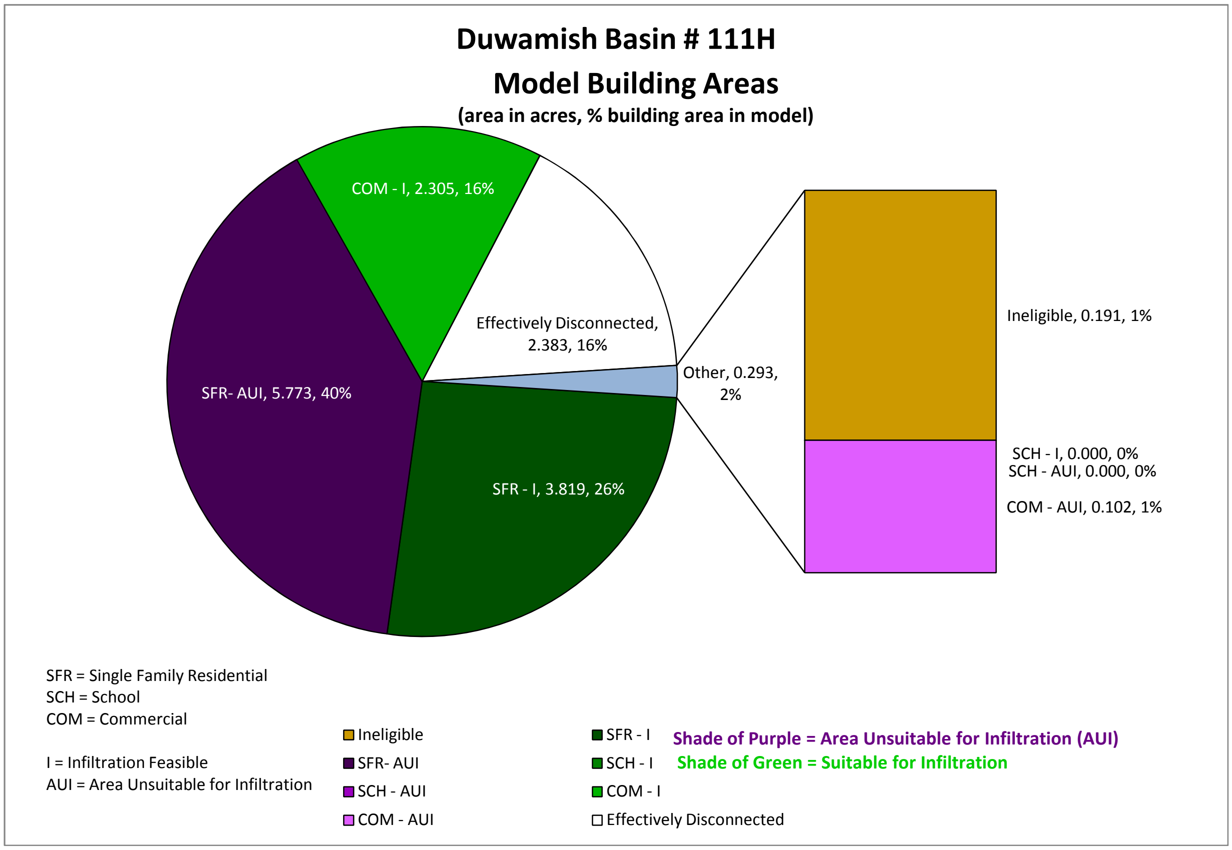

Ballard
Model ROW Area
(area in acres, % of ROW area in model)
ROW- AUI, 58.655, 27%
ROW- I- Alley, 5.760, 3%
ROW- I- Street, 68.500, 31%
ROW- Effectively Disconnected, 86.019, 39%
ROW- AUI
ROW- I- Alley
ROW- I- Street
ROW- Effectively Disconnected

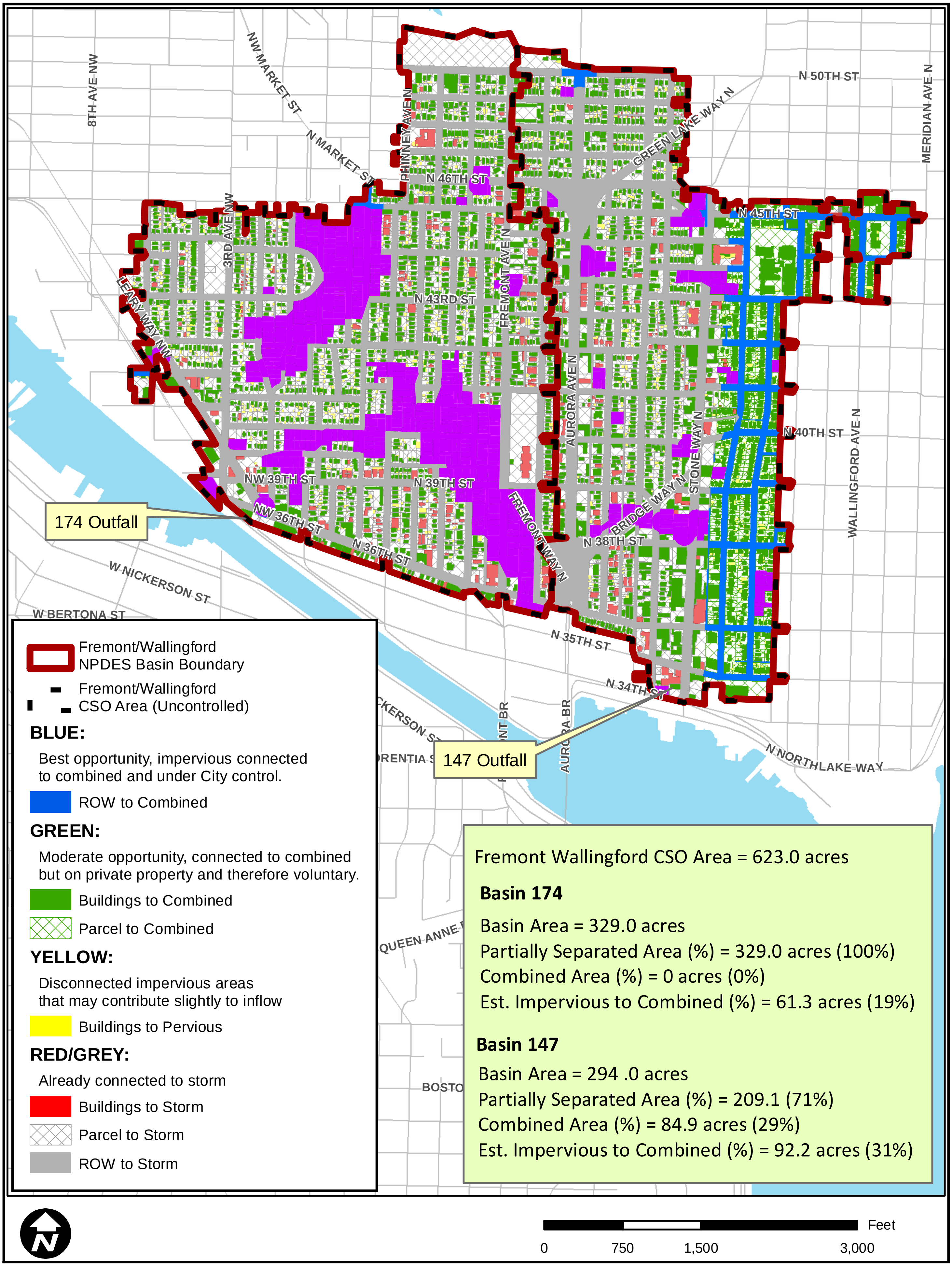

Ballard
Model Building Areas
(area in acres, % building area in model)
Effectively Disconnected, 91.130, 61%
Other, 10.97650547, 8%
SFR - I, 46.487, 31%
SFR- AUI, 3.621, 3%
SCH - I, 0.746, 1%
SCH - AUI, 0.000, 0%
COM - I, 6.363, 4%
COM - AUI, 0.247, 0%
SFR = Single Family Residential
SCH = School
COM = Commercial
I = Infiltration Feasible
AUI = Area Unsuitable for Infiltration
Ineligible
SFR- AUI
SCH - AUI
COM - AUI
SFR - I
SCH - I
COM - I
Effectively Disconnected
Shade of Purple = Area Unsuitable for Infiltration (AUI)
Shade of Green = Suitable for Infiltration

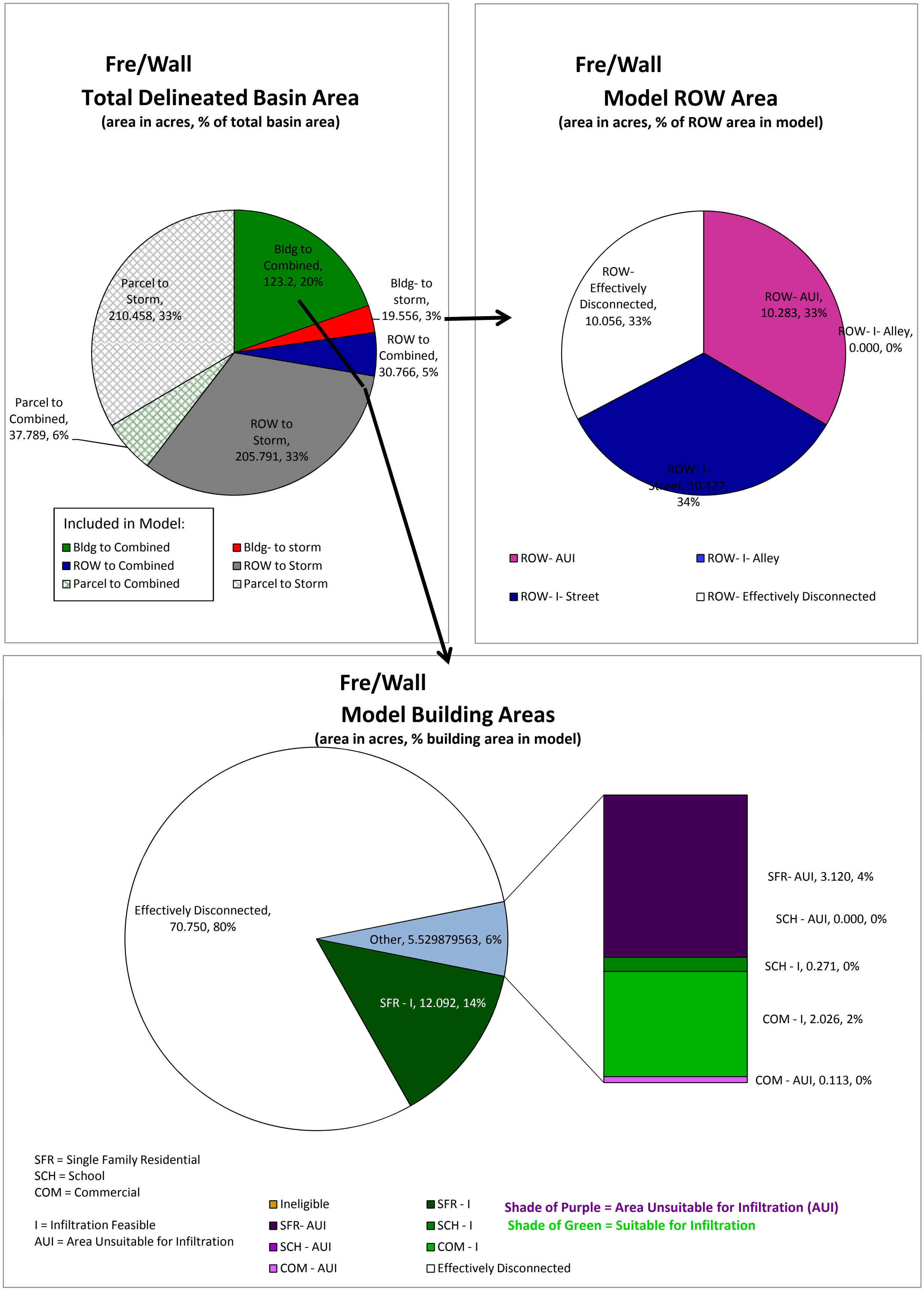


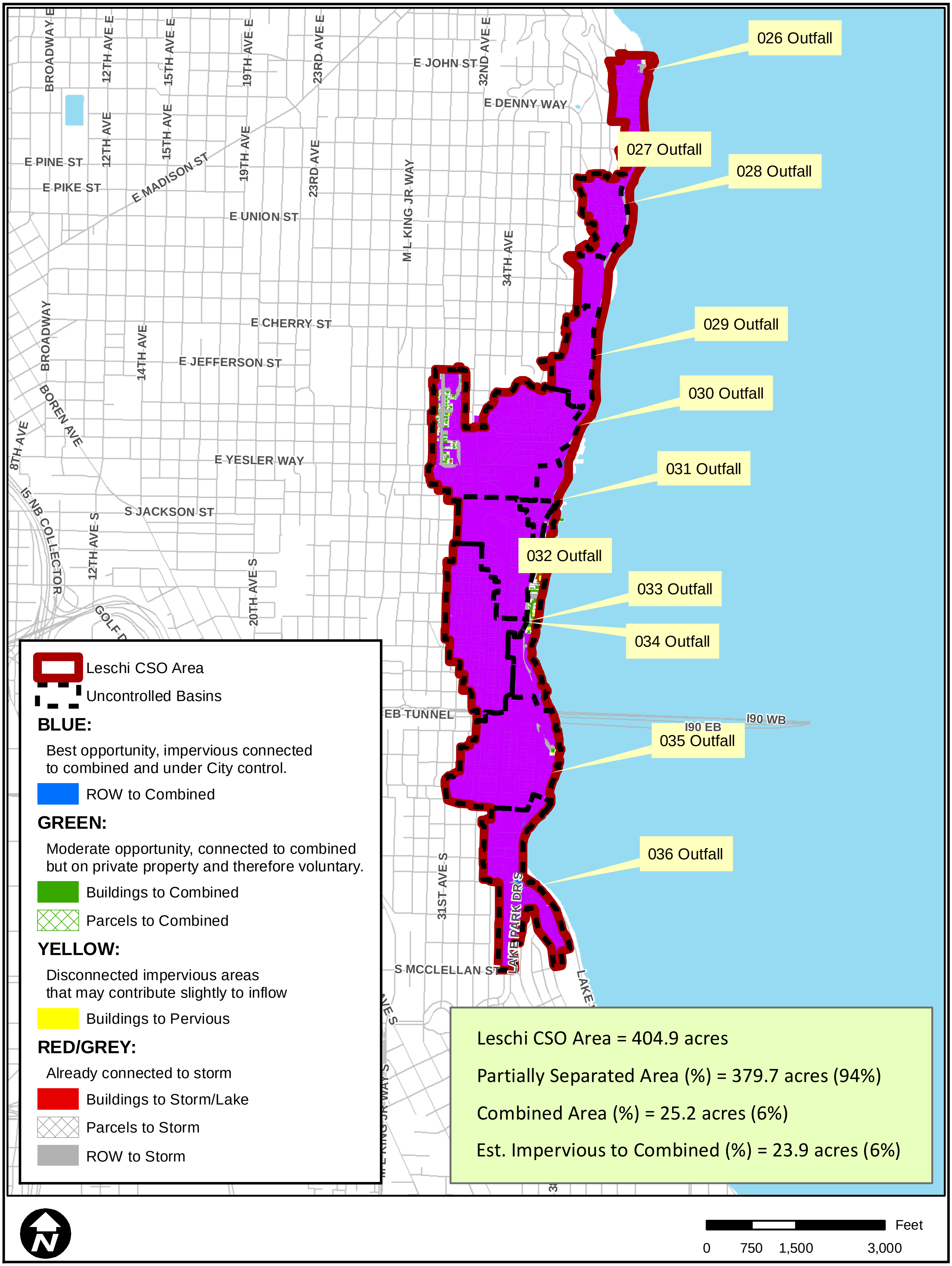
099 Outfall
168 Outfall
170 Outfall
169 Outfall
SW CHARLESTOWN ST
SW GENESEE ST
SW OREGON ST
SW ALASKA ST
BEACH DR SW
ERSKINE WAY SW
SW AVALON WAY
23RD AVE SW
SW DAWSON ST
DELRIDGE WAY SW
WEST MARGINAL WAY SW
S HUDSON ST
S LUCILE ST
1ST AVE S
SW GRAHAM ST
FAUNTLEROY WAY SW
35TH AVE SW
HIGHLAND PARK WAY SW
SW HOLDEN ST
SW THISTLE ST
SW TRENTON ST
SW BARTON ST
SW HENDERSON ST
SW ROXBURY ST
16TH AVE SW
26TH AVE SW
9TH AVE SW
8TH AVE SW
2ND AVE SW
SR509 NBSR509 SB
MYERS WAY S
55TH AVE SW
49TH AVE SW
48TH AVE SW
47TH AVE SW
Area Unsuitable for Infiltration
Delridge CSO Area Boundary
Uncontrolled Basin Boundary
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm
ROW to Storm
Delridge CSO Area = 725.7 acres
Partially Separated Area (%) = 514.4 acres (71%)
Combined Area (%) = 211.6 acres (29%)
Est. Impervious to Combined (%) = 143.6 acres (20%)
Feet
0 750 1,500 3,000
N

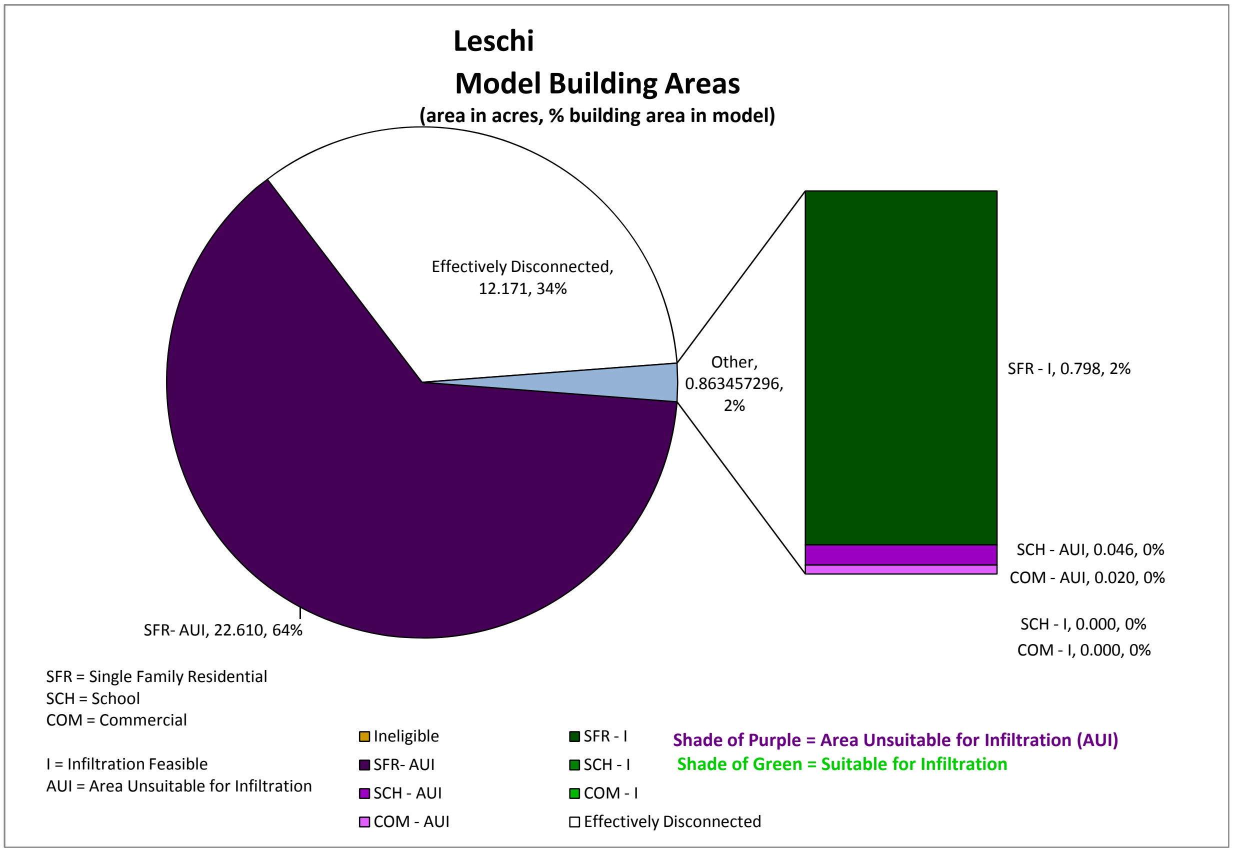

111A Outfall
111B Outfall
111C Outfall
111D Outfall
111E Outfall
111F Outfall
111G Outfall
111H Outfall
S SPOKANE ST
WEST SEATTLE BR EB
WEST SEATTLE BR WB
S COLUMBIAN WAY
6TH AVE S
15TH AVE S
BEACON AVE S
ALASKAN WAY
S INDUSTRIAL WAY
4TH AVE S
1ST AVE S
I5 SB
S HUDSON ST
S LUCILE ST
I5 NB
SWIFT AVE S
S BAILEY ST
13TH AVE S
S MICHIGAN ST
S HARDY ST
Area Unsuitable for Infiltration
Duwamish NPDES Basin 111 Boundary
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm
ROW to Storm
Duwamish Basin Area = 534.0 acres
Partially Separated Area (%) = 512.3 acres (96%)
Combined Area (%) = 21.6 acres (4%)
Est. Impervious to Combined (%) = 69.08 acres (13%)
N
Feet
0
750
1,500
3,000


Duwamish Basin # 111H
Model Building Areas
(area in acres, % building area in model)
COM - I, 2.305, 16%
Effectively Disconnected, 2.383, 16%
SFR- AUI, 5.773, 40%
SFR - I, 3.819, 26%
Other, 0.293, 2%
Ineligible, 0.191, 1%
SCH - I, 0.000, 0%
SCH - AUI, 0.000, 0%
COM - AUI, 0.102, 1%
SFR = Single Family Residential
SCH = School
COM = Commercial
I = Infiltration Feasible
AUI = Area Unsuitable for Infiltration
Ineligible
SFR- AUI
SCH - AUI
COM - AUI
SFR - I
SCH - I
COM - I
Effectively Disconnected
Shade of Purple = Area Unsuitable for Infiltration (AUI)
Shade of Green = Suitable for Infiltration

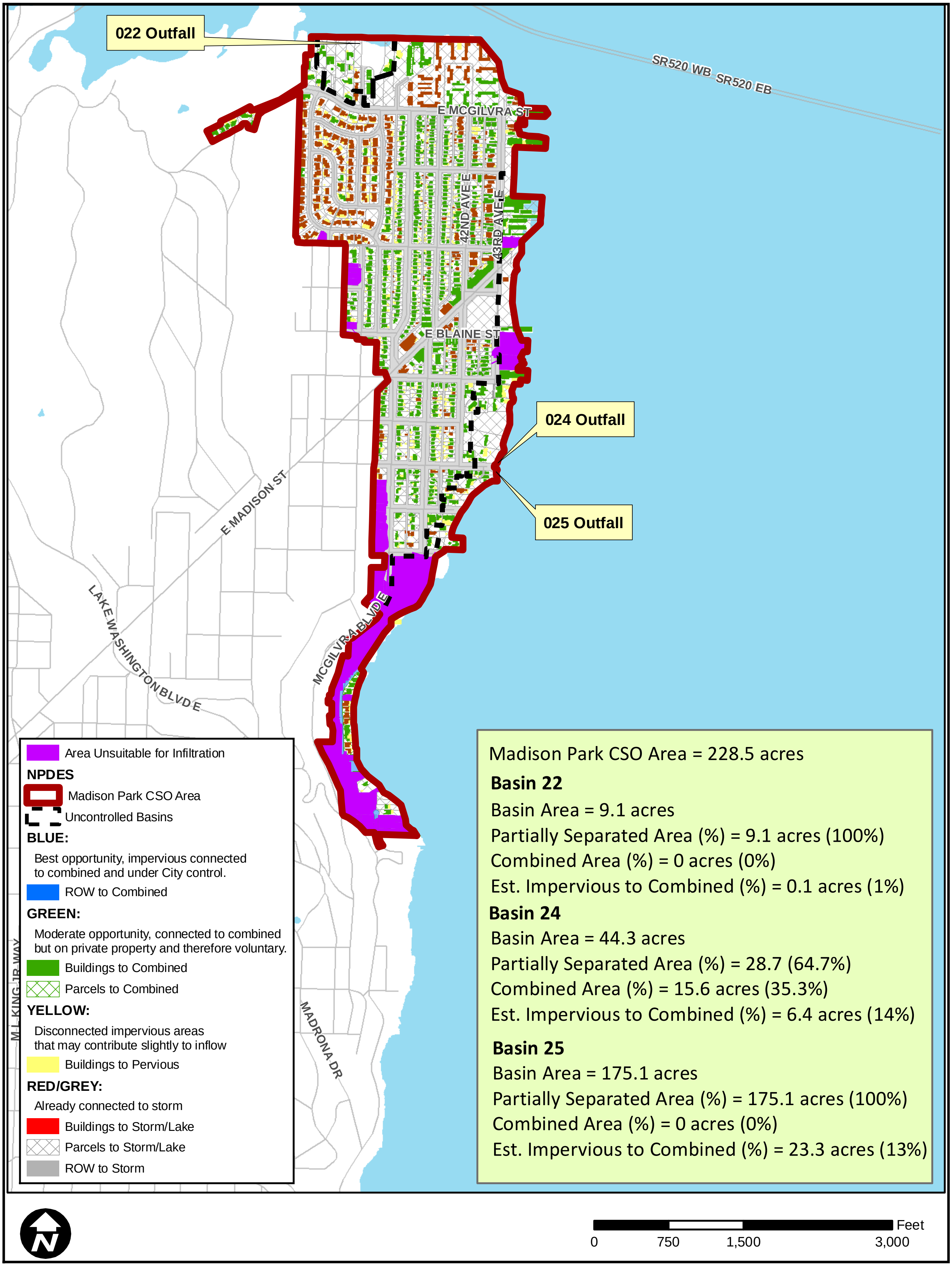

Fremont Wallingford CSO Area = 623.0 acres
Basin 174
Basin Area = 329.0 acres
Partially Separated Area (%) = 329.0 acres (100%)
Combined Area (%) = 0 acres (0%)
Est. Impervious to Combined (%) = 61.3 acres (19%)
Basin 147
Basin Area = 294 .0 acres
Partially Separated Area (%) = 209.1 (71%)
Combined Area (%) = 84.9 acres (29%)
Est. Impervious to Combined (%) = 92.2 acres (31%)
Fremont/Wallingford NPDES Basin Boundary
Fremont/Wallingford CSO Area (Uncontrolled)
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcel to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcel to Storm
ROW to Storm
174 Outfall
147 Outfall
8TH AVE NW
NW MARKET ST
N MARKET ST
PHINNEY AVE N
N 46TH ST
N 50TH ST
GREEN LAKE WAY N
MERIDIAN AVE N
N 45TH ST
3RD AVE NW
LEARY WAY NW
N 43RD ST
FREMONT AVE N
AURORA AVE N
STONE WAY N
N 40TH ST
WALLINGFORD AVE N
NW 39TH ST
N 39TH ST
NW 36TH ST
N 36TH ST
FREMONT WAY N
BRIDGE WAY N
N 38TH ST
W NICKERSON ST
W BERTONA ST
N 35TH ST
N 34TH ST
N NORTHLAKE WAY
QUEEN ANNE
Feet
0
750
1,500
3,000


Fre/Wall
Total Delineated Basin Area
(area in acres, % of total basin area)
Bldg to Combined, 123.2, 20%
Bldg- to storm, 19.556, 3%
ROW to Combined, 30.766, 5%
ROW to Storm, 205.791, 33%
Parcel to Combined, 37.789, 6%
Parcel to Storm, 210.458, 33%
Included in Model:
Bldg to Combined
ROW to Combined
Parcel to Combined
Bldg- to storm
ROW to Storm
Parcel to Storm
Fre/Wall
Model ROW Area
(area in acres, % of ROW area in model)
ROW- AUI, 10.283, 33%
ROW- I- Alley, 0.000, 0%
ROW- I- Street, 10.427, 34%
ROW- Effectively Disconnected, 10.056, 33%
ROW- AUI
ROW- I- Alley
ROW- I- Street
ROW- Effectively Disconnected
Fre/Wall
Model Building Areas
(area in acres, % building area in model)
Effectively Disconnected, 70.750, 80%
Other, 5.529879563, 6%
SFR - I, 12.092, 14%
SFR- AUI, 3.120, 4%
SCH - AUI, 0.000, 0%
SCH - I, 0.271, 0%
COM - I, 2.026, 2%
COM - AUI, 0.113, 0%
SFR = Single Family Residential
SCH = School
COM = Commercial
I = Infiltration Feasible
AUI = Area Unsuitable for Infiltration
Ineligible
SFR- AUI
SCH - AUI
COM - AUI
SFR - I
SCH - I
COM - I
Effectively Disconnected
Shade of Purple = Area Unsuitable for Infiltration (AUI)
Shade of Green = Suitable for Infiltration

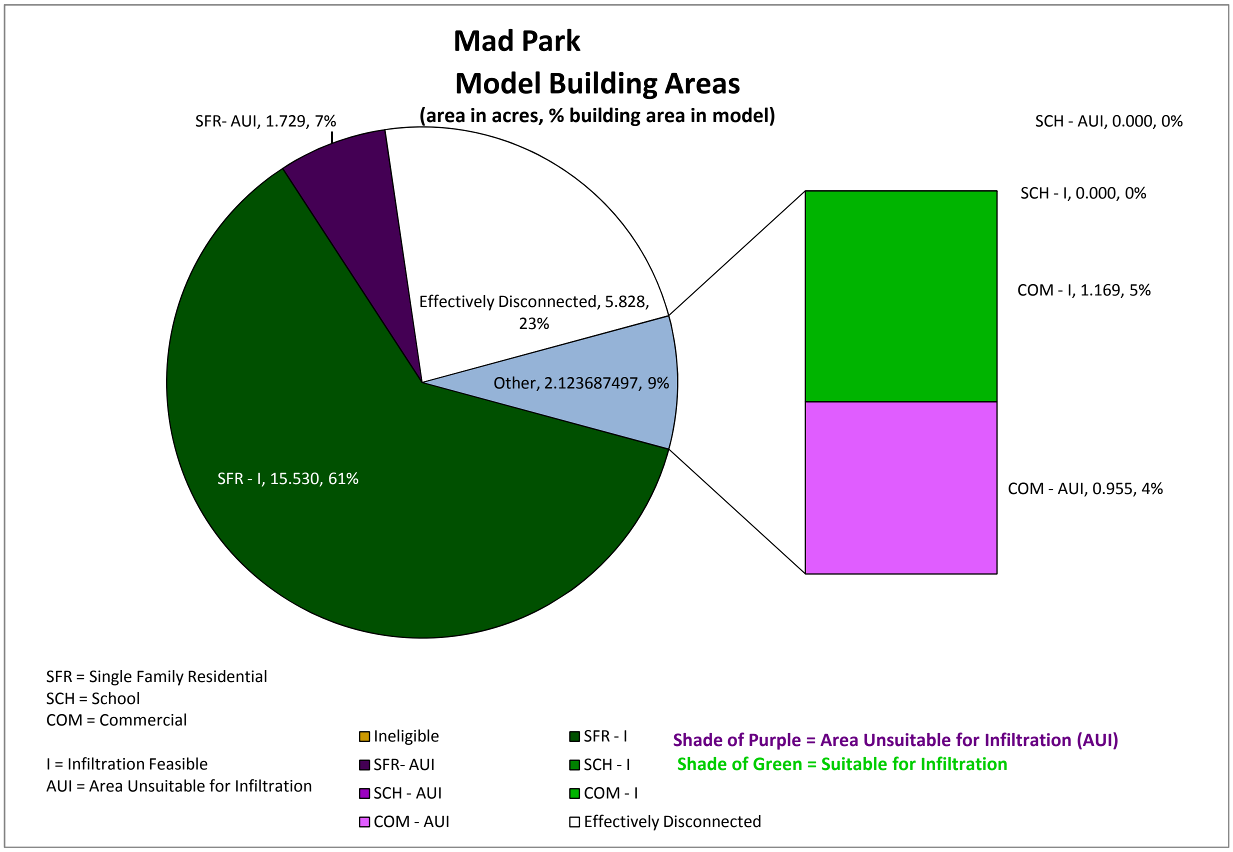

026 Outfall
027 Outfall
028 Outfall
029 Outfall
030 Outfall
031 Outfall
032 Outfall
033 Outfall
034 Outfall
035 Outfall
036 Outfall
BROADWAY E
12TH AVE E
15TH AVE E
19TH AVE E
23RD AVE E
E JOHN ST
32ND AVE E
E DENNY WAY
12TH AVE
15TH AVE
19TH AVE
23RD AVE
E PINE ST
E PIKE ST
E MADISON ST
E UNION ST
M L KING JR WAY
34TH AVE
BROADWAY
14TH AVE
E CHERRY ST
E JEFFERSON ST
BOREN AVE
8TH AVE
E YESLER WAY
S JACKSON ST
I5 NB COLLECTOR
12TH AVE S
20TH AVE S
EB TUNNEL
I90 EB
I90 WB
31ST AVE S
LAKE PARK DR S
S MCCLELLAN ST
Leschi CSO Area
Uncontrolled Basins
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm/Lake
Parcels to Storm
ROW to Storm
Leschi CSO Area = 404.9 acres
Partially Separated Area (%) = 379.7 acres (94%)
Combined Area (%) = 25.2 acres (6%)
Est. Impervious to Combined (%) = 23.9 acres (6%)
Feet
0 750 1,500 3,000

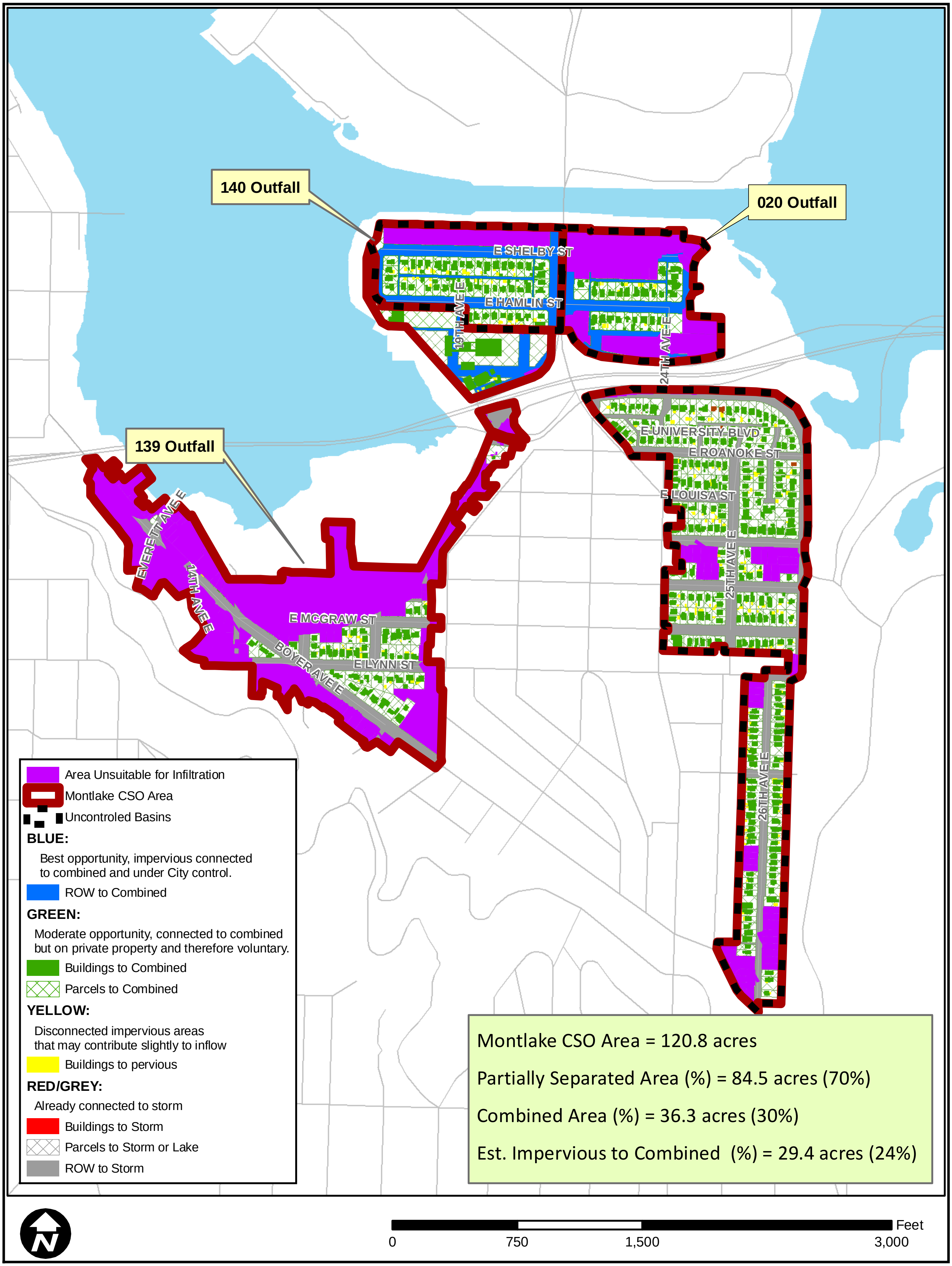


Leschi
Model Building Areas
(area in acres, % building area in model)
Effectively Disconnected, 12.171, 34%
Other, 0.863457296, 2%
SFR - I, 0.798, 2%
SCH - AUI, 0.046, 0%
COM - AUI, 0.020, 0%
SCH - I, 0.000, 0%
COM - I, 0.000, 0%
SFR- AUI, 22.610, 64%
SFR = Single Family Residential
SCH = School
COM = Commercial
I = Infiltration Feasible
AUI = Area Unsuitable for Infiltration
Ineligible
SFR- AUI
SCH - AUI
COM - AUI
SFR - I
SCH - I
COM - I
Effectively Disconnected
Shade of Purple = Area Unsuitable for Infiltration (AUI)
Shade of Green = Suitable for Infiltration

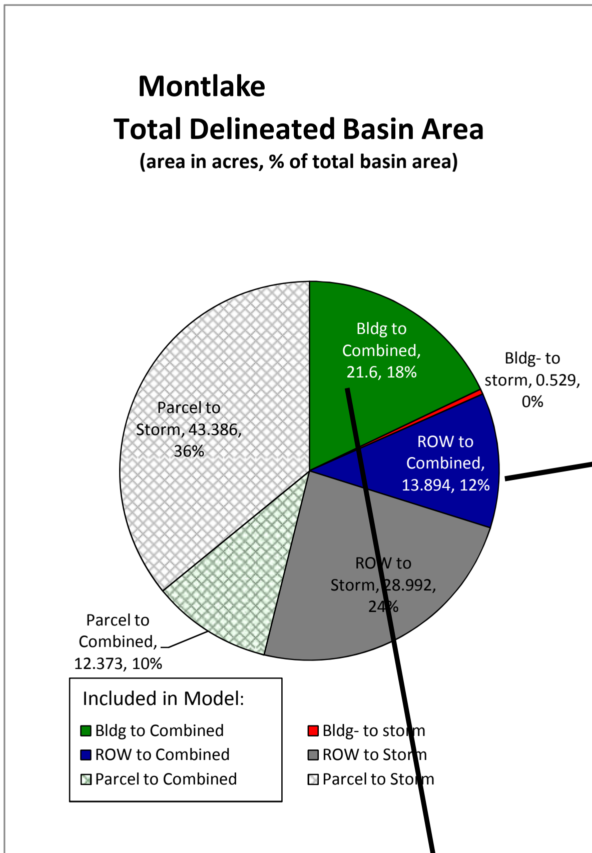


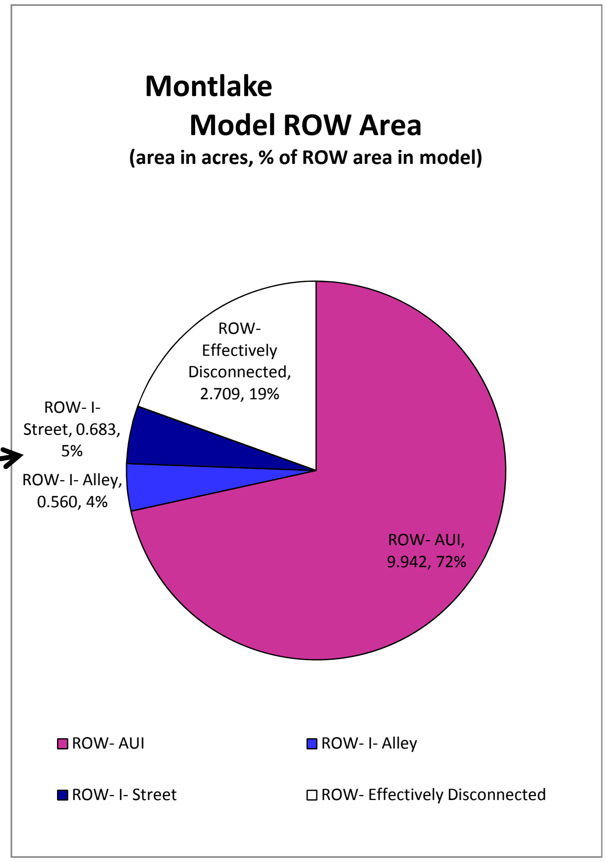
022 Outfall
SR520 WB
SR520 EB
E MCGILVRA ST
42ND AVE E
43RD AVE E
E BLAINE ST
024 Outfall
025 Outfall
E MADISON ST
LAKE WASHINGTON BLVD E
MCGILVRA BLVD E
MADRONA DR
M L KING JR WAY
Area Unsuitable for Infiltration
NPDES
Madison Park CSO Area
Uncontrolled Basins
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm/Lake
Parcels to Storm/Lake
ROW to Storm
Madison Park CSO Area = 228.5 acres
Basin 22
Basin Area = 9.1 acres
Partially Separated Area (%) = 9.1 acres (100%)
Combined Area (%) = 0 acres (0%)
Est. Impervious to Combined (%) = 0.1 acres (1%)
Basin 24
Basin Area = 44.3 acres
Partially Separated Area (%) = 28.7 (64.7%)
Combined Area (%) = 15.6 acres (35.3%)
Est. Impervious to Combined (%) = 6.4 acres (14%)
Basin 25
Basin Area = 175.1 acres
Partially Separated Area (%) = 175.1 acres (100%)
Combined Area (%) = 0 acres (0%)
Est. Impervious to Combined (%) = 23.3 acres (13%)
N
Feet
0
750
1,500
3,000

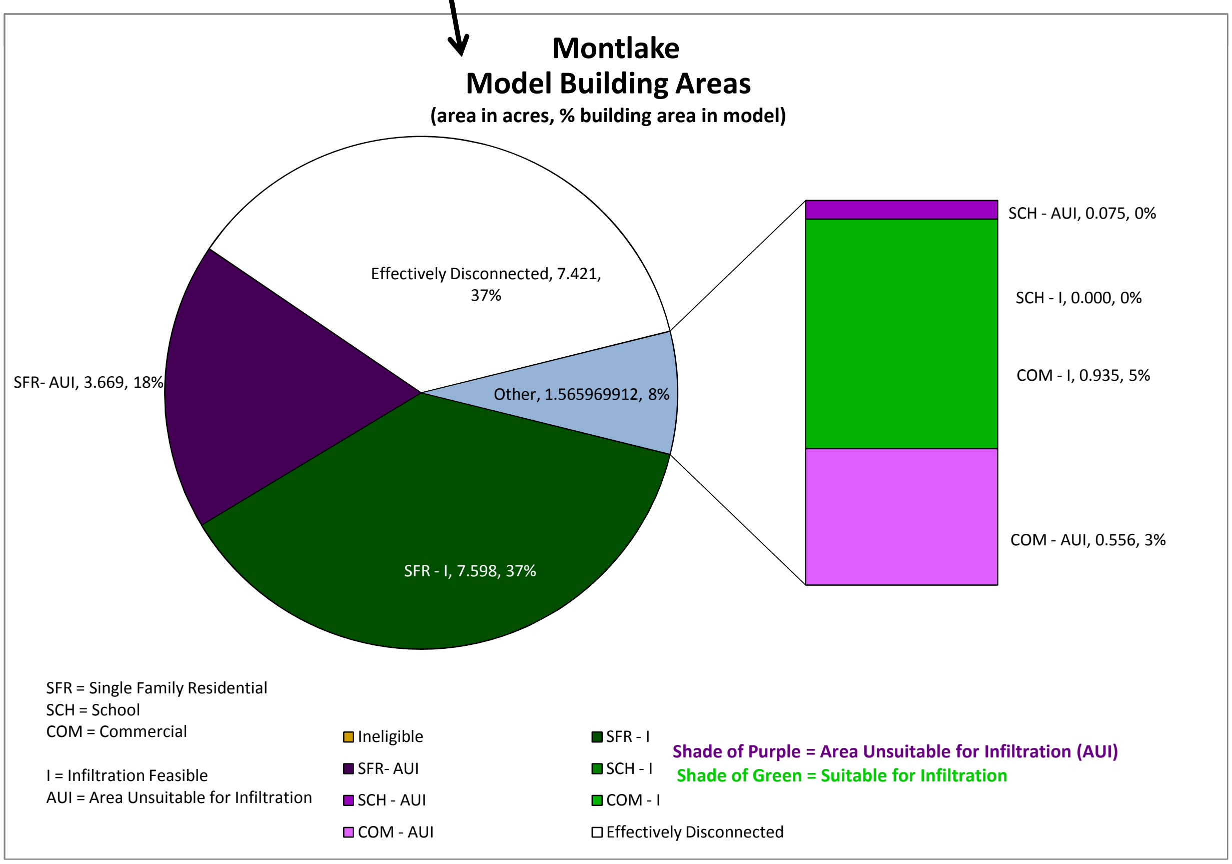

Mad Park
Model Building Areas
(area in acres, % building area in model)
SFR- AUI, 1.729, 7%
Effectively Disconnected, 5.828, 23%
Other, 2.123687497, 9%
SFR - I, 15.530, 61%
SCH - AUI, 0.000, 0%
SCH - I, 0.000, 0%
COM - I, 1.169, 5%
COM - AUI, 0.955, 4%
SFR = Single Family Residential
SCH = School
COM = Commercial
I = Infiltration Feasible
AUI = Area Unsuitable for Infiltration
Ineligible
SFR- AUI
SCH - AUI
COM - AUI
SFR - I
SCH - I
COM - I
Effectively Disconnected
Shade of Purple = Area Unsuitable for Infiltration (AUI)
Shade of Green = Suitable for Infiltration

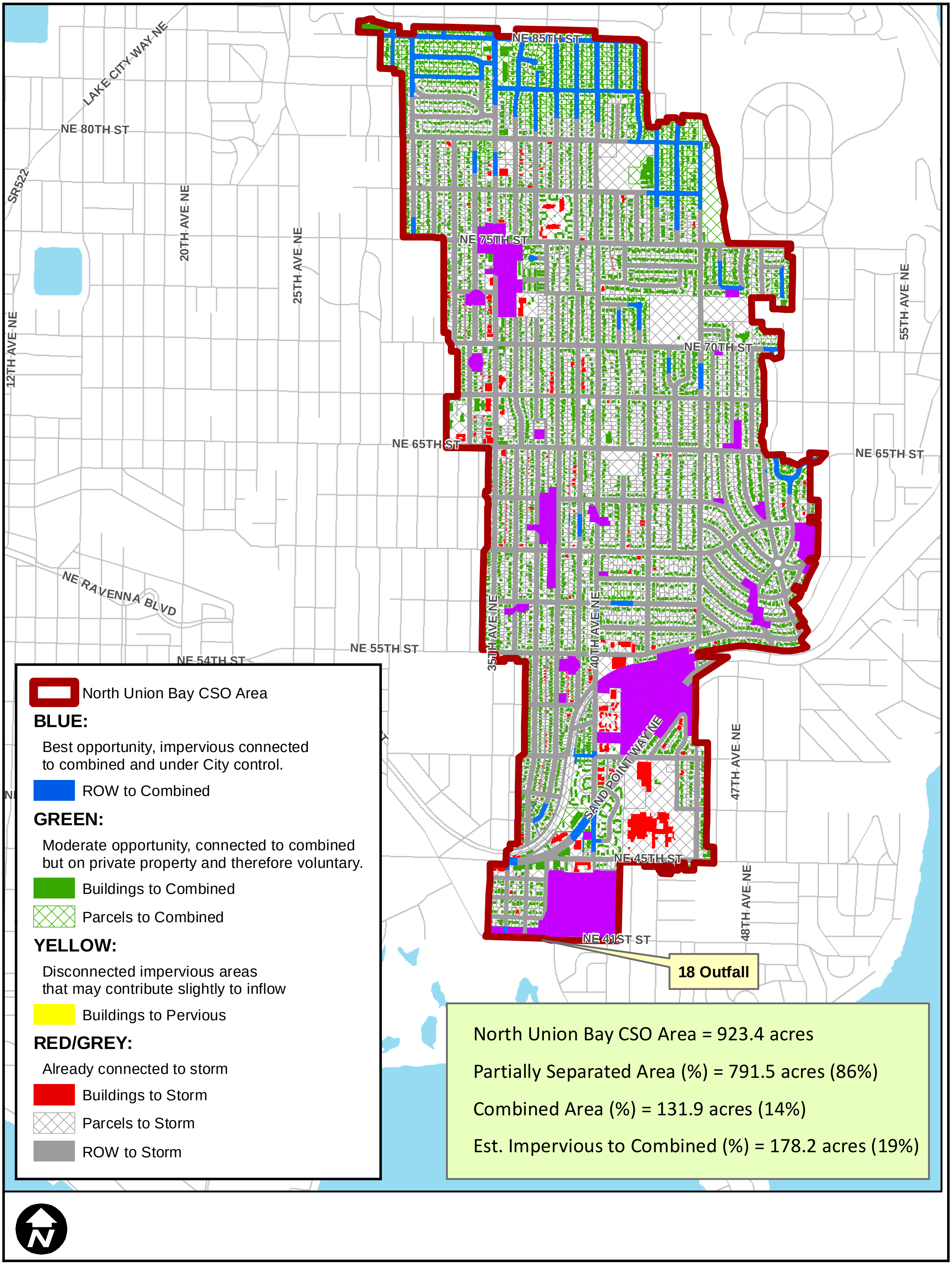


140 Outfall
020 Outfall
139 Outfall
E SHELBY ST
E HAMLIN ST
19TH AVE E
24TH AVE E
E UNIVERSITY BLVD
E ROANOKE ST
E LOUISA ST
25TH AVE E
26TH AVE E
EVERETT AVE E
14TH AVE E
E MCGRAW ST
E LYNN ST
BOYER AVE E
Area Unsuitable for Infiltration
Montlake CSO Area
Uncontroled Basins
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm or Lake
ROW to Storm
Montlake CSO Area = 120.8 acres
Partially Separated Area (%) = 84.5 acres (70%)
Combined Area (%) = 36.3 acres (30%)
Est. Impervious to Combined (%) = 29.4 acres (24%)
N
Feet
0
750
1,500
3,000

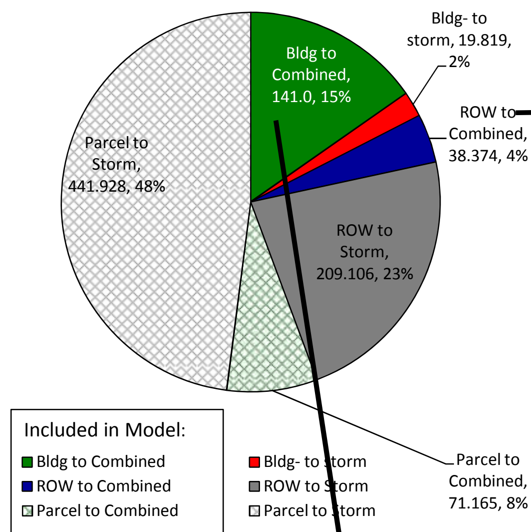

Montlake
Total Delineated Basin Area
(area in acres, % of total basin area)
Bldg to Combined, 21.6, 18%
Bldg- to storm, 0.529, 0%
ROW to Combined, 13.894, 12%
ROW to Storm, 28.992, 24%
Parcel to Combined, 12.373, 10%
Parcel to Storm, 43.386, 36%
Included in Model:
Bldg to Combined
ROW to Combined
Parcel to Combined
Bldg- to storm
ROW to Storm
Parcel to Storm


Montlake
Model ROW Area
(area in acres, % of ROW area in model)
ROW- Effectively Disconnected, 2.709, 19%
ROW- I- Street, 0.683, 5%
ROW- I- Alley, 0.560, 4%
ROW- AUI, 9.942, 72%
ROW- AUI
ROW- I- Alley
ROW- I- Street
ROW- Effectively Disconnected

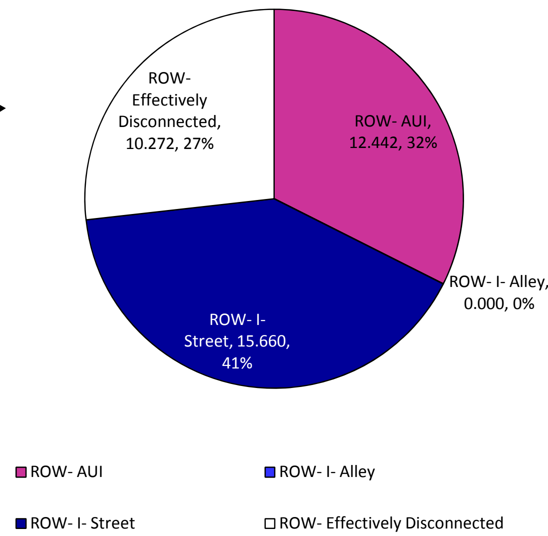

Montlake
Model Building Areas
(area in acres, % building area in model)
Effectively Disconnected, 7.421, 37%
SFR- AUI, 3.669, 18%
Other, 1.565969912, 8%
SFR - I, 7.598, 37%
SCH - AUI, 0.075, 0%
SCH - I, 0.000, 0%
COM - I, 0.935, 5%
COM - AUI, 0.556, 3%
SFR = Single Family Residential
SCH = School
COM = Commercial
I = Infiltration Feasible
AUI = Area Unsuitable for Infiltration
Ineligible
SFR- AUI
SCH - AUI
COM - AUI
SFR - I
SCH - I
COM - I
Effectively Disconnected
Shade of Purple = Area Unsuitable for Infiltration (AUI)
Shade of Green = Suitable for Infiltration


NE 85TH ST
LAKE CITY WAY NE
NE 80TH ST
SR522
20TH AVE NE
25TH AVE NE
12TH AVE NE
NE 75TH ST
NE 70TH ST
55TH AVE NE
NE 65TH ST
NE 65TH ST
NE RAVENNA BLVD
NE 55TH ST
NE 54TH ST
35TH AVE NE
40TH AVE NE
SAND POINT WAY NE
47TH AVE NE
NE 45TH ST
48TH AVE NE
NE 41ST ST
18 Outfall
North Union Bay CSO Area
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm
Parcels to Storm
ROW to Storm
North Union Bay CSO Area = 923.4 acres
Partially Separated Area (%) = 791.5 acres (86%)
Combined Area (%) = 131.9 acres (14%)
Est. Impervious to Combined (%) = 178.2 acres (19%)
N

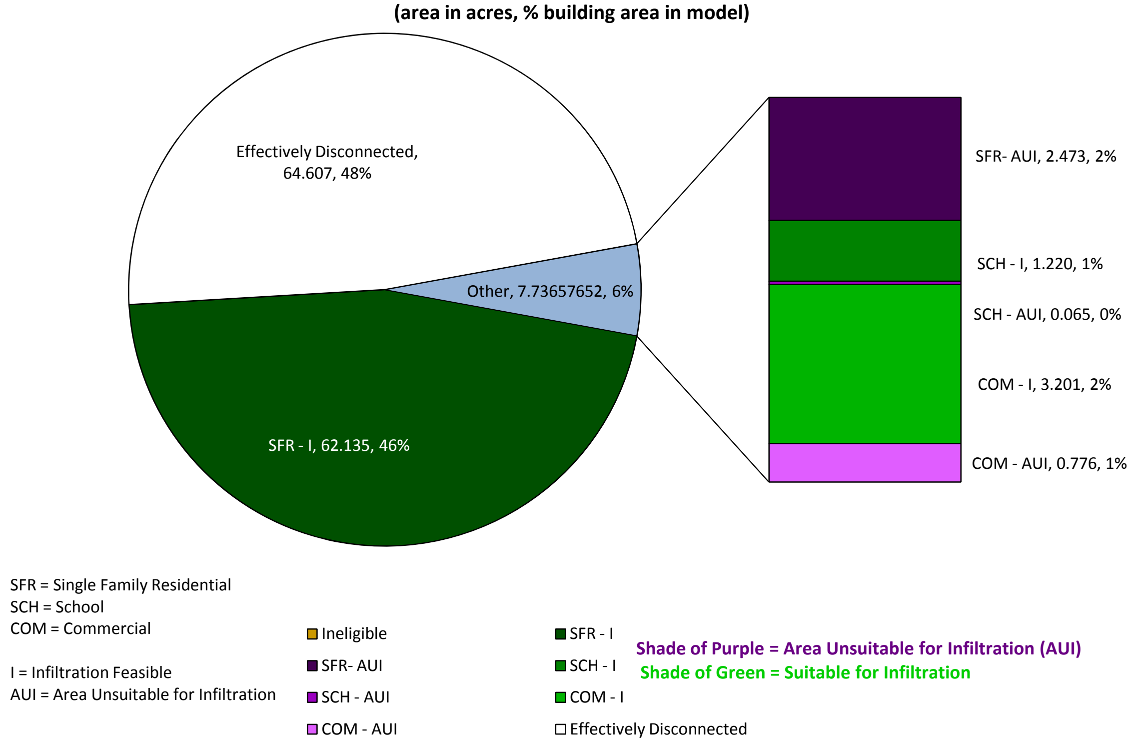
N. Union Bay
Total Delineated Basin Area
(area in acres, % of total basin area)

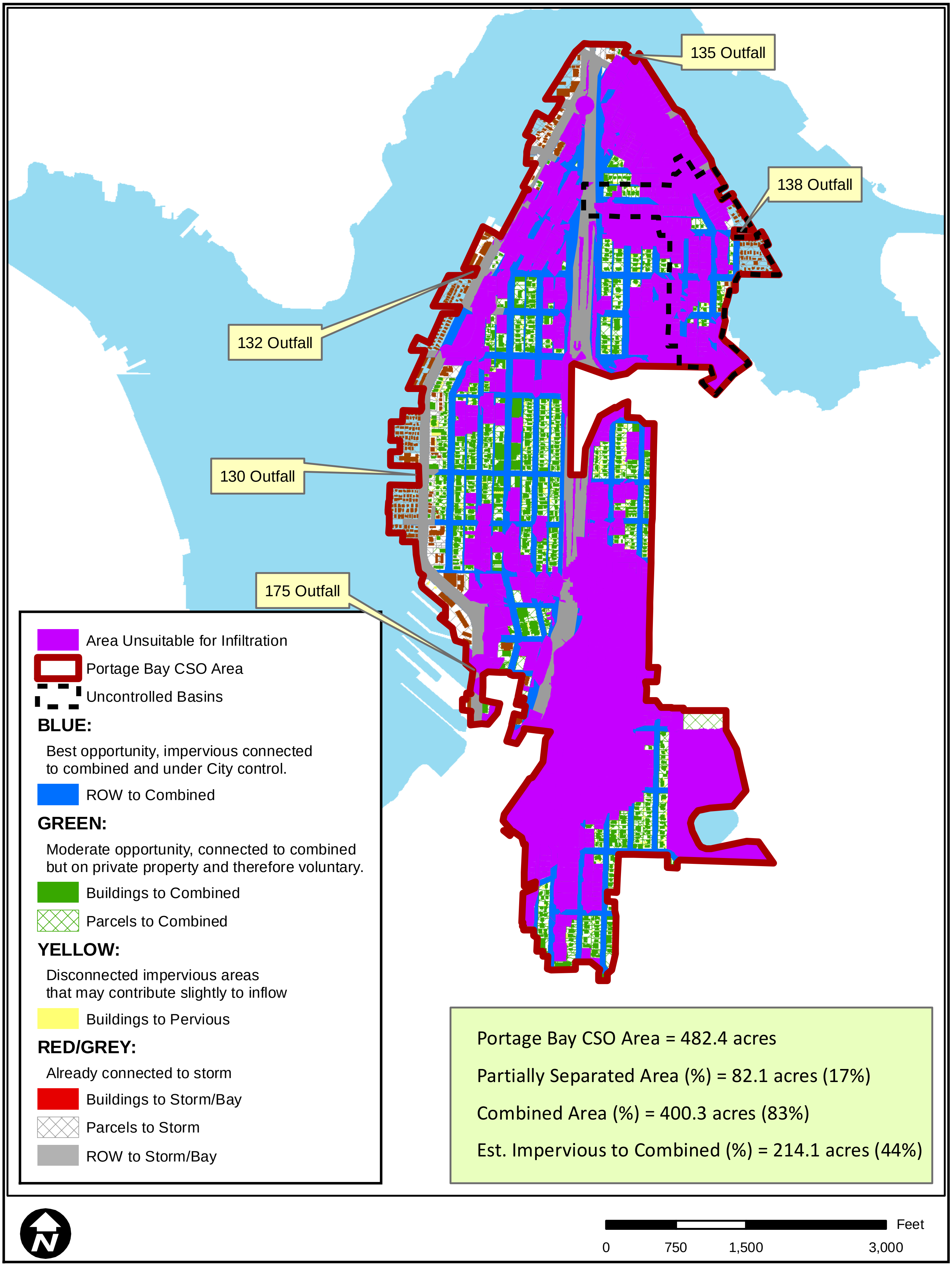


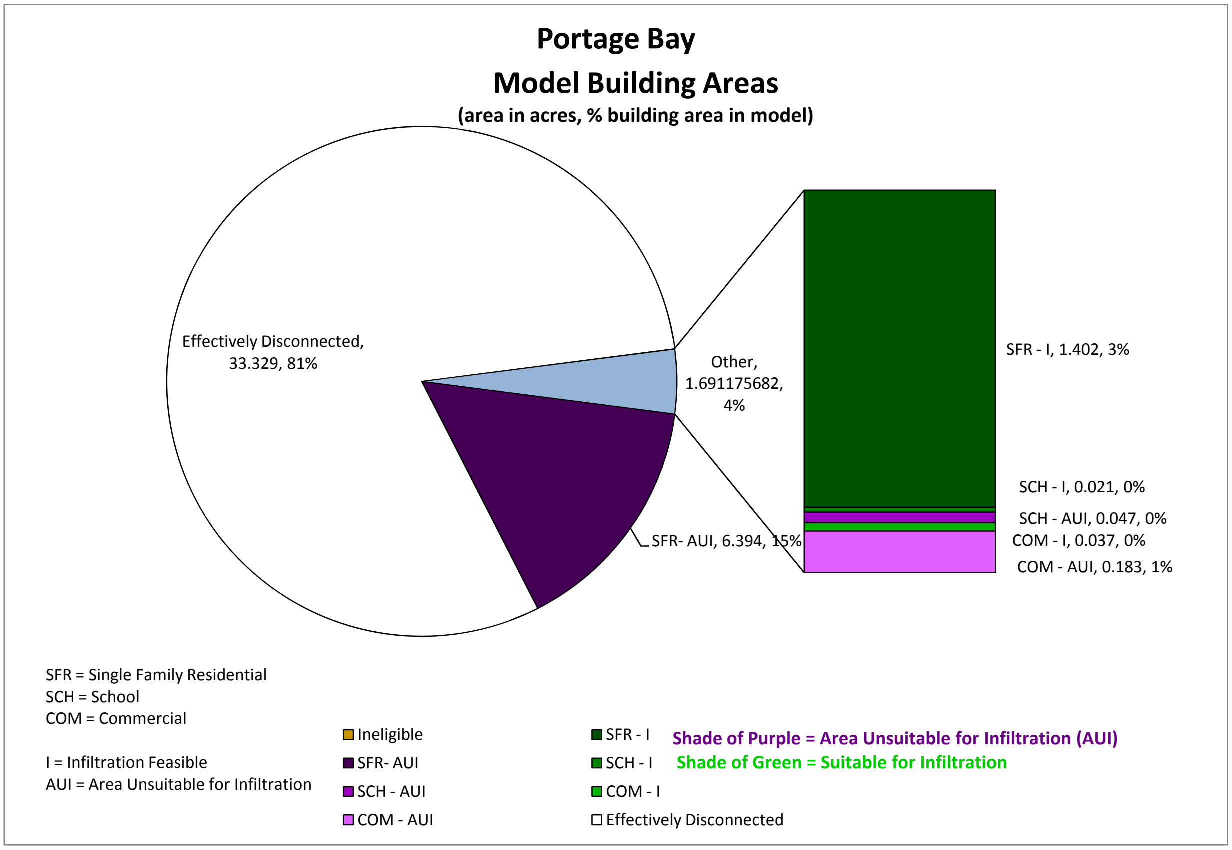
N. Union Bay
Model ROW Area
(area in acres, % of ROW area in model)



N. Union Bay
Model Building Areas
(area in acres, % building area in model)




135 Outfall
138 Outfall
132 Outfall
130 Outfall
175 Outfall
Area Unsuitable for Infiltration
Portage Bay CSO Area
Uncontrolled Basins
BLUE:
Best opportunity, impervious connected to combined and under City control.
ROW to Combined
GREEN:
Moderate opportunity, connected to combined but on private property and therefore voluntary.
Buildings to Combined
Parcels to Combined
YELLOW:
Disconnected impervious areas that may contribute slightly to inflow
Buildings to Pervious
RED/GREY:
Already connected to storm
Buildings to Storm/Bay
Parcels to Storm
ROW to Storm/Bay
Portage Bay CSO Area = 482.4 acres
Partially Separated Area (%) = 82.1 acres (17%)
Combined Area (%) = 400.3 acres (83%)
Est. Impervious to Combined (%) = 214.1 acres (44%)
N
Feet
0
750
1,500
3,000


Portage Bay
Model Building Areas
(area in acres, % building area in model)
Effectively Disconnected, 33.329, 81%
Other, 1.691175682, 4%
SFR- AUI, 6.394, 15%
SFR - I, 1.402, 3%
SCH - I, 0.021, 0%
SCH - AUI, 0.047, 0%
COM - I, 0.037, 0%
COM - AUI, 0.183, 1%
SFR = Single Family Residential
SCH = School
COM = Commercial
I = Infiltration Feasible
AUI = Area Unsuitable for Infiltration
Ineligible
SFR- AUI
SCH - AUI
COM - AUI
SFR - I
SCH - I
COM - I
Effectively Disconnected
Shade of Purple = Area Unsuitable for Infiltration (AUI)
Shade of Green = Suitable for Infiltration

Appendix D
Estimation of Technical Feasibility and Participation in RainWise

City of Seattle's GSI Estimation of Technical Feasiblity and Participation in Residential RainWise for CSO Mitigation

Field Analysis

To: Tracy Tackett, Seattle Public Utilities

From: April Mills, Seattle Public Utilities

Field Team: April Mills, SPU; Bob Spencer, SPU; Craig Chatburn, SPU; Gretchen Muller, SPU

9/16/2010

CSO Basin GSI Feasibility

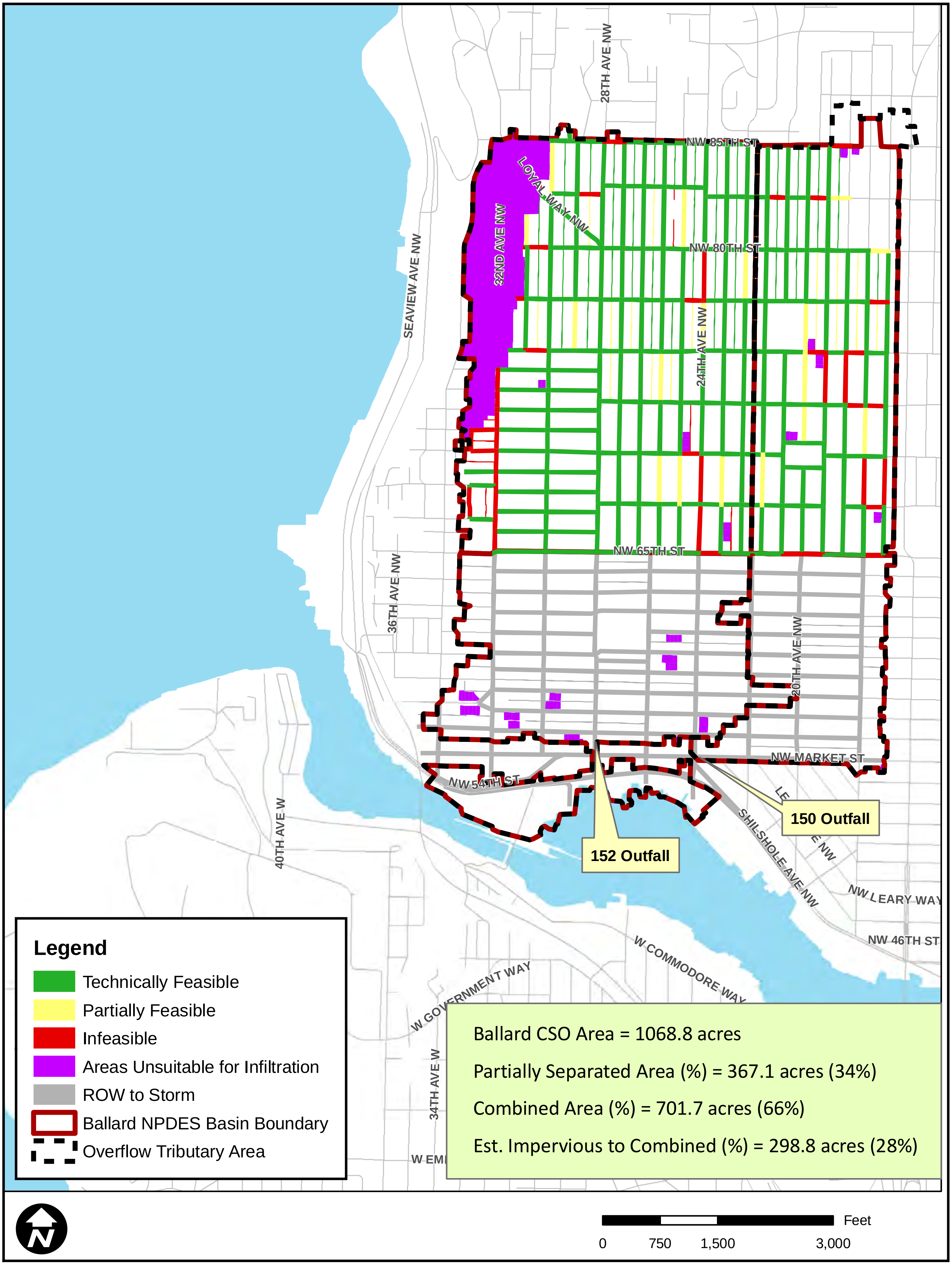
Field analysis by April Mills, Bob Spencer, Craig Chatburn, and Gretchen Muller

Dates: May-July 2010

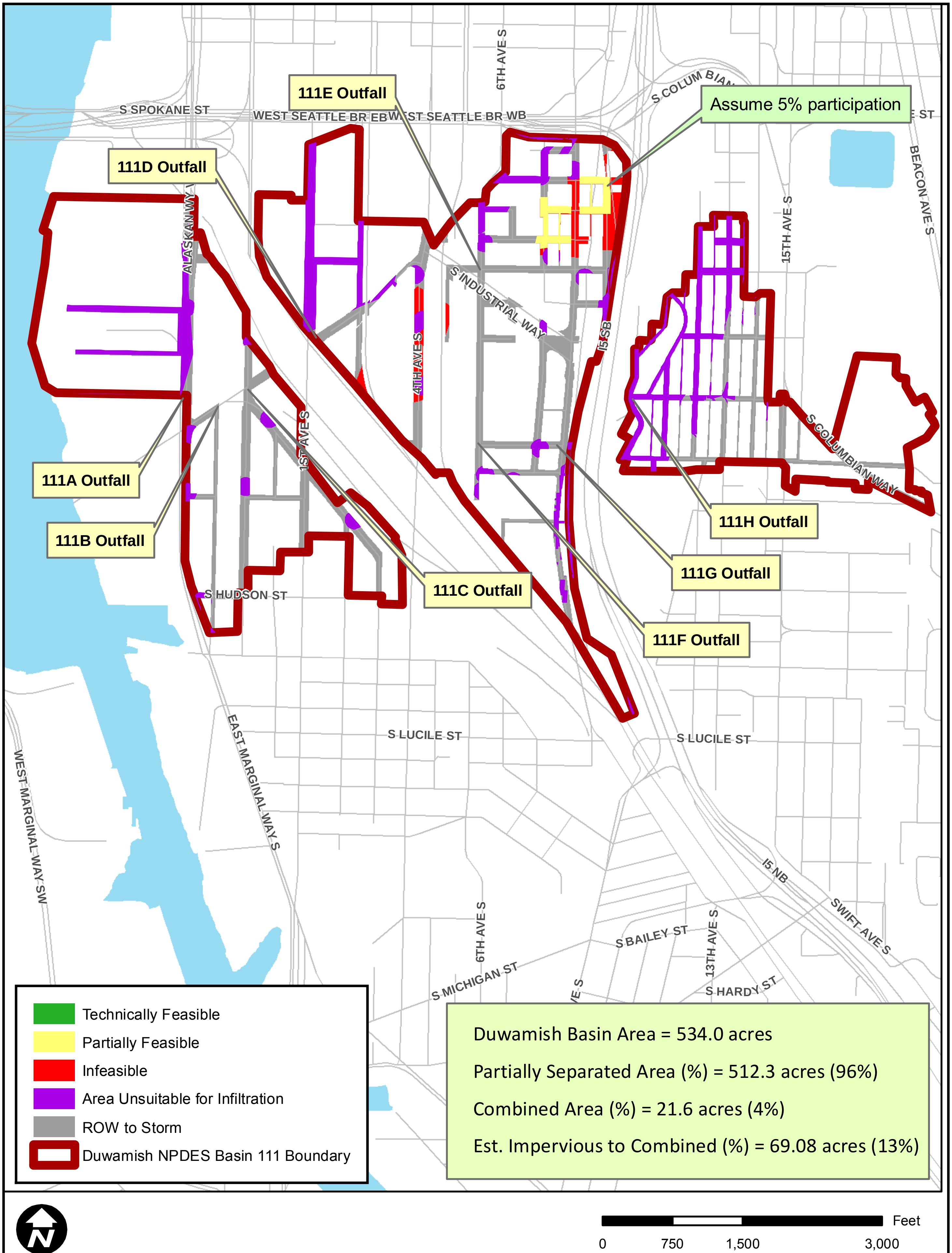
Site feasibility analysis for on-parcel estimates. Assumes percentages will be applied to sites *not* excluded by geotech analysis, except for cistern estimates (see note), and *not* in urban village area.

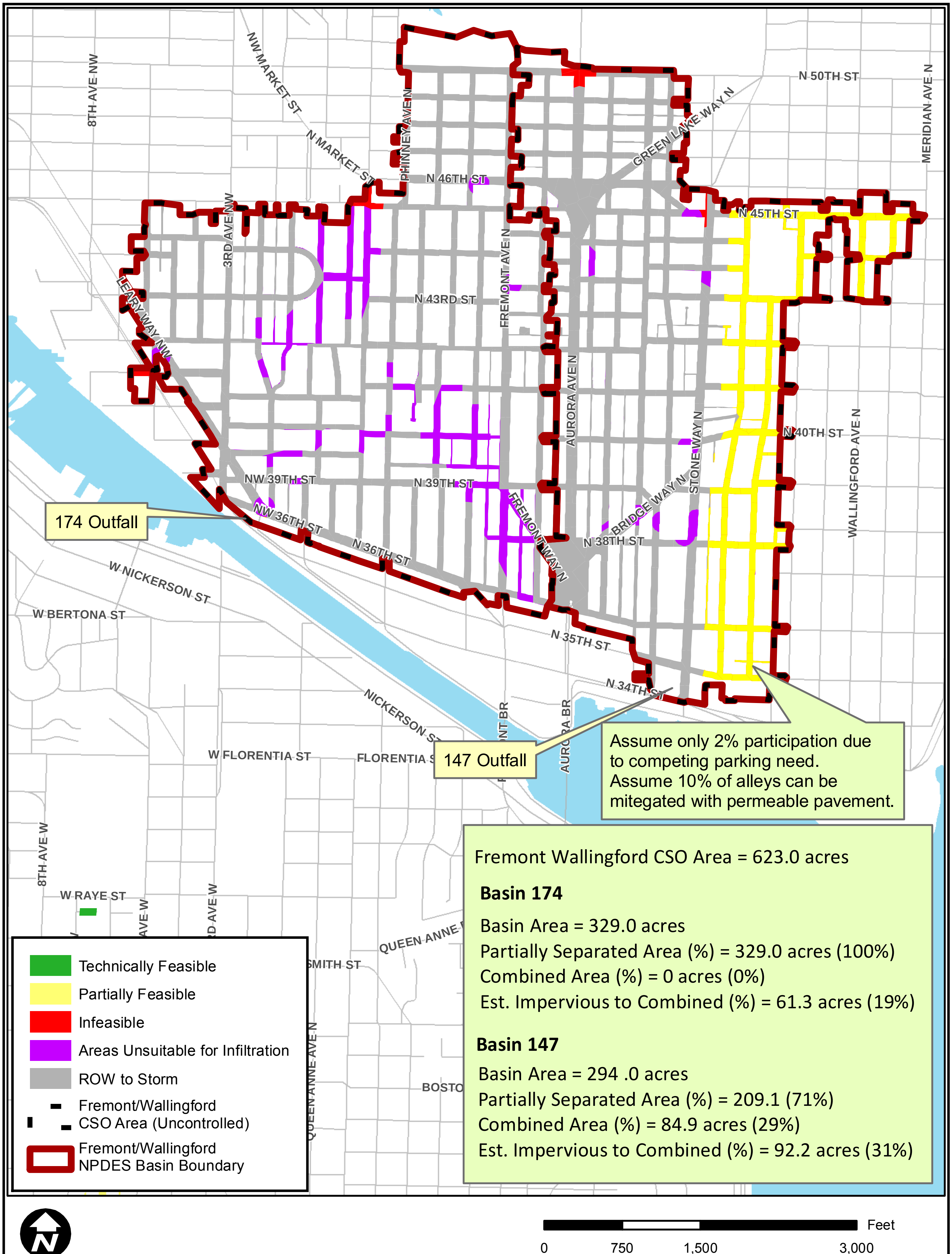
			HIGH						LOW						
			Technical Feasibility						Technical Feasibility						
			Site Feasibility						Site Feasibility						
			Fully Combined		Partially Separated				Fully Combined		Partially Separated				
Basin name	**NPDES number**	**Land Use**	**Raingardens**	**Cisterns**	**Disconnections Feasible**	**Cistern back to sewer**	**% Roof**	**Participation**	**Raingardens**	**Cisterns**	**Disconnections Feasible**	**Cistern back to sewer**	**% Roof**	**Participation**	**Notes**
		Commercial	10	15	5		20% of median	20	0	0	0		10% of median	5	
All Basins		Schools	50	50	50		40% of median	80	30	30	30		10% of median	30	
		SFR	---	---	---	90	50% of median					80	25% of median		
Montlake	140	SFR	20	48	---	90	50% of median	20	10	25	---	---	25% of median	5	Mostly traditional expensive landscapes. Park downhill.
Montlake	139	SFR	---	---	15	90	50% of median	20	---	---	8	80	25% of median	5	Good opportunity with parking lot/downspouts? at NMFS. Montlake Community Center - setback from liquifaction zone?
Montlake	20	SFR	10	20	35	90	50% of median	5	5	15	20	80	25% of median	1	In combined area, old majestic homes with mature expensive landscaping and small yards.
Leschi	26-36	SFR	0	0	0	90	50% of median	10	0	0	0	80	25% of median	2	
Fremont/ Wallingford	147	SFR	10	35	25	90	50% of median	35	5	5	5	80	25% of median	10	Lincoln Middle School
Fremont/ Wallingford	174	SFR	---	---	15	90	50% of median	35	---	---	8	80	25% of median	10	
North Union Bay	18 A/B	SFR	30	95	50	90	50% of median	30	5	90	35	80	25% of median	5	
Madison Park/ Union Bay	22	SFR	---	---	92	90	50% of median	15	---	---	83	80	25% of median	5	
Madison Park/ Union Bay	24	SFR	0	0	0	90	50% of median	15	0	0	0	80	25% of median	5	
Madison Park/ Union Bay	25	SFR	---	---	20	90	50% of median	15	---	---	10	80	25% of median	5	
Duwamish	111 H	SFR	---	---	28	90	50% of median	25	---	---	15	80	25% of median	10	
Interbay	68 A/B	SFR	27	36	33	90	50% of median	30	8	15	10	80	25% of median	15	
Portage Bay	138	SFR	21	22	---	90	50% of median	30	8	10	---	80	25% of median	10	

Appendix E
Estimation of Feasibility and Implementation of GSI within the Right-of-Way

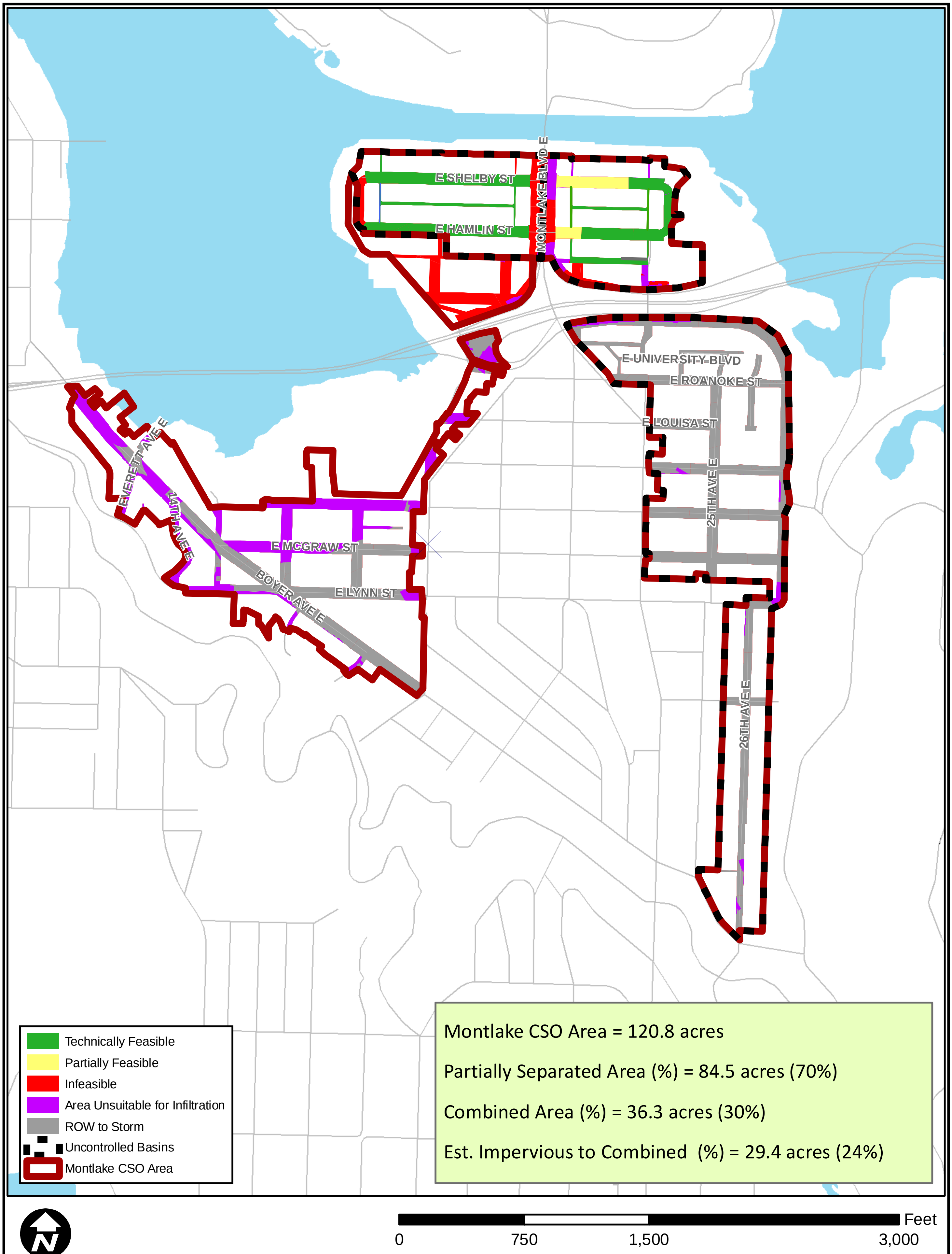


28TH AVE NW
NW 85TH ST
LOYAL WAY NW
32ND AVE NW
NW 80TH ST
SEAVIEW AVE NW
24TH AVE NW
NW 65TH ST
36TH AVE NW
20TH AVE NW
NW MARKET ST
NW 54TH ST
150 Outfall
152 Outfall
SHILSHOLE AVE NW
40TH AVE W
NW LEARY WAY
NW 46TH ST
W COMMODORE WAY
W GOVERNMENT WAY
34TH AVE W
Legend
Technically Feasible
Partially Feasible
Infeasible
Areas Unsuitable for Infiltration
ROW to Storm
Ballard NPDES Basin Boundary
Overflow Tributary Area
Ballard CSO Area = 1068.8 acres
Partially Separated Area (%) = 367.1 acres (34%)
Combined Area (%) = 701.7 acres (66%)
Est. Impervious to Combined (%) = 298.8 acres (28%)
Feet
0
750
1,500
3,000


111E Outfall
111D Outfall
Assume 5% participation
111A Outfall
111B Outfall
111C Outfall
111F Outfall
111G Outfall
111H Outfall
S SPOKANE ST
WEST SEATTLE BR EB
WEST SEATTLE BR WB
6TH AVE S
S COLUMBIAN WAY
BEACON AVE S
15TH AVE S
ALASKAN WY V
S INDUSTRIAL WAY
4TH AVE S
1ST AVE S
I5 SB
S HUDSON ST
S LUCILE ST
EAST MARGINAL WAY S
WEST MARGINAL WAY SW
I5 NB
SWIFT AVE S
S BAILEY ST
13TH AVE S
S HARDY ST
S MICHIGAN ST
Technically Feasible
Partially Feasible
Infeasible
Area Unsuitable for Infiltration
ROW to Storm
Duwamish NPDES Basin 111 Boundary
Duwamish Basin Area = 534.0 acres
Partially Separated Area (%) = 512.3 acres (96%)
Combined Area (%) = 21.6 acres (4%)
Est. Impervious to Combined (%) = 69.08 acres (13%)
N
Feet
0
750
1,500
3,000
4/13/2011

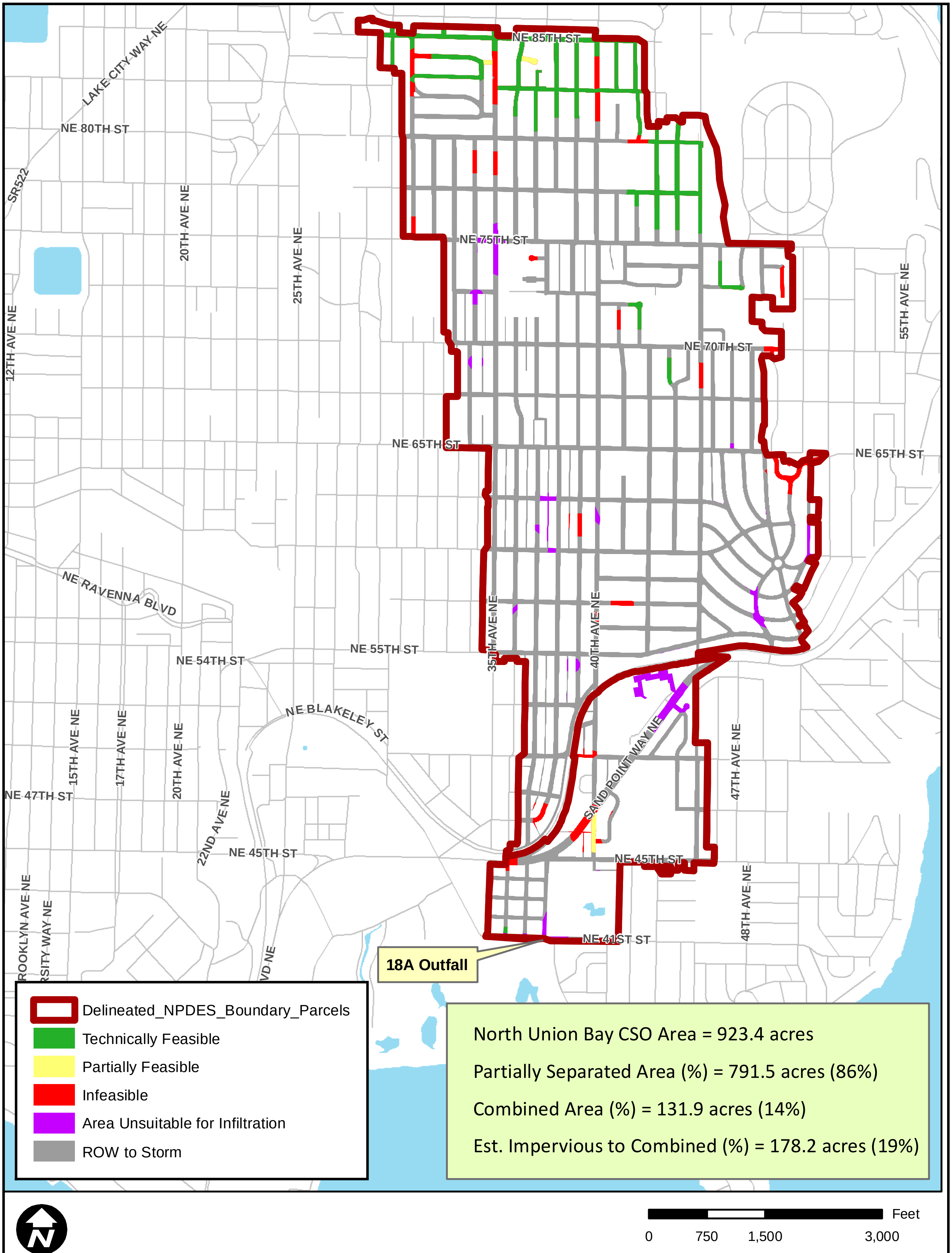

174 Outfall
147 Outfall
Assume only 2% participation due to competing parking need. Assume 10% of alleys can be mitegated with permeable pavement.
Fremont Wallingford CSO Area = 623.0 acres
Basin 174
Basin Area = 329.0 acres
Partially Separated Area (%) = 329.0 acres (100%)
Combined Area (%) = 0 acres (0%)
Est. Impervious to Combined (%) = 61.3 acres (19%)
Basin 147
Basin Area = 294 .0 acres
Partially Separated Area (%) = 209.1 (71%)
Combined Area (%) = 84.9 acres (29%)
Est. Impervious to Combined (%) = 92.2 acres (31%)
Technically Feasible
Partially Feasible
Infeasible
Areas Unsuitable for Infiltration
ROW to Storm
Fremont/Wallingford CSO Area (Uncontrolled)
Fremont/Wallingford NPDES Basin Boundary
N 50TH ST
N 46TH ST
N 45TH ST
N 43RD ST
N 40TH ST
NW 39TH ST
N 39TH ST
N 38TH ST
NW 36TH ST
N 36TH ST
N 35TH ST
N 34TH ST
W NICKERSON ST
W BERTONA ST
W FLORENTIA ST
W RAYE ST
8TH AVE NW
3RD AVE NW
NW MARKET ST
N MARKET ST
PHINNEY AVE N
FREMONT AVE N
AURORA AVE N
STONE WAY N
GREEN LAKE WAY N
BRIDGE WAY N
FREMONT WAY N
LEARY WAY NW
WALLINGFORD AVE N
MERIDIAN AVE N
8TH AVE W
QUEEN ANNE AVE N
Feet
0
750
1,500
3,000

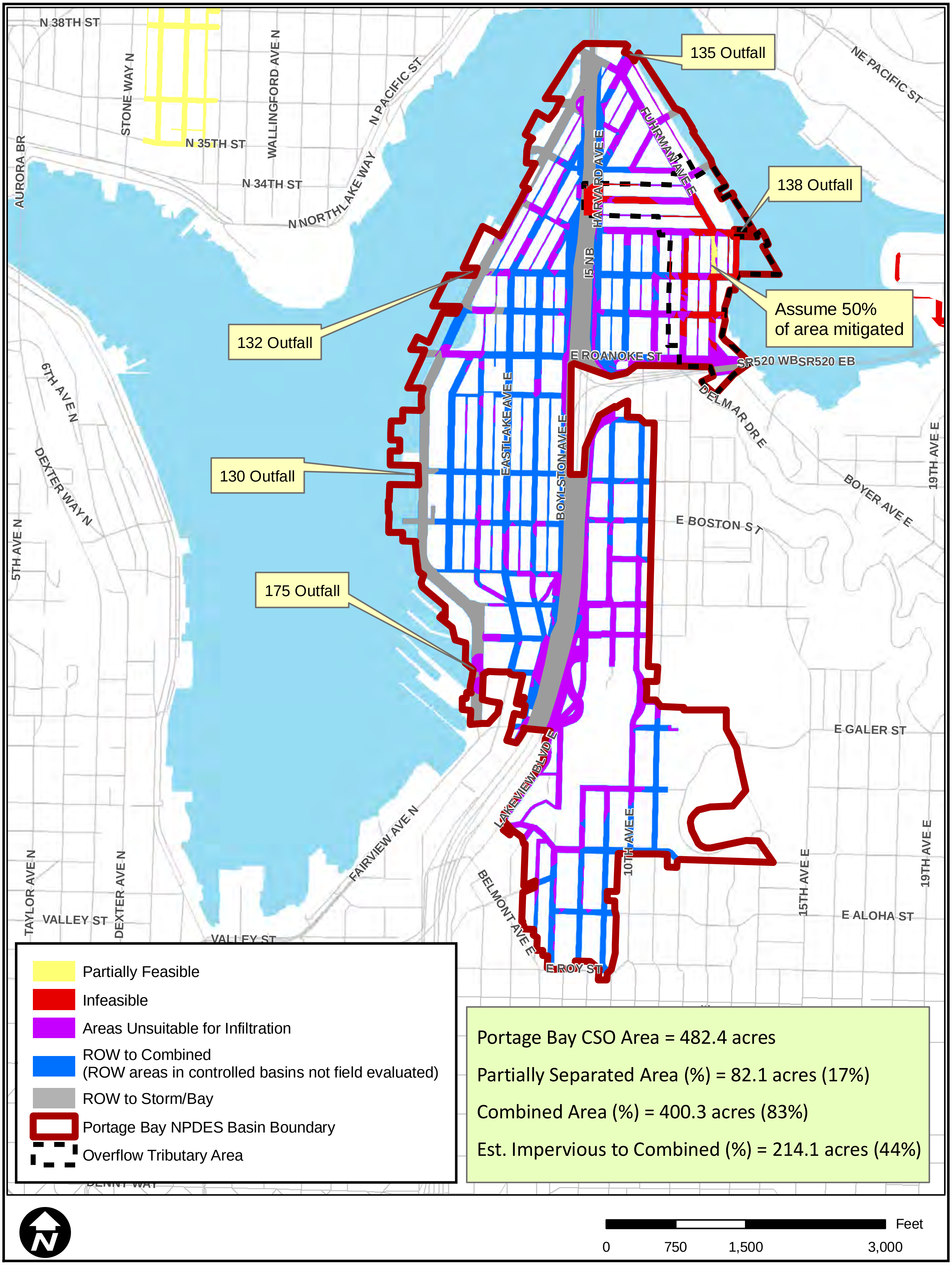
4/13/2011



E SHELBY ST
E HAMLIN ST
MONTLAKE BLVD E
E UNIVERSITY BLVD
E ROANOKE ST
E LOUISA ST
25TH AVE E
26TH AVE E
EVERETT AVE E
14TH AVE E
E MCGRAW ST
BOYER AVE E
E LYNN ST
Technically Feasible
Partially Feasible
Infeasible
Area Unsuitable for Infiltration
ROW to Storm
Uncontrolled Basins
Montlake CSO Area
Montlake CSO Area = 120.8 acres
Partially Separated Area (%) = 84.5 acres (70%)
Combined Area (%) = 36.3 acres (30%)
Est. Impervious to Combined (%) = 29.4 acres (24%)
Feet
0
750
1,500
3,000
N

4/13/2011


NE 85TH ST
LAKE CITY WAY NE
NE 80TH ST
SR522
20TH AVE NE
25TH AVE NE
12TH AVE NE
NE 75TH ST
NE 70TH ST
55TH AVE NE
NE 65TH ST
NE 65TH ST
NE RAVENNA BLVD
NE 54TH ST
NE 55TH ST
35TH AVE NE
40TH AVE NE
NE BLAKELEY ST
15TH AVE NE
17TH AVE NE
20TH AVE NE
22ND AVE NE
NE 47TH ST
SAND POINT WAY NE
47TH AVE NE
NE 45TH ST
NE 45TH ST
48TH AVE NE
BROOKLYN AVE NE
UNIVERSITY WAY NE
NE 41ST ST
18A Outfall
Delineated_NPDES_Boundary_Parcels
Technically Feasible
Partially Feasible
Infeasible
Area Unsuitable for Infiltration
ROW to Storm
North Union Bay CSO Area = 923.4 acres
Partially Separated Area (%) = 791.5 acres (86%)
Combined Area (%) = 131.9 acres (14%)
Est. Impervious to Combined (%) = 178.2 acres (19%)
N
Feet
0
750
1,500
3,000
4/13/2011


135 Outfall
138 Outfall
132 Outfall
130 Outfall
175 Outfall
Assume 50% of area mitigated
N 38TH ST
N 35TH ST
N 34TH ST
STONE WAY N
WALLINGFORD AVE N
N PACIFIC ST
N NORTHLAKE WAY
NE PACIFIC ST
AURORA BR
FUHRMAN AVE E
HARVARD AVE E
I5 NB
E ROANOKE ST
SR520 WB
SR520 EB
DELMAR DR E
6TH AVE N
DEXTER WAY N
5TH AVE N
EASTLAKE AVE E
BOYLSTON AVE E
E BOSTON ST
BOYER AVE E
19TH AVE E
E GALER ST
LAKEVIEW BLVD E
FAIRVIEW AVE N
BELMONT AVE E
10TH AVE E
15TH AVE E
E ALOHA ST
TAYLOR AVE N
VALLEY ST
DEXTER AVE N
E ROY ST
DENNY WAY
Partially Feasible
Infeasible
Areas Unsuitable for Infiltration
ROW to Combined
(ROW areas in controlled basins not field evaluated)
ROW to Storm/Bay
Portage Bay NPDES Basin Boundary
Overflow Tributary Area
Portage Bay CSO Area = 482.4 acres
Partially Separated Area (%) = 82.1 acres (17%)
Combined Area (%) = 400.3 acres (83%)
Est. Impervious to Combined (%) = 214.1 acres (44%)
Feet
0
750
1,500
3,000

Appendix F
Updated Calculation of Potential Areas Managed by GSI

Appendix F: Calculation of Potential Areas Managed by GSI

Introduction

This appendix describes in detail the methods used to calculate potential areas managed by GSI, which are in turn used to develop estimates of CSO volume reduction due to GSI. Potential areas managed by GSI were calculated using information from the delineation of combined sewer connectivity (Appendix B), evaluation of areas unsuitable for infiltration (Appendix C), estimation of technical feasibility and participation in RainWise (Appendix D) and estimation of feasibility and implementation of GSI within the right-of-way (Appendix E). These calculations were made at a level consistent with the model subcatchments in order that GSI implementation may be most easily simulated once calibrated models are available for all basins. Similarly, these calculations were performed in Excel workbooks unique to individual CSO Areas (i.e. Montlake, Leschi, Ballard etc.), consistent with CSO model construction. Within each CSO Area, areas managed by GSI are summarized by NPDES Basin. These areas, summarized by basin, were used within the flow summary worksheet (GSI_FlowAnalysisSummary.xlsx) to develop estimates of CSO volume reduction.

Methods

A series of CSO Area workbooks and one Flow Analysis Summary workbook were used in conjunction with available GIS and model data to calculate areas managed by GSI. CSO volume reduction due to GSI for the Ballard CSO Area was developed separately, as part of *Business Case – 2 for Ballard Green Stormwater Infrastructure for CSO Reduction, Presented to AMC on 05/05/2010.*

CSO Area Workbook

One workbook was created for each CSO Area, using the naming convention [Area Name]_AreasSummary.xlsx (such as Montlake_AreasSummary.xlsx). Each of the CSO Area workbooks has a series of interconnected sheets, described in Table F-1.

TABLE F-1
CSO Area Workbook Sheet Descriptions

Sheet Name	Description	Notes
Summary	Summarizes areas managed by GSI by NPDES Basin	
PivotTables	Summarizes GIS information by subcatchment ID; summarizes “Bldg_Subcatchments” sheet by NPDES Basin	
Bldg_Subcatchments	Calculates areas managed by GSI by subcatchment, based on information from GIS data pivot tables and participation levels.	

TABLE F-1
CSO Area Workbook Sheet Descriptions

Sheet Name	Description	Notes
ParticipationLevels	Described in Appendix D	
(Un)CalibratedModelSubcatchments	Subcatchments information imported from PCSWMM model for building type subcatchments only.	May be uncalibrated, depending on information available at the time of analysis.
Building_Catchments	Data exported from the building GIS shapefile. Includes indication of subcatchment routing, combined sewer connectivity (Appendix B) and areas unsuitable for infiltration (Appendix C). In addition, each building as identified as being in a partially separated or combined building based on proximity to combined right-of-way areas.	
ROW_Areas	Data exported from the right-of-way shapefile. Includes indication of combined sewer connectivity,	In some CSO Areas, ROW feasibility and implementation was provided in a tabular format. In these CSO Areas, this sheet was not created.
Source = GIS		
Source = Other external input such as model or results from external analysis		
Internal Calculations		

The following steps were used to develop each CSO Area workbook.

Step 1: Summarize infiltration feasibility and system type by model subcatchment

1. GIS Steps
   a. **Infiltration Feasibility:** Identify all buildings that are located in parcels that are have more than 5% of the area unsuitable for infiltration. In GIS, add "AUI_v4" field to buildings. *AUI_v4* = "Yes" if building intersects with AUI_v4 parcel; otherwise *AUI_v4* = "".

   b. **System Type:** Identify all Buildings that are in Fully Combined area. *PtSepArea* = Combined; otherwise *PtSepArea* = Partial.

   c. **Urban Village Exclusion**: Identify all Buildings that are in Urban Village areas. Add field *Eligibility*. Intersect buildings with "cenvill.shp" (do not include "Manufacturing Industrial"), and set *Elgibility* = "UrbanVillage".

2. Spreadsheet Steps
   a. **Add Column to Calculate Areas Suitable for Infiltration:** Load GIS Buildings data to Building_Catchments sheet. Add *Area_Feasible* column. If unsuitable for infiltration *Area_Feasible* = 0; otherwise *Area_Feasible* = *AREA [building area]*.

b. **Summarize Totals:** Summarize areas by subcatchment on PivotTables sheet. PivotTable group by Subcatchment ID (field varies by basin and modeler). Filter only buildings going to combined (filter out buildings to storm, buildings to pervious; field varies by basin and modeler).

   i. Summarize total area of buildings in subcatchment (PivotTable 1)

   ii. Summarize total area feasible for infiltration in subcatchment. (PivotTable 1)

   iii. Summarize total area unfeasible for infiltration in subcatchment. (PivotTable 2; copy of PivotTable 1 filtered to AUI_v4 = Yes only)

   Create three sets of pivot tables filtering only: single family residence, commercial, and schools. Based on the field "PU_CAT_DESC", the following three zoning groupings were assumed:

   1. Single family residence: *Single Family*
   2. Commercial: *Office, Public Facility, Recreation/Entertainment, Retail/Service, Church, Government Service, Mixed Use*
   3. Schools: *School/Daycare, Park/Playground*

   "PU_CAT_DESC" categories not included in the area analysis are: *Industrial, Multi-Family, Parking, Terminal/Warehouse, Utility, Other Housing*

Step 2: Calculate areas to RainWise GSI practices (rain garden, to be disconnected, to cisterns, etc.) by subcatchment

a. Insert entire list of model building subcatchments (from model) in to Bldg_Subcatchments sheet. Add column for NPDES Basin and Area Type (Combined vs. Partially Separated). Methods to determine NPDES Basin and Area Type vary:

   i. NPDES Basin methods

      1. If CSO area has only one NPDES Basin, all subcatchments are assigned to that Basin
      2. If "Aquifer Name" appears to be linked to the flow monitoring ID, sort by this field and identify NPDES Basin by flow monitoring ID with the help of the Meter Schematic Diagram from the Data Mentoring Report.
      3. If GIS NPDES Basin delineation is available, create *NPDES_Basin* field in the BLDG shapefile, populate based on GIS NPDES Basin delineation, and summarize by subcatchment in the PivotTables

   ii. Area Type method

      1. If only a few subcatchments are in combined areas, identify these manually and identify as such in Area Type field.

2. If many subcatchments are in combined areas, create a pivot table in the PivotTables sheet summarizing total subcatchment area and total combined subcatchment area. If more than 50% of the subcatchment area is combined (based on PtSepArea field), assign as combined in Bldg_Subcatchments sheet.

b. In Bldg_Subcatchments sheet, calculate the fields listed in Table F-2, by subcatchment

TABLE F-2
Column Descriptions for CSO Area Workbook, Bldg_Subcatchments Sheet

Column Letter[1]	**Field**	**Source / Explanation**
A	Subcatchment ID	Copied from Modeler's "subcatchment's list" or copied from subcatchments table within model
B	NPDES Basin	Varies - developed from GIS (source on *Building_Catchments* sheet), developed from model (often from Aquifer field, linked to basin)
C	Area Type (Combined or Partially Separated)	From GIS- if few combined areas, manually found subcatchments that are combined. If many combined areas, used "PtSepArea" from GIS Bldg. shapefile (field created for GSI feasibility), developed PivotTable to determine all subcatchments where >50% of Bldgs. are considered Combined
D	Total Bldg. Area	From model
E	% Connected (% Impervious)	From model- depending on basin, may not be calibrated. See Status spreadsheet for uncalibrated models
F	Effectively Connected Building Area	=E/D
G	Effectively Connected, Combined Feasible SFR Bldg. Area - (non AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible single family residence bldg. area from Pivot Tables of GIS data) * E
H	Effectively Connected, Combined Infeasible SFR Bldg. Area - (AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible single family residence bldg. area from Pivot Tables of GIS data) * E
I	Effectively Connected, Combined Feasible School Bldg. Area - (non AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible school bldg. area from Pivot Tables of GIS data) * E
J	Effectively Connected, Combined Infeasible School Bldg. Area - (AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible school bldg. area from Pivot Tables of GIS data) * E
K	Effectively Connected, Combined Feasible Commercial Bldg. Area - (non AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible commercial bldg. area from Pivot Tables of GIS data) * E
L	Effectively Connected, Combined Infeasible Commercial Bldg. Area - (AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible commercial bldg. area from Pivot Tables of GIS data) * E

TABLE F-2
Column Descriptions for CSO Area Workbook, Bldg_Subcatchments Sheet

Column Letter[1]	Field	Source / Explanation
M	Areas to RG (high)	IF Combined = [(G * Participation Level Col. D) + (I * High School RG Participation Level) + (K * High Commercial RG Participation Level) * I * J]; otherwise 0
N	Areas to RG (low)	Same as above, using low participation levels
O	Area to be Disconnected (high)	IF Partially Separated = [(G * Participation Level Col. F) + (I * High School Disconnections Participation Level) + (K * High Commercial Disconnections Participation Level) * I * J]; otherwise 0
P	Areas to be Disconnected (low)	Same as above, using low participation levels
Q	Areas to Cisterns (high)	IF Combined = [{(G * Participation Level Col. (1-D) *E) +(I * (1 - High School RG Participation Level) * High School Cisterns Participation Level) + (K * (1 - High Commercial RG Participation Level) * High Commercial Cisterns Level)}* I * J]; otherwise 0
R	Areas to Cisterns (low)	Same as above, using low participation levels
S	Areas to Cisterns back to Sewer (high)	IF Combined = (H+[G*(Participation Level Col. (1-D) *(1-E)]*G*I*J) IF Partially Separated = (H+[G * (Participation Level Col. (1-F)] *G* I * J)
T	Areas to Cisterns back to Sewer (low)	Same as above, using low participation levels
U	Total Area to Cisterns (high)	= Q+ S
V	Total Area to Cisterns (low)	Same as above, using low participation levels

[1] Column letters based on Fremont-Wallingford CSO Area, other areas are similar but may include more columns

Step 3. Summarize Total Area Mitigated using GSI through the RainWise Program by Basin

a. Summarize Building Areas for both High and Low participation levels and for all three zone types in PivotTables sheet: Total Building Area, Effectively Connected Building Area, Areas to RG, Areas to be Disconnected, Areas to Cisterns

Step 4. Identify and summarize impervious ROW areas feasible for infiltration and GSI

1. Methods vary by basin, depending on information available

   a. Ballard: Calculate alley_gsi and row_gsi (roads) in GIS file Ballard_ROW_combined.shp based on alley_gsi.shp and row_gsi.shp, provided by SPU (sent to Tyler Jantzen/CH2M HILL on 8/17 by Justin Twenter/B&C). ID combined areas and NPDES Basin of ROW in GIS. Import GIS data to row_gsi sheet in Excel. Summarize: total combined ROW impervious area; combined ROW impervious area to rain garden, and combined ROW impervious area for Alley GSI, by NPDES Basin in PivotTable sheet.

b. Duwamish: ID ROW areas for GSI in GIS based on SPU field markups sent 8/5. ID NPDES Basins. Import GIS data to ROW_Areas sheet. Summarize impervious areas by NPDES basin on PivotTables sheet. NOTE- all the identified ROW areas for NDS are in the King County basin (d/s of overflows and tributary to KC Pump Station)

c. Fremont-Wallingford: ID ROW areas for GSI in GIS based on SPU field markups sent 8/5. All area in Basin 147. Import GIS data to ROW_Areas sheet. Summarize impervious areas for Basin 147 on PivotTables sheet.

d. Interbay: Delineate ROW areas for GSI in GIS based on SPU field markups sent 8/5 (need to distinguish between alleys and roads). Distinguish in GIS attributes ROW subcatchments that are in areas 1, 2, 3, 4, 5, PP1 and PP2. Import GIS data to ROW_Areas sheet; all in Basin 68A. Summarize impervious areas for Basin 68A on PivotTables sheet. NOTE: Basins 68A and 68B are reversed in printed maps- see email from Ben Marre on 6/9/09, via Santtu Winter/CH2M HILL on 8/16/10.

e. Leschi: no ROW data; assume not feasible

f. Madison Park / Union Bay: no ROW data; assume not feasible

g. Montlake: Use areas developed in memo "Green Stormwater Infrastructure feasibility for NPDES Basin 140, 20, & 139" from Craig Chatburn to Tracy Tackett, dated June 29, 2010.

h. North Union Bay: Use areas developed in "NUB Street Feasibility.xlsx" workbook, sent via email on June 10, 2010.

i. Portage Bay: Delineate ROW areas for GSI in GIS based on SPU field markups sent 8/5. Because only one area, reported directly in Summary sheet.

Results

Most Practical of potential areas managed by GSI, summarized by CSO Area and NPDES Basin, are presented in Tables F-1 and F-2. Potential areas managed by GSI assuming low participation and maximum possible (e.g. full implementation of GSI in right-of-way where feasible and full participation in RainWise) are presented in Tables F-3 and F-4, respectively.

TABLE F-1
Potential Areas Managed by GSI, Summarized by CSO Area

CSO Area	Existing CSO Facility	2010 Planned Facility	Basin/ Overflow Structure	LTCP Control Volume (MG)	Bldg % Connectivity	Most Practical Residential Participation	Total Building Area (acres)	Single Family Residence					
								Combined SFR Area, Suitable for Infil. (acres)	Combined SFR Area, Unsuitable for Infil. (acres)	Pt. Sep SFR Area, Suitable for Infiltration (acres)	Pt. Sep SFR Area, Unsuitable for Infiltration (acres)	# of Buildings in Combined Area	# of Buildings in Pt. Sep Area
Fre/Wall	N/A	Off-Line Storage	174	1.06	46%	35%	61.094	0.000	0.000	9.800	3.037	0	946
Fre/Wall	N/A	Off-Line Storage	147	2.15	39%	35%	62.093	0.398	0.048	1.894	0.035	128	143
Mad Park	N/A		22	<0.01	87%	15%	1.138	0.000	0.000	0.988	0.000	0	10
Mad Park	N/A		24	0.11	64%	15%	5.922	0.422	1.182	0.456	0.000	29	7
Mad Park	N/A		25	0.01	86%	15%	24.723	3.691	0.158	9.973	0.389	120	317
Leschi	N/A		26	0	100%	10%	2.112	0.000	0.000	0.119	2.093	0	34
Leschi	N/A		27	0	93%	10%	1.182	0.000	0.000	0.510	0.360	0	18
Leschi	N/A	In-Line Storage	28	<0.01	66%	10%	2.837	0.000	0.000	0.000	1.691	0	73
Leschi	In-line Storage	In-Line Storage	29	0.02	44%	10%	2.854	0.000	0.099	0.000	1.216	3	69
Leschi	N/A	Off-Line Storage	31	0.31	100%	10%	0.846	0.000	0.122	0.000	0.401	3	15
Leschi	In-line Storage	Off-Line Storage	32	0.08	70%	10%	2.602	0.000	0.000	0.000	1.877	0	78
Leschi	Off-line Storage		33	0	74%	10%	8.550	0.000	0.000	0.000	6.582	0	243
Leschi	In-line Storage	GSI Only	30	0	56%	10%	5.430	0.000	0.000	0.000	3.046	0	138
Leschi	Off-line Storage	GSI Only	34	0.03	59%	10%	1.905	0.000	0.039	0.124	0.584	2	26
Leschi	Off-line Storage	GSI Only	35	<0.01	41%	10%	5.557	0.000	0.000	0.045	2.318	0	144
Leschi	In-line Storage	In-Line Storage	36	0.03	98%	10%	1.982	0.000	0.000	0.000	2.181	0	45
Montlake	Off-line Storage	GSI Only	20	0.16	55%	5%	11.942	0.541	0.501	4.395	0.580	49	274
Montlake	Off-line Storage	GSI Only	140	0.05	72%	20%	3.857	1.206	0.483	0.000	0.055	65	2
Montlake	N/A		139	0.01	84%	20%	5.848	0.000	0.000	1.456	2.051	0	124
N. Union Bay		In-Line Storage	18A	0.26	69%	30%	12.291	0.107	0.168	2.751	0.111	12	119
N. Union Bay		In-Line Storage	18B	1.37	53%	30%	128.737	8.162	0.060	51.115	2.135	541	2857
Ballard		In-Line Storage	150/151	0.62	51%	35%	54.390	16.243	0.150	3.539	0.000	1387	183
Ballard		Off-Line Storage	152	5.38	37%	35%	102.650	14.889	2.840	11.816	0.631	2587	583
Duwamish	In-line Storage	Off-Line Storage	111H	0.01	84%	25%	14.580	0.000	0.000	3.819	5.773	0	347
Portage Bay	KC CSO		130		25%	30%	6.833	0.374	0.702	0.000	0.000	118	0
Portage Bay	KC CSO		132		43%	30%	27.238	0.830	2.592	0.000	0.000	168	0
Portage Bay	KC CSO		135		55%	30%	10.582	0.000	0.063	0.000	0.000	2	0
Portage Bay	Off-line Storage	In-Line Storage	138	0.11	48%	30%	8.407	0.176	2.638	0.000	0.000	149	0
Portage Bay	KC CSO		175		49%	30%	6.593	0.022	0.399	0.000	0.000	26	0
Delridge	Off-line Storage		099	0.17	99%	30%	15.530	1.015	0.295	2.479	3.241	41	205
Delridge	Off-line Storage	Retrofit	168	2.00	53%	30%	37.510	3.564	0.089	11.236	3.736	301	778
Delridge	Off-line Storage	Retrofit	169	1.19	13%	30%	30.400	1.681	0.316	0.575	0.017	497	148

CSO Area	Basin/ Overflow Structure	Schools						Commercial						
		Combined School Area, Suitable for Infiltration (acres)	Combined School Area, Unsuitable for Infiltration (acres)	Pt. Sep School Area, Suitable for Infiltration (acres)	Pt. Sep School Area, Unsuitable for Infiltration (acres)	# of Buildings in Combined Area	# of Buildings in Pt. Sep Area	Combined Commercial Area, Suitable for Infiltration (acres)	Combined Commercial Area, Unsuitable for Infiltration (acres)	Pt. Sep Commercial Area, Suitable for Infiltration (acres)	Pt. Sep Commercial Area, Unsuitable for Infiltration (acres)	# of Buildings in Combined Area	# of Buildings in Pt. Sep Area	% Unsuitable for Infiltration or Ineligible
Fre/Wall	174	0.000	0.000	0.258	0.000	0	2	0.000	0.000	1.411	0.098	0	46	60%
Fre/Wall	147	0.000	0.000	0.013	0.000	0	1	0.000	0.000	0.615	0.015	0	24	88%
Mad Park	22	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	0%
Mad Park	24	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.901	0	3	78%
Mad Park	25	0.000	0.000	0.000	0.000	0	0	0.000	0.000	1.169	0.054	0	20	30%
Leschi	26	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	96%
Leschi	27	0.000	0.000	0.000	0.030	0	1	0.000	0.000	0.000	0.000	0	0	55%
Leschi	28	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	100%
Leschi	29	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	100%
Leschi	31	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	100%
Leschi	32	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	100%
Leschi	33	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	100%
Leschi	30	0.000	0.000	0.000	0.007	0	2	0.000	0.000	0.000	0.020	0	0	100%
Leschi	34	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	89%
Leschi	35	0.000	0.000	0.000	0.009	0	1	0.000	0.000	0.000	0.000	0	0	98%
Leschi	36	0.000	0.000	0.000	0.000	0	1	0.000	0.000	0.000	0.000	0	0	100%
Montlake	20	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.067	0.000	0	1	24%
Montlake	140	0.000	0.000	0.000	0.000	0	0	0.868	0.000	0.000	0.000	4	0	26%
Montlake	139	0.000	0.000	0.000	0.075	0	2	0.000	0.000	0.000	0.556	0	1	70%
N. Union Bay	18A	0.000	0.000	0.000	0.000	0	0	0.000	0.000	1.357	0.206	0	17	50%
N. Union Bay	18B	0.000	0.000	1.220	0.065	0	12	0.000	0.000	1.844	0.570	0	48	8%
Ballard	150/151	0.600	0.000	0.000	0.000	3	0	0.375	0.000	3.735	0.055	6	52	12%
Ballard	152	0.146	0.000	0.000	0.000	5	0	1.017	0.192	1.236	0.000	39	29	27%
Duwamish	111H	0.000	0.000	0.000	0.000	0	0	0.000	0.000	2.305	0.102	0	20	50%
Portage Bay	130	0.021	0.047	0.000	0.000	5	0	0.000	0.000	0.000	0.000	0	0	78%
Portage Bay	132	0.000	0.000	0.000	0.000	0	0	0.037	0.120	0.000	0.000	3	0	93%
Portage Bay	135	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	100%
Portage Bay	138	0.000	0.000	0.000	0.000	0	0	0.000	0.063	0.000	0.000	3	0	96%
Portage Bay	175	0.000	0.000	0.000	0.000	0	0	0.000	0.000	0.000	0.000	0	0	99%
Delridge	099	0.000	0.000	0.023	0.000	0	1	0.274	0.311	0.478	1.490	10	19	72%
Delridge	168	0.000	0.000	0.000	0.943	0	6	0.048	0.000	0.058	0.044	3	4	26%
Delridge	169	0.000	0.019	0.000	0.000	3	0	0.723	0.015	0.013	0.000	76	1	26%

TABLE F-2
Most Practical of Potential Areas Managed by GSI, Summarized by NPDES Basin

			RainWise Estimates – Most Practical						CSO Volume Managed-Most Practical (MG)						
CSO Area	Basin/ Overflow Structure	LTCP Control Volume (MG)	Technical Feasibility-Rain Gardens	Technical Feasibility-Cistern to Street	Technical Feasibility-Rain Gardens in Pt. Separated Areas	Technical Feasibility-Cistern to Sewer	% of Roof Feasible	Participation	Roadside Rain Gardens	Green Alleys	RainWise - Rain Gardens	RainWise - Downspout Disconnection	RainWise - Cisterns	Total CSO Reduction	Estimated % of Control Volume Managed thru GSI
Fre/Wall	174	1.06	0%	0%	15%	90%	50%	35%	0.000	0.000	0.000	0.011	0.043	0.054	5%
Fre/Wall	147	2.15	10%	35%	25%	90%	50%	35%	0.007	0.000	0.000	0.004	0.008	0.020	1%
Mad Park	22	<0.01	0%	0%	92%	90%	50%	15%	0.000	0.000	0.000	0.001	0.000	0.001	12%
Mad Park	24	0.11	0%	0%	0%	90%	50%	15%	0.000	0.000	0.000	0.000	0.002	0.002	1%
Mad Park	25	0.01	0%	0%	20%	90%	50%	15%	0.000	0.000	0.000	0.003	0.009	0.012	118%
Leschi	26	0	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.001	0.001	Controlled
Leschi	27	0	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.001	0.001	Controlled
Leschi	28	<0.01	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.002	0.002	19%
Leschi	29	0.02	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.001	0.001	5%
Leschi	31	0.31	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.000	0.000	0%
Leschi	32	0.08	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.001	0.001	2%
Leschi	33	0	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.005	0.005	Controlled
Leschi	30	0	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.002	0.002	Controlled
Leschi	34	0.03	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.001	0.001	2%
Leschi	35	<0.01	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.002	0.002	Controlled
Leschi	36	0.03	0%	0%	0%	90%	50%	10%	0.000	0.000	0.000	0.000	0.001	0.001	5%
Montlake	20	0.16	10%	20%	35%	90%	50%	5%	0.007	0.011	0.000	0.001	0.002	0.021	13%
Montlake	140	0.05	20%	48%	0%	90%	50%	20%	0.009	0.006	0.001	0.000	0.003	0.019	37%
Montlake	139	0.01	0%	0%	15%	90%	50%	20%	0.000	0.000	0.000	0.001	0.006	0.006	63%
N. Union Bay	18A	0.26	30%	95%	50%	90%	50%	30%	0.044	0.000	0.001	0.024	0.017	0.085	33%
N. Union Bay	18B	1.37	30%	95%	50%	90%	50%	30%	0.227	0.000	0.007	0.076	0.055	0.365	27%
Ballard	150/151	0.62	***60%***	***90%***	***0%***	***90%***	***50%***	***35%***	***0.124***	***0.016***	***0.019***	***0.004***	***0.010***	***0.172***	28%
Ballard	152	5.38	***60%***	***90%***	***0%***	***90%***	***50%***	***35%***	***0.828***	***0.119***	***0.045***	***0.035***	***0.042***	***1.070***	20%
Duwamish	111H	0.01	0%	0%	28%	90%	50%	25%	0.000	0.000	0.000	0.003	0.013	0.016	164%
Portage Bay	130						50%		0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Portage Bay	132						50%		0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Portage Bay	135						50%		0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Portage Bay	138	0.11	21%	22%	0%	90%	50%	30%	0.002	0.000	0.000	0.000	0.005	0.007	6%
Portage Bay	175						50%		0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Delridge	099	0.17	43%	85%	94%	90%	50%	30%	0.000	0.000	0.001	0.008	0.008	0.017	10%
Delridge	168	2.00	43%	85%	94%	90%	50%	30%	0.105	0.005	0.005	0.035	0.013	0.162	8%
Delridge	169	1.19	43%	85%	94%	90%	50%	30%	0.135	0.010	0.002	0.002	0.003	0.152	13%

TABLE F-3
Low Estimate of Potential Areas Managed by GSI, Summarized by NPDES Basin

			RainWise Estimates – Low Participation						CSO Volume Managed-Low Participation (MG)						
CSO Area	**Basin/ Overflow Structure**	**LTCP Control Volume (MG)**	**Technical Feasibility-Rain Gardens**	**Technical Feasibility-Cistern to Street**	**Technical Feasibility-Rain Gardens in Pt. Separated Areas**	**Technical Feasibility-Cistern to Sewer**	**% of Roof Feasible**	**Participation**	**Roadside Rain Gardens**	**Green Alleys**	**RainWise - Rain Gardens**	**RainWise - Downspout Disconnection**	**RainWise - Cisterns**	**Total CSO Reduction**	**Estimated % of Control Volume Managed thru GSI**
Fre/Wall	174	1.06	0%	0%	8%	80%	25%	10%	0.000	0.000	0.000	0.001	0.006	0.007	1%
Fre/Wall	147	2.15	5%	5%	5%	80%	25%	10%	0.007	0.000	0.000	0.000	0.001	0.009	0%
Mad Park	22	<0.01	0%	0%	83%	80%	25%	5%	0.000	0.000	0.000	0.000	0.000	0.000	2%
Mad Park	24	0.11	0%	0%	0%	80%	25%	5%	0.000	0.000	0.000	0.000	0.000	0.000	0%
Mad Park	25	0.01	0%	0%	10%	80%	25%	5%	0.000	0.000	0.000	0.000	0.001	0.002	17%
Leschi	26	0	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Leschi	27	0	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Leschi	28	<0.01	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	2%
Leschi	29	0.02	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	0%
Leschi	31	0.31	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	0%
Leschi	32	0.08	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	0%
Leschi	33	0	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Leschi	30	0	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Leschi	34	0.03	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	0%
Leschi	35	<0.01	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Leschi	36	0.03	0%	0%	0%	80%	25%	2%	0.000	0.000	0.000	0.000	0.000	0.000	0%
Montlake	20	0.16	5%	15%	20%	80%	25%	1%	0.007	0.011	0.000	0.000	0.000	0.018	11%
Montlake	140	0.05	10%	25%	0%	0%	25%	5%	0.009	0.006	0.000	0.000	0.000	0.015	30%
Montlake	139	0.01	0%	0%	8%	80%	25%	5%	0.000	0.000	0.000	0.000	0.001	0.001	7%
N. Union Bay	18A	0.26	5%	90%	35%	80%	25%	5%	0.044	0.000	0.000	0.001	0.002	0.047	18%
N. Union Bay	18B	1.37	5%	90%	35%	80%	25%	5%	0.227	0.000	0.000	0.004	0.005	0.237	17%
Ballard	150/151	0.62	5%	70%		70%	25%	10%	0.124	0.016	0.000	0.000	0.003	0.143	23%
Ballard	152	5.38	5%	70%		70%	25%	10%	0.828	0.119	0.001	0.000	0.011	0.959	18%
Duwamish	111H	0.01	0%	0%	15%	80%	25%	10%	0.000	0.000	0.000	0.000	0.003	0.003	28%
Portage Bay	130								0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Portage Bay	132								0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Portage Bay	135								0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Portage Bay	138	0.11	8%	10%	0%	80%	25%	10%	0.002	0.000	0.000	0.000	0.001	0.003	2%
Portage Bay	175								0.000	0.000	0.000	0.000	0.000	0.000	Controlled
Delridge	099	0.17	33%	75%	84%	0%	25%	20%	0.000	0.000	0.000	0.002	0.000	0.003	2%
Delridge	168	2.00	33%	75%	84%	0%	25%	20%	0.124	0.006	0.002	0.012	0.001	0.145	7%
Delridge	169	1.19	33%	75%	84%	0%	25%	20%	0.104	0.008	0.000	0.000	0.000	0.113	10%

TABLE F-4
Maximum Potential Areas Managed by GSI, Summarized by NPDES Basin

CSO Area	Basin/ Overflow Structure	LTCP Control Volume (MG)	CSO Reduction 100% Participation			Max % of CV Managed thru GSI	% Residential Part. Necessary in order to achieve CV
			Residential	ROW	Total		
Fre/Wall	174	1.06	0.122		0.122	12%	Not Achievable
Fre/Wall	147	2.15	0.027	0.458	0.484	23%	Not Achievable
Mad Park	22	<0.01	0.007		0.007	67%	Not Achievable
Mad Park	24	0.11	0.006		0.006	5%	Not Achievable
Mad Park	25	0.01	0.057		0.057	573%	17%
Leschi	26		0.011		0.011	Controlled	N/A
Leschi	27		0.004		0.004	Controlled	N/A
Leschi	28	<0.01	0.015		0.015	149%	67%
Leschi	29	0.02	0.008		0.008	38%	Not Achievable
Leschi	31	0.31	0.003		0.003	1%	Not Achievable
Leschi	32	0.08	0.010		0.010	13%	Not Achievable
Leschi	33	0	0.039		0.039	Controlled	N/A
Leschi	30	0	0.017		0.017	Controlled	N/A
Leschi	34	0.03	0.005		0.005	17%	Not Achievable
Leschi	35	<0.01	0.017		0.017	Controlled	N/A
Leschi	36	0.03	0.011		0.011	36%	Not Achievable
Montlake	20	0.16	0.046	0.019	0.066	41%	Not Achievable
Montlake	140	0.05	0.009	0.017	0.026	53%	Not Achievable
Montlake	139	0.01	0.025		0.025	250%	40%
N. Union Bay	18A	0.26	0.107	0.055	0.162	62%	Not Achievable
N. Union Bay	18B	1.37	0.344	0.284	0.628	46%	Not Achievable

TABLE F-4
Maximum Potential Areas Managed by GSI, Summarized by NPDES Basin

CSO Area	Basin/ Overflow Structure	LTCP Control Volume (MG)	CSO Reduction 100% Participation			Max % of CV Managed thru GSI	% Residential Part. Necessary in order to achieve CV
			Residential	ROW	Total		
Ballard	150/151	0.62	0.050	0.223	0.273	44%	Not Achievable
Ballard	152	5.38	0.218	1.500	1.718	32%	Not Achievable
Duwamish	111H	0.01	0.052		0.052	525%	19%
Portage Bay	130		0.000		0.000	Controlled	N/A
Portage Bay	132		0.000		0.000	Controlled	N/A
Portage Bay	135		0.000		0.000	Controlled	N/A
Portage Bay	138	0.011	0.009	0.002	0.011	10%	Not Achievable
Portage Bay	175		0.000		0.000	Controlled	N/A
Delridge	099	0.17	0.043	0.000	0.043	25%	Not Achievable
Delridge	168	2.00	0.130	0.136	0.266	13%	Not Achievable
Delridge	169	1.19	0.013	0.178	0.192	16%	Not Achievable

Appendix G
Flow Monitoring Analysis

Appendix G: Flow Monitoring Analysis

Last published and updated: July 2011

Introduction

Basin models of SPU's CSO areas are currently being developed and calibrated based on flow monitoring data collected since 2007. In advance of completion of these models, the flow monitoring data was reviewed to estimate two primary factors affecting estimates of the effectiveness of GSI to reduce control volumes:

1. To estimate the approximate degree of directly connected imperviousness of the basin
2. To develop an approximate conversion from impervious area mitigated by GSI to amount of overflow volume reduced.

Methods

Directly Connected Impervious Area Estimation

Preliminary models of the City of Seattle's CSO areas are currently undergoing calibration, however, to varying degrees each preliminary model has been hand calibrated to verify model inputs and construction. For the GSI feasibility analysis included in this study, the values for directly connected impervious area from the preliminary, hand-calibrated models was used. The analysis described below was used to compare the hand calibrated values versus the flow monitoring data from selected storms.

GIS data was used to delineate the land coverage for input into the models and development of the maps of GSI opportunities within each CSO area provided in Appendix B. The data was used to identify areas that are likely connected to the storm drainage system versus the combined sewer system. However, the degree of connection of these areas to the system cannot be determined through GIS alone as roof and paved surfaces may not necessarily be directly connected to the combined system through a variety of conditions. Therefore, hydrograph separation techniques were applied to the flow monitoring data to estimate the degree of connectivity of the delineated impervious area in each basin.

Flow monitoring data from Stantec's ZFM database (for temporary monitors) and ADS's Intelliserve database (for permanent monitors and rainfall) was used to determine flows and rainfall for three hydrologic conditions: dry weather flow (up to three periods), summer/dry season storm flow (up to three events), and typical wet season CSO storm flow (two largest events). The total flows from these conditions were calculated to segregate into the hydrograph into the following flow components:

- **Dry Weather Flow:** Dry weather flow consists of flow that occurs in the system in the absence of rainfall and typically consists of sanitary wastewater flows. Dry weather flow was estimated using the flow monitoring data by evaluating the total volume of flow measured at monitoring sites closest to the overflow location after periods of dry weather (typically two weeks or more without significant rainfall).

- **Directly Connected Impervious Flow:** Directly connected impervious flow consists of flow that occurs in the system from rainfall falling directly on impervious areas and being conveyed directly to the combined sewer system with minimal losses. The contribution to total flow by directly connected impervious areas was estimated using the flow monitoring data by evaluating the total volume of flow measured during a 24-hour period following a significant storm event (greater than 0.25 inches) following a period of dry weather (typically one or more weeks of without significant rainfall). The difference in total volume of flow measured versus the estimated dry weather flow is estimated to be due to directly connected impervious areas. The degree of connectivity is calculated by comparing the volume of excess flow (above dry weather flow) to the measured rainfall minus initial abstraction (typically 0 to 0.12 inches). This results in an estimate of impervious area necessary to generate the calculated volume. The resulting area is then divided by the delineated impervious area to generate the degree of connectivity as a percentage of impervious area.
- **Non-impervious Wet-weather Flow:** During periods of extended wet weather additional flow can enter the system from a variety of sources. These sources include runoff from pervious surfaces, inflow from groundwater (including perched on impervious soil layers) into leakages in the side sewers and mains, flow from sump pumps and flow from partially connected impervious areas that may effectively lose water during dry weather periods and numerous other potential sources. This flow component is estimated during a typical CSO control event by subtracting both dry weather flow and directly connected impervious flow from the total flow measured at the site.

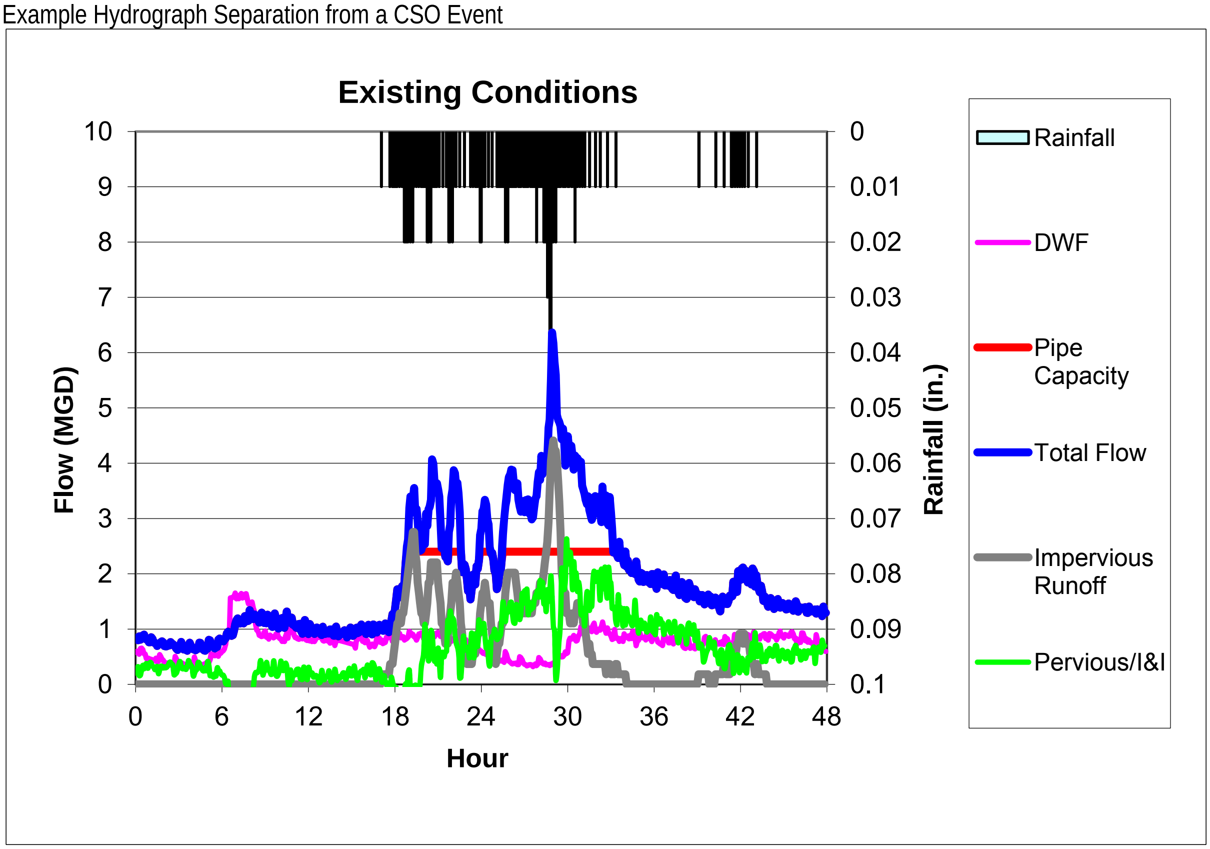
Table G-1 below provides a typical summary of the event analysis.

TABLE G-1
Storm Event Generated Flow Analysis Summary
From NPDES Basin 174, MH 021-052, from November 25, 2009 Event

	Date	Flow (MG/D)	Rain Fall (in)	% of Impervious Area Directly Connected
DWF	7/9/2009	0.811	0	
	6/13/2009	0.834	0	
	8/22/2009	0.7794	0	
	Average	**0.8067**	**0**	
Summer Storm Events	8/11/2009	0.9881	0.41	35.16
	9/19/2009	1.0059	0.47	32.35
	10/14/2009	1.1847	0.73	36.05
	Average	**1.059566667**	**0.54**	**34.50**
Winter Storm Events	11/6/2009	1.61	1.02	52.46
	1/11/2010	2.104	1.22	69.59
	Average	1.8570	1.12	56.34

The results of the event analysis and calculated directly connected impervious area were then used to perform a hydrograph separation of the monitored flow from a typical CSO event for each basin. The first step is to separate the dry weather flow component, this was done by subtracting a typical dry weather flow diurnal pattern from the monitoring data from total flow during a CSO event. Dry weather flow is not being reducible through GSI techniques. Next, the directly connected impervious flow during typical CSO control events was estimated by multiplying the delineated impervious area by the estimated percent of direct connectivity and measured rainfall during the event. The flow generated by directly connected impervious areas is considered to be the primary source of flow reduction achievable through GSI techniques. The remaining flow from the monitored CSO event is considered to be non-impervious wet weather flow, likely runoff from pervious areas and infiltration/inflow into the system during saturated conditions. In this analysis, GSI techniques are not estimated to significantly reduce flow contributed from non-impervious wet weather flow. It is possible that GSI techniques could reduce flow from some of these sources, particularly partially disconnected impervious areas but it is not considered to be significant enough (nor quantifiable) to consider in this conceptual level analysis. An example hydrograph separation from a CSO event is shown in Figure G-1 below.

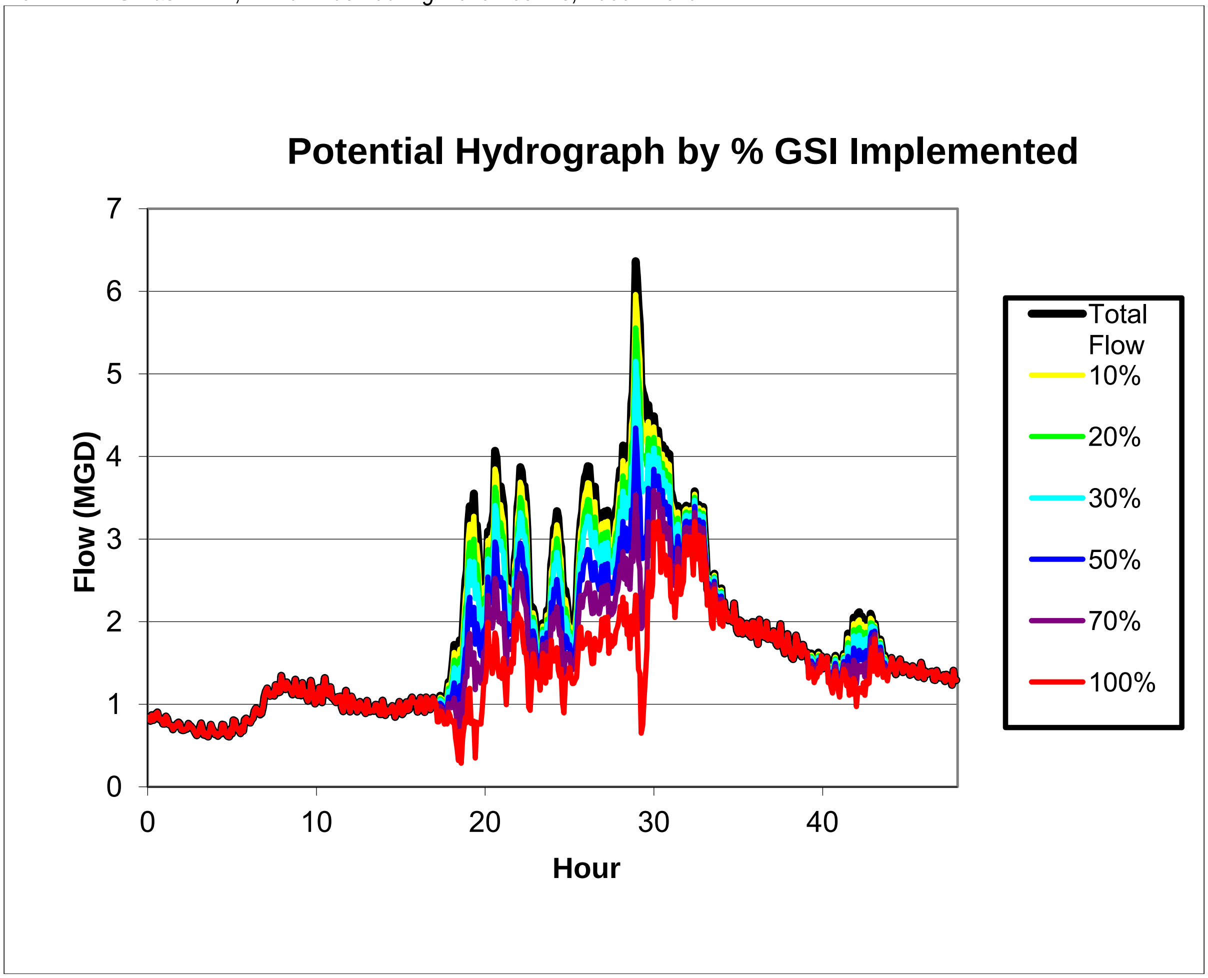
FIGURE G-1
Example Hydrograph Separation from a CSO Event



CSO Reduction through GSI Estimation

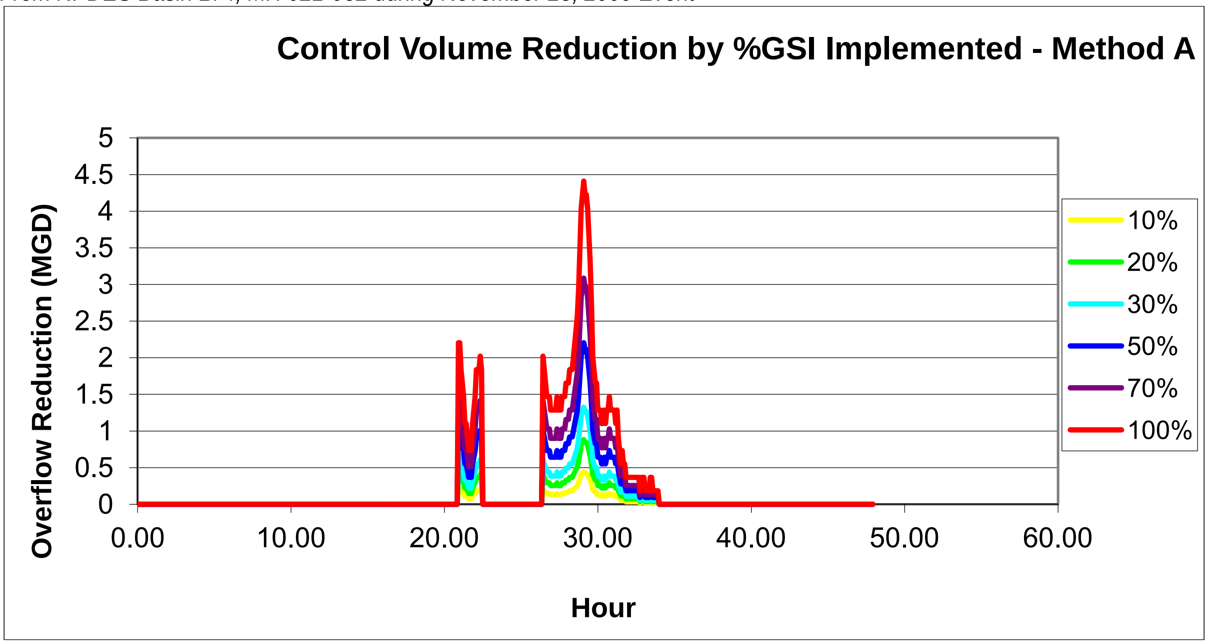
The amount of CSO control volume reduction potential through GSI techniques was then estimated by calculating the volume of runoff reduced from directly connected impervious areas during periods contributing flow during a monitored CSO event, see Figure G-2. It should be noted that the analysis only estimates the amount of CSO control volume reduction which is not necessarily equivalent to required storage volume. For in-line storage systems, the amount of storage required can include flow volume that occurs prior to overflow events, whereas for off-line systems the volume stored is typically closer to the control volume as only flows that exceed the capacity of the downstream system are captured. The required storage volume can also include residual volume remaining in the storage facility from prior events.

FIGURE G-2
Typical Predicted Hydrograph Based on % of Directly Connected Impervious Area Mitigated by GSI
From NPDES Basin 174, MH 021-052 during November 25, 2009 Event



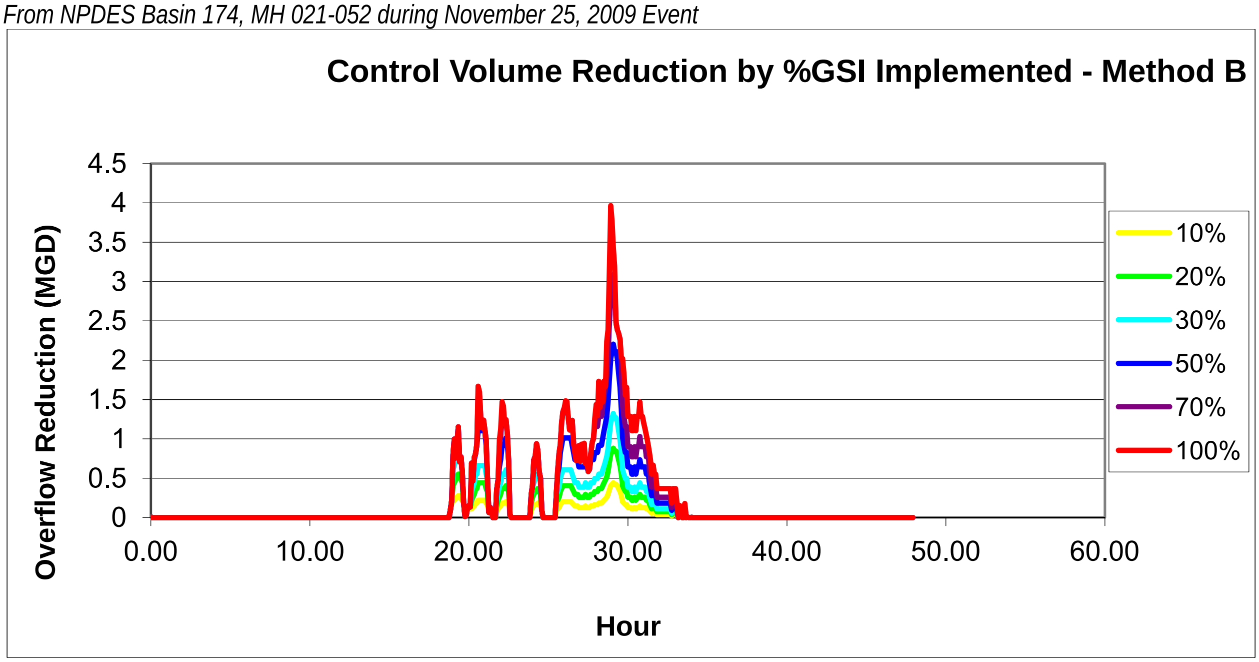
Two methods for calculating the potential CSO reduction are included. Method A calculates the total volume of flow reduction as the total volume reduced through reduction of a percentage (depending on a range of degrees of implementation resulting from the feasibility and participation analysis described above) of directly connected impervious flow during a reported CSO period. Therefore, for every time step where an overflow is reported, the volume of estimated flow from directly connected impervious areas is multiplied by the degree of implementation and summed throughout the event. Figure G-3 below shows an example control volume reduction hydrograph using Method A.

FIGURE G-3
Typical CSO Control Volume Reduction Based on % of Directly Connected Impervious Area Mitigated by GSI – Method A
From NPDES Basin 174, MH 021-052 during November 25, 2009 Event



Method B calculates the total volume of flow reduction in a similar manner, however, only values that occur where the total flow exceeds the estimated capacity of the downstream system are summed. Where storage exists within the existing system, the capacity of the downstream system is estimated to equal the approximate flow at which flow begins to fill storage. Otherwise, the capacity is determined to be the flow at which overflows begin. Figure G-4 below shows an example control volume reduction hydrograph using Method B.

FIGURE G-4
Typical CSO Control Volume Reduction Based on % of Directly Connected Impervious Area Mitigated by GSI – Method B
From NPDES Basin 174, MH 021-052 during November 25, 2009 Event



Results

In general, the ability to match preliminary model values in the flow analysis for building connectivity was variable. Ultimately, the calibrated models which will explore a large range of storms and monitors will provide the most reliable estimate of existing direct connectivity of impervious areas to the combined sewer system. Changes to these values would have an impact on the effectiveness of GSI approaches to reduce control volumes. Calculated values for CSO volume reduction related to impervious area mitigated by GSI ranged between 0.55 gal/sf and 1.02 gal/sf. The higher values area associated with the Fremont/Wallingford basins (174 and 147) where overflows occur for longer periods due to restrictions in the capacity of the downstream system. Where insufficient data was available to determine the ratio based on flow monitoring, a default value of 0.5 gal/sf was used, which is consistent with prior studies and appears to be conservative based on this analysis. Again, long-term simulations of GSI using the calibrated models will provide a more refined estimate of the control volume reduction achievable through GSI. Table G-2 summarizes the results of the flow analysis.

TABLE G-2
Summary of Flow Analysis

CSO Area	Basin/ Overflow Structure	Existing CSO Facility	2010 Planned Facility	Bldg % Connectivity from Preliminary Model	Bldg % Connectivity from Flow Analysis	CSO Volume Managed/sf Area Managed (gal/sf)
Fre/Wall	174	N/A	Off-Line Storage	46%	35%	0.860
Fre/Wall	147	N/A	Off-Line Storage	60%	43%	1.020
Interbay	68A	Off-line Storage		33%	39%	0.500[1]
Interbay	68B	In-line Storage	In-Line Storage	25%	32%	0.500[2]
Mad Park	22	N/A		100%	45%	0.500[3]
Mad Park	24	N/A		100%	60%	0.500
Mad Park	25	N/A	Off-Line Storage	100%	68%	0.500
Leschi	26	N/A		50%	n/a	0.500
Leschi	27	N/A		50%	n/a	0.500
Leschi	28	N/A	In-Line Storage	50%	62%	0.880[4]
Leschi	29	In-line Storage	In-Line Storage	50%	50%	0.600[4]
Leschi	30	In-line Storage	GSI Only	36%	24%	0.550[4]
Leschi	31	N/A	Off-Line Storage	75%	43%	0.600[5]
Leschi	32	In-line Storage	Off-Line Storage	38%	55%	0.550[5]
Leschi	33	Off-line Storage		50%	n/a	0.590[6]
Leschi	34	Off-line Storage	GSI Only	50%	94%	0.700[7]

TABLE G-2
Summary of Flow Analysis

CSO Area	Basin/ Overflow Structure	Existing CSO Facility	2010 Planned Facility	Bldg % Connectivity from Preliminary Model	Bldg % Connectivity from Flow Analysis	CSO Volume Managed/sf Area Managed (gal/sf)
Leschi	35	Off-line Storage	GSI Only	43%	67%	0.700[7]
Leschi	36	In-line Storage	In-Line Storage	50%	30%	0.500
Montlake	20	Off-line Storage	GSI Only	55%	n/a	0.680[8]
Montlake	139	N/A		84%	n/a	0.680[9]
Montlake	140	Off-line Storage	GSI Only	72%	n/a	0.670[10]
N. Union Bay	18A	In-Line Storage	In-Line Storage	69%	n/a	0.500
N. Union Bay	18B	In-Line Storage	In-Line Storage	53%	n/a	0.500
Ballard	150		In-Line Storage	74%	n/a	0.43 [11]
Ballard	152		Off-Line Storage	37%	n/a	0.43 [11]
Duwamish	111H	In-line Storage	Off-Line Storage	84%	n/a	0.500
Portage Bay	130	KC CSO		25%	n/a	0.500
Portage Bay	132	KC CSO		43%	n/a	0.500
Portage Bay	135	KC CSO		55%	n/a	0.500
Portage Bay	138	Off-line Storage	In-Line Storage	48%	n/a	0.500
Portage Bay	175	KC CSO		49%	n/a	0.500

Notes:

1. No Flow Data Available
2. Flow Data Cuts Out During 1/7/2009 Storm and Used CSO data from MP25
3. Revised to use average CSO reduction of 0.5 gal/sf (January 2008 event with CSO volume of 467,000 gallons had 0.99 inches of rainfall therefore in range)
4. Due to in-line storage, all flow during Jan 2009 event assumed to count.
5. Used flow data from Basin 30 during overflow period for this basin in January 2009 event. Data cuts out for this monitoring during this period.
6. Used CSO data from LES29
7. Storage estimated to being filling 1.5 hours prior to overflow on January 2009 event
8. Storage estimated to begin filling at 17:20 on January 7, 2009 event
9. Used CSO data from Mon20
10. Storage estimated to begin filling at 16:55 on January 7, 2009 event
11. See Ballard Business Case. No independent evaluation was conducted in this analysis.

Appendix H
GSI SWMM Modeling Parameters

SWMM GSI Model Parameters

Revised: January 27, 2011

The following five GSI practices are used in the calibrated PCSWMM basin models to evaluate the effects of GSI implementation on CSO control volume. The model parameters listed are used in the *LID Controls* module of PCSWMM, available in SWMM5 version 5.0.021. The document "SWMM_GSI_Modeling_Steps.docx" describes the steps needed to add these five GSI practices to a PCSWMM model.

RainWise GSI Parameters

RainWise Rain Gardens

SWMM LID Control Name: "RW_RG"

SWMM LID Control Type: Bio-Retention Cell

Parameter	Value	Source/Description
Surface: Storage Depth	6 in.	Per RainWise Sizing
Surface: Vegetative Cover	0	All overflow goes directly back to system
Surface: Surface Roughness		
Surface: Surface Slope		
Soil: Thickness	11 in	12 inches minimum per RainWise Sizing, see note on storage
Soil: Porosity	0.4	Per Green-Ampt Parameters summary provided by Andrew Lee, based on Brakensiek and Rawls data.
Soil: Field Capacity	0.13	Per Rawls (1992) for Loamy Sand texture
Soil: Wilting Point	0.04	Per Green-Ampt Parameters summary provided by Andrew Lee, based on Brakensiek and Rawls data. Difference between total and effective porosity
Soil Conductivity	1.5 in/hr	Per RainWise Sizing
Soil: Conductivity Slope	10	Per user's manual, average between sand and silt loam.
Soil: Suction Head	2.42 in.	Assumed, Loamy Sand.
Storage: Height	1 in.	No effective storage assumed, however, 0 is not an allowable value
Storage: Void Ratio	0.667	Equivalent to 0.4 porosity used for soil

Storage: Conductivity	0.25 in/hr	Min. assumed for till.
Storage: Clogging Factor	0	Not used.
Underdrain: Drain Coefficient	0	No underdrains used
Underdrain: Drain Exponent		
Underdrain: Drain Offset Height		

Additional Data for spreadsheet development

Rain Garden Sizing factor: 7.4% of tributary impervious area, assuming 0.25 in/hr infiltration rate.

Typical Roof Area draining to a rain garden in RainWise: 1 rain garden is applied to each catchment where applicable. The size of the garden area varies based on tributary area, using the sizing factor described above. The size of the rain garden is determined in the [Basin Name]_GSI_input.xls spreadsheet.

Rain Garden Initial Saturation: 30% based on typical values for field capacity. This likely is not significant for long term simulations.

RainWise Cisterns

SWMM LID Control Name: "RW_cisterns"

SWMM LID Control Type: Bio-Retention Cell

Cisterns were not modeled as type Rain Barrel because these features only drain during time-steps with zero inflow. This is not consistent with how RainWise Cisterns are set up. Thus, RainWise Cisterns were modeled as type Bio-Retention Cell with appropriate parameters, shown below.

Parameter	Value	Source/Description
Surface: Storage Depth	0.5 in	Increases model stability, vs. 0 in.
Surface: Vegetative Cover	0	All overflow goes directly back to system
Surface: Surface Roughness		
Surface: Surface Slope		
Soil: Thickness	2 in	Increases model stability, vs. 0 in.
Soil: Porosity	0.4	Consistent with RW_RG
Soil: Field Capacity	0.13	Consistent with RW_RG
Soil: Wilting Point	0.04	Consistent with RW_RG
Soil Conductivity	50 in/hr	Causes inflow to pass almost immediately into Storage layer; increases model stability
Soil: Conductivity Slope	10	Consistent with RW_RG
Soil: Suction Head	2.42 in.	Consistent with RW_RG
Storage: Height	34.7 in.	Creates an equivalent of 36 in. of storage (34.7 +(2 in. soil thickness *0.4 porosity) +0.5 in. surface storage = 36 in. total storage). Per RainWise descriptions, up to 48 in. total storage allowed.
Storage: Void Ratio	0.667	Equivalent to 0.4 porosity used for soil
Storage: Conductivity	0.25 in/hr	Min. assumed for till. Check if this needs to be varied with perm_assessment layer.
Storage: Clogging Factor	0	Not used.
Underdrain: Drain Coefficient	0.1622	0.25 inch orifice. Coefficient calculated based on assumed cistern size in excel worksheet.
Underdrain: Drain Exponent	0.5	Orifice Flow

Underdrain: Drain Offset Height	0	Drain assumed on bottom

Typical Cistern Size/Roof Area Draining: Assume 650 square foot roof. Cistern area is 2.5% the roof area (Facility Sizing Table 7). Cistern volume is thus 364.65 gallons (650*0.025*3*7.48; where 3 is the storage height in feet and 7.48 converts from cubic feet to gallons). Note, similar to rain gardens, using too high of a value here will probably leave a large amount of variability due to rounding.

RainWise Downspout Disconnection

SWMM LID Control Name: "RW_disconnect"

SWMM LID Control Type: Vegetated Swale

Parameter	Value	Source/Description
Surface: Storage Depth	0	No storage assumed
Surface: Vegetated Cover Fraction	0	Translate overflow directly to flow
Surface: Surface Roughness	0.1	Assumed
Surface: Surface Slope	1.0 %	Minimum necessary for feasibility
Surface: Swale Side Slope	4	Assumed

The primary intent of these parameters is to translate the total area to be disconnected and connect it directly to the pervious area, so there should be no direct runoff back to the system

Right-of-Way GSI

Roadside Rain Gardens

SWMM LID Control Name: “row_gsi”

SWMM LID Control Type: Bio-Retention Cell

Parameter	Value	Source/Description
Surface: Storage Depth	6 in.	Per Director’s Rules
Surface: Vegetative Cover	0	All overflow goes directly back to system
Surface: Surface Roughness		
Surface: Surface Slope		
Soil: Thickness	11 in	12 inches minimum per RainWise Sizing, see note on storage
Soil: Porosity	0.4	Per Green-Ampt Parameters summary provided by Andrew Lee, based on Brakensiek and Rawls data.
Soil: Field Capacity	0.13	Per Rawls (1992) for Loamy Sand texture
Soil: Wilting Point	0.04	Per Green-Ampt Parameters summary provided by Andrew Lee, based on Brakensiek and Rawls data. Difference between total and effective porosity
Soil Conductivity	1.5 in/hr	Per RainWise Sizing
Soil: Conductivity Slope	10	Per user’s manual, average between sand and silt loam.
Soil: Suction Head	2.42 in.	Assumed, Loamy Sand.
Storage: Height	1 in.	No effective storage assumed, however, 0 is not an allowable value
Storage: Void Ratio	0.667	Equivalent to 0.4 porosity used for soil
Storage: Conductivity	0.25 in/hr	Min. assumed for till.
Storage: Clogging Factor	0	Not used.
Underdrain: Drain Coefficient	0	No underdrains used
Underdrain: Drain Exponent		
Underdrain: Drain Offset		

Height		

Green Alleys

Parameter	Value	Source/Description
Surface: Storage Depth	0 in.	
Surface: Vegetative Cover	0	All overflow goes directly back to system
Surface: Surface Roughness		
Surface: Surface Slope		
Pavement: Thickness	8 in	Assumed
Pavement: Void Ratio	0.15	Default used
Pavement: Impervious Surface	0.75	Assumed 12 foot alley with 3 foot permeable strip
Pavement: Permeability	20 in/hr	Assumed, industry standard (100 in/hr) with a factor of safety of 5.
Pavement: Clogging Factor	0	Not used.
Storage: Height	24 in.	Assumed
Storage: Void Ratio	0.667	Equivalent to 0.4 porosity
Storage: Conductivity	0.25 in/hr	Assumed
Storage: Clogging Factor	0	Not used.
Underdrain: Drain Coefficient	0	No underdrains used
Underdrain: Drain Exponent		
Underdrain: Drain Offset Height		

Appendix I
GSI SWMM Modeling Methodology

Modeling Platform

The GSI practices were modeled using PCSWMM 2011 Standard computer model by Computation Hydraulics International (CHI) which utilizes EPA's SWMM5 Engine version 5.0.021. Each of the LTCP CSO basins were developed, calibrated and run to develop best-estimate control volumes using SWMM5 engine version 5.0.018. Some significant updates between these two models are important to consider when evaluating the results of the GSI analysis.

1. Version 5.0.021 adds the capability to simulate capture and retention of rainfall/runoff through the addition of Low Impact Development (LID) (AKA GI or GSI) controls. This capability is not available in version 5.0.018, and therefore the only way to simulate GSI practices using this version would be to effectively reduce impervious area or to construct modules for each individual practices which would be impractical for the scale of the CSO modeling.

2. Version 5.0.021, according to EPA, corrects an error in calculating evapotranspiration from subcatchments. This error is rooted in the syncing of the evaporation time series with the simulation time steps and results in an increase in evapotranspiration from the aquifer storage when using Version 5.0.018. The impact of this correction is that simulations using the updated engine (5.0.021) using parameters calibrated under Version 5.0.018 typically generate greater inflow to the sewer system from groundwater and thus greater control volumes.

Analysis of the Ballard model indicates that Version 5.0.021 will generate a Control Volume, defined as the 32nd ranked overflow volume in a 31-year simulation, that is approximately 27 to 33 percent greater than Version 5.0.018, see Table 1 below. This increase varies by basin and in some cases creates model instability (e.g. North Union Bay) as the resulting aquifer levels greatly exceed the node elevations where inflow into the combined sewer system is simulated and overwhelms the system. For Ballard, the resulting increase in Control Volume is within the confidence bounds of the estimated Control Volume from the model development uncertainty analysis. Therefore, SPU determined that at this interim stage, the resulting simulated control volume reduction from GSI practices in Ballard provides a reasonable estimate for planning purposes.

Table 1. Comparison of Control Volume Estimates from Versions 5.0.018 and 5.0.021

Basin	Best-Estimate CV (mg)	v. 5.0.018 -no GSI (mg)	v. 5.0.021 -no GSI (mg)
150/151	0.467	0.454	0.580
152	4.070	3.869	5.156

SWMM Version 5.0.021 simulates GSI practices through two input modules. The LID Controls Editor defines the general characteristics of each type of GSI practice. In general, these are parameters that define the cross section of the various practices, for example the depth, porosity and hydraulic conductivity of each layer in a GSI practice. The LID Usage Editor defines the individual application of practices within a catchment by defining the area, number and tributary area of each practice.

GSI Practices Modeled

The following practices were modeled in SWMM:

- **Raingardens:** Raingardens through the roadside raingarden program and RainWise are both defined in the model using SWMM's "Bio-retention Cell" LID Control. These practices are defined by entering parameters for the ponding, soil and storage layers and defining whether the practice has an underdrain.
- **Cisterns:** Cisterns through the RainWise program were initially defined in the model using the "Rain Barrel" LID Control. However, this control as defined in the SWMM model does not appropriately simulate the actual function of these practices. The SWMM engine simulates the rain barrels as having a closed outlet during periods of rainfall and then allows discharge from the storage after a defined dry period. However, in practice the RainWise cisterns will not be actively managed during and immediately after a storm and will be allowed to drain through an orifice both during and after a storm. Therefore, the cisterns were modeled using the "Bio-Retention Cell" LID control which allows drainage from the storage layer during a storm.
- **Green Alleys:** Green alleys are simulated using the "Porous Pavement" LID control which simulates a ponding depth, pavement layer and storage layer with the option of having an underdrain.
- **Downspout Disconnection:** Downspout disconnections were simulated using the "Vegetative Swale" LID control. This control simulates the flow of the runoff from the impervious surfaces through a vegetative swale and allows the user to output the runoff from the swale to the pervious surface of the catchment rather than direct discharge to the combined sewer system, similar to the function of a downspout disconnection.

Modeling Steps and Parameters

The GSI Feasibility Analysis developed previously serves as the first step in developing the GSI models for each CSO basin. This feasibility analysis combined the subcatchment delineation that was used to develop the calibrated models (including delineation of impervious areas and connectivity to the combined sewer system) with GIS data to determine areas that are suitable for infiltration and SPU field investigations and estimates of technical feasibility and participation in GSI programs (RainWise, Roadside Raingardens and Green Alleys). The feasibility analysis therefore created an estimate of the total area draining to individual practices under low, high (or most practical) and maximum participation levels. The steps to convert the results of the feasibility analysis to a GSI SWMM model are briefly summarized below:

- **ROW Pivot table:** A table is created to relate the areas feasible for roadside or alley GSI practices with the model subcatchments.
- **Add sub-Model filters to the data:** Filters are added to the RainWise feasibility analysis summaries to subdivide the data in to the appropriate model where the overall basin is represented by a collection of submodels (e.g. for Ballard, the

model is divided between two upper basin models (150/151 and 152) and a lower basin.

- **LID Controls Assumptions:** A spreadsheet is added to apply sizing factors and assumptions for modeling the individual LID controls.
- **Individual GSI practice worksheets :** Separate spreadsheets are then created for each GSI practice to summarize the number of practices, practice area and tributary area by subcatchment for direct import into the model.
- **LID Controls:** LID controls inputs as described above are pasted into the model input (.inp) file to define the practices.
- **LID Usage Import:** LID usage data is copy and pasted from the individual GSI practice worksheets into the model input (.inp) file to define the application of GSI practices at the subcatchment level.
- **Open and Run Model:** The model is then opened and run.

These steps are described in greater detail in the attached document titled "SWMM_GSI_Modeling_Steps_012811.docx". Each NPDES basin model construction may differ slightly; therefore minor modifications to this general procedure on a basin-by-basin basis may be necessary.

A summary of parameters for each GSI practice is included in the attached document titled "SWMM_GSI_Modeling_Parameters_012811.docx".

Appendix J
GSI SWMM Detailed Modeling Steps

Combined Sewer Overflow Reduction associated with Green Stormwater Infrastructure: Feasibility and Modeling Methods

Prepared by Tyler Jantzen and Dustin Atchison, CH2M HILL

Revised July 21, 2011

Introduction

This document describes in detail the methods used to calculate potential areas managed by Green Stormwater Infrastructure (GSI), which are in turn used to develop hydrologic and hydraulic models to estimate Combined Sewer Overflow (CSO) volume reduction due to GSI. This document is divided into two main sections: Feasibility Methods (steps beginning with "F") and Modeling Methods (steps beginning with M).

The feasibility analysis is calculated using information from the delineation of combined sewer connectivity, evaluation of areas unsuitable for infiltration, estimation of technical feasibility and participation in RainWise and estimation of feasibility and implementation of GSI within the right-of-way. See the GSI Feasibility Evaluation Report Volumes 2 and 3 for more information on the development of potential areas managed by GSI. These calculations are made at a level consistent with the CSO model subcatchments in order that GSI implementation may be most easily simulated with calibrated models for all basins. Similarly, these calculations were performed in Excel workbooks ([CSO area name]_AreasSummary.xlsx) unique to individual CSO Areas (i.e. Montlake, Leschi, Ballard etc.), consistent with CSO model construction. Within each CSO Area, areas managed by GSI are summarized by NPDES Basin. These areas, summarized by basin, were used within the flow summary worksheet (GSI_SummaryVol2.xlsx and GSI_SummaryVol3.xlsx) to develop estimates of CSO volume reduction. The main steps associated with feasibility analysis are:

- F.1 Summarize infiltration feasibility and system type by model subcatchment
- F.2 Calculated areas to RainWise GSI practices (rain gardens, to be disconnected, to cisterns)
- F.3 Summarize Total Area Mitigated using GSI through the RainWise Program, by Basin
- F.4 Identify and summarize impervious right-of-way (ROW) areas feasible for infiltration and GSI.

The product of the feasibility analysis ([CSO area name]_AreasSummary.xlsx spreadsheet) is modified in order to generate and format data added to the model to simulate GSI. Modification of the calibrated model to evaluate CSO volume reduction due to GSI involves the following main steps:

- M.1. Create a GSI Model Input spreadsheet using the [CSO area name]_AreasSummary and the example Ballard_GSI_input.xlsx spreadsheet.
- M.2. Add LID Controls to the calibrated CSO model from the example Ballard_GSI model.

M.3. Add LID Usage to the calibrated CSO model from the GSI Model Input spreadsheet (step 1)

M.4. Run two versions of the model in PCSWMM- one with and one without GSI

M.5. Using ACU-SWMM, generate overflow statistics for both models and compare results.

Document formatting notes: user actions are highlighted in **bold text**, with additional discussion highlighted in *italic text*. Required Software: Microsoft Excel, PCSWMM v4.1.878 (uses SWMM v.5.0.021), ACU-SWMM v.1 (October 24, 2010 update), TXT2CSV.xlsx macro

Optional Software: Microsoft Access

Prerequisite Skills: Familiarity with Excel Pivot Tables and VLOOKUP functions, basic navigation around PCSWMM, familiarity with the structure of the CSO basin model to be used for GSI evaluation

GSI Feasability Methods

A series of CSO Area workbooks and one Flow Analysis Summary workbook were used in conjunction with available GIS and model data to calculate areas managed by GSI.

One workbook was created for each CSO Area, using the naming convention [Area Name]_AreasSummary.xlsx (such as Montlake_AreasSummary.xlsx). Each of the CSO Area workbooks has a series of interconnected sheets, described in Table F-1.

TABLE F-1
CSO Area Workbook Sheet Descriptions

Sheet Name	Description	Notes
Summary	Summarizes areas managed by GSI by NPDES Basin	Values on this sheet are dependent on PivotTables being refreshed, and are not always up-to-date. This applies especially to ROW areas.
PivotTables	Summarizes GIS information by subcatchment ID; summarizes “Bldg_Subcatchments” sheet by NPDES Basin	
Rainwise	Calculates the number of buildings meeting RainWise criteria, grouped by present use.	This sheet was only computed for a few basins, does not exist for all areas.
Bldg_Subcatchments	Calculates areas managed by GSI by subcatchment, based on information from GIS data pivot tables and participation levels.	
ParticipationLevels	Described in Appendix D	
(Un)CalibratedModelSubcatchments	Subcatchments information imported from PCSWMM model for building type subcatchments only.	May be uncalibrated, depending on information available at the time of analysis.

TABLE F-1
CSO Area Workbook Sheet Descriptions

Sheet Name	Description	Notes
Building_Catchments	Data exported from the building GIS shapefile. Includes indication of subcatchment routing, combined sewer connectivity (Appendix B) and areas unsuitable for infiltration (Appendix C). In addition, each building as identified as being in a partially separated or combined building based on proximity to combined right-of-way areas.	
ROW_Areas	Data exported from the right-of-way shapefile. Includes indication of combined sewer connectivity.	In some CSO Areas, ROW feasibility and implementation was provided in a tabular format. In these CSO Areas, this sheet was not created.
row_gsi	Data for ROW that is feasible for GSI (as opposed to all ROW, included in ROW_Areas).	In some CSO Areas, ROW feasibility and implementation was provided in a tabular format. In these CSO Areas, this sheet was not created.
ROW_Pivot	A pivot table summarizing ROW areas feasible for GSI, by subcatchment. Includes indication of alley vs. roadway, where applicable.	In some CSO Areas, ROW feasibility and implementation was provided in a tabular format. In these CSO Areas, this sheet was not created.
Source = GIS		
Source = Other external input such as model or results from external analysis		
Internal Calculations		

The following steps were used to develop each CSO Area workbook.

F.1. Summarize infiltration feasibility and system type by model subcatchment

F.1.1. GIS Steps

F.1.1.1. **Infiltration Feasibility:** Identify all buildings that are located in parcels that are have more than 5% of the area unsuitable for infiltration. In GIS, add "AUI_v4" field to buildings. *AUI_v4* = "Yes" if building intersects with AUI_v4 parcel; otherwise *AUI_v4* = "".

F.1.1.2. **System Type:** Identify all Buildings that are in Fully Combined area. *PtSepArea* = Combined; otherwise *PtSepArea* = Partial.

F.1.1.3. **Urban Village Exclusion**: Identify all Buildings that are in Urban Village areas. Add field *Eligibility*. Intersect buildings with "cenvill.shp" (do not include "Manufacturing Industrial"), and set *Elgibility* = "UrbanVillage".

F.1.2. Spreadsheet Steps

F.1.2.1. **Add Column to Calculate Areas Suitable for Infiltration:** Load GIS Buildings data to Building_Catchments sheet. Add *Area_Feasible* column. If unsuitable for infiltration *Area_Feasible* = 0; otherwise *Area_Feasible* = *AREA [building area]*.

F.1.2.2. **Summarize Totals:** Summarize areas by subcatchment on PivotTables sheet. PivotTable group by Subcatchment ID (field varies by basin and modeler). Filter only buildings going to combined (filter out buildings to storm, buildings to pervious; field varies by basin and modeler).

Summarize total area of buildings in subcatchment (PivotTable 1)

Summarize total area feasible for infiltration in subcatchment. (PivotTable 1)

Summarize total area unfeasible for infiltration in subcatchment. (PivotTable 2; copy of PivotTable 1 filtered to AUI_v4 = Yes only)

Create three sets of pivot tables filtering only: single family residence, commercial, and schools. Based on the field "PU_CAT_DESC", the following three zoning groupings were assumed:

Single family residence: *Single Family*

Commercial: *Office, Public Facility, Recreation/Entertainment, Retail/Service, Church, Government Service, Mixed Use*

Schools: *School/Daycare, Park/Playground*

"PU_CAT_DESC" categories not included in the area analysis are: *Industrial, Multi-Family, Parking, Terminal/Warehouse, Utility, Other Housing*

F.2. Calculate areas to RainWise GSI practices (rain garden, to be disconnected, to cisterns, etc.) by subcatchment

F.2.1. Insert entire list of model building subcatchments (from model) in to Bldg_Subcatchments sheet. Add column for NPDES Basin and Area Type (Combined vs. Partially Separated). Methods to determine NPDES Basin and Area Type vary:

F.2.2. NPDES Basin methods

F.2.2.1. If CSO area has only one NPDES Basin, all subcatchments are assigned to that Basin

F.2.2.2. If "Aquifer Name" appears to be linked to the flow monitoring ID, sort by this field and identify NPDES Basin by flow monitoring ID with the help of the Meter Schematic Diagram from the Data Mentoring Report.

F.2.2.3. If GIS NPDES Basin delineation is available, create *NPDES_Basin* field in the BLDG shapefile, populate based on GIS NPDES Basin delineation, and summarize by subcatchment in the PivotTables

F.2.3. Area Type method

F.2.4. If only a few subcatchments are in combined areas, identify these manually and identify as such in Area Type field.

F.2.5. If many subcatchments are in combined areas, create a pivot table in the PivotTables sheet summarizing total subcatchment area and total combined subcatchment area. If more than 50% of the subcatchment area is combined (based on PtSepArea field), assign as combined in Bldg_Subcatchments sheet.

F.2.6. In Bldg_Subcatchments sheet, calculate the fields listed in Table F-2, by subcatchment

TABLE F-2
Column Descriptions for CSO Area Workbook, Bldg_Subcatchments Sheet

Column Letter[1]	Field	Source / Explanation
A	Subcatchment ID	Copied from Modeler's "subcatchment's list" or copied from subcatchments table within model
B	NPDES Basin	Varies - developed from GIS (source on *Building_Catchments* sheet), developed from model (often from Aquifer field, linked to basin)
C	Area Type (Combined or Partially Separated)	From GIS- if few combined areas, manually found subcatchments that are combined. If many combined areas, used "PtSepArea" from GIS Bldg. shapefile (field created for GSI feasibility), developed PivotTable to determine all subcatchments where >50% of Bldgs. are considered Combined
D	Total Bldg. Area	From model
E	% Connected (% Impervious)	From model- depending on basin, may not be calibrated. See Status spreadsheet for uncalibrated models
F	Effectively Connected Building Area	=E/D
G	Effectively Connected, Combined Feasible SFR Bldg. Area - (non AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible single family residence bldg. area from Pivot Tables of GIS data) * E
H	Effectively Connected, Combined Infeasible SFR Bldg. Area - (AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible single family residence bldg. area from Pivot Tables of GIS data) * E
I	Effectively Connected, Combined Feasible School Bldg. Area - (non AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible school bldg. area from Pivot Tables of GIS data) * E
J	Effectively Connected, Combined Infeasible School Bldg. Area - (AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible school bldg. area from Pivot Tables of GIS data) * E

TABLE F-2
Column Descriptions for CSO Area Workbook, Bldg_Subcatchments Sheet

Column Letter[1]	Field	Source / Explanation
K	Effectively Connected, Combined Feasible Commercial Bldg. Area - (non AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible commercial bldg. area from Pivot Tables of GIS data) * E
L	Effectively Connected, Combined Infeasible Commercial Bldg. Area - (AUI, not to pervious, not to Storm)	(VLOOKUP on sum of combined feasible commercial bldg. area from Pivot Tables of GIS data) * E
M	Areas to RG (high)	IF Combined = [(G * Participation Level Col. D) + (I * High School RG Participation Level) + (K * High Commercial RG Participation Level) * I * J]; otherwise 0
N	Areas to RG (low)	Same as above, using low participation levels
O	Area to be Disconnected (high)	IF Partially Separated = [(G * Participation Level Col. F) + (I * High School Disconnections Participation Level) + (K * High Commercial Disconnections Participation Level) * I * J]; otherwise 0
P	Areas to be Disconnected (low)	Same as above, using low participation levels
Q	Areas to Cisterns (high)	IF Combined = [{(G * Participation Level Col. (1-D) *E) +(I * (1 - High School RG Participation Level) * High School Cisterns Participation Level) + (K * (1 - High Commercial RG Participation Level) * High Commercial Cisterns Level)}* I * J]; otherwise 0
R	Areas to Cisterns (low)	Same as above, using low participation levels
S	Areas to Cisterns back to Sewer (high)	IF Combined = (H+[G*(Participation Level Col. (1-D) *(1-E)]*G*I*J) IF Partially Separated = (H+[G * (Participation Level Col. (1-F)] *G* I * J)
T	Areas to Cisterns back to Sewer (low)	Same as above, using low participation levels
U	Total Area to Cisterns (high)	= Q+ S
V	Total Area to Cisterns (low)	Same as above, using low participation levels

[1] Column letters based on Fremont-Wallingford CSO Area, other areas are similar but may include more columns

F.3. Summarize Total Area Mitigated using GSI through the RainWise Program by Basin

F.3.1. Summarize Building Areas for both High and Low participation levels and for all three zone types in PivotTables sheet: Total Building Area, Effectively Connected Building Area, Areas to RG, Areas to be Disconnected, Areas to Cisterns

F.4. Identify and summarize impervious ROW areas feasible for infiltration and GSI

F.4.1. Methods vary by basin, depending on information available

F.4.1.1. Ballard: Calculate alley_gsi and row_gsi (roads) in GIS file Ballard_ROW_combined.shp based on alley_gsi.shp and row_gsi.shp, provided by SPU (sent to Tyler on 8/17 by Justin Twenter/B&C). ID combined areas and NPDES Basin of ROW in GIS. Import GIS data to row_gsi sheet in Excel. Summarize: total combined ROW impervious area; combined ROW impervious area to rain garden, and combined ROW impervious area for Alley GSI, by NPDES Basin in PivotTable sheet.

F.4.1.2. Duwamish: ID ROW areas for GSI in GIS based on SPU field markups sent 8/5. ID NPDES Basins. Import GIS data to ROW_Areas sheet. Summarize impervious areas by NPDES basin on PivotTables sheet. NOTE- all the identified ROW areas for NDS are in the King County basin (d/s of overflows and tributary to KC Pump Station)

F.4.1.3. Fremont-Wallingford: ID ROW areas for GSI in GIS based on SPU field markups sent 8/5. All area in Basin 147. Import GIS data to ROW_Areas sheet. Summarize impervious areas for Basin 147 on PivotTables sheet.

F.4.1.4. Interbay: Delineate ROW areas for GSI in GIS based on SPU field markups sent 8/5 (need to distinguish between alleys and roads). Distinguish in GIS attributes ROW subcatchments that are in areas 1, 2, 3, 4, 5, PP1 and PP2. Import GIS data to ROW_Areas sheet; all in Basin 68A. Summarize impervious areas for Basin 68A on PivotTables sheet. NOTE: Basins 68A and 68B are reversed in printed maps- see email from Ben Marre on 6/9/09, via Santtu on 8/16/10.

F.4.1.5. Leschi: no ROW data; assume not feasible

F.4.1.6. Madison Park / Union Bay: no ROW data; assume not feasible

F.4.1.7. Montlake: Use areas developed in memo "Green Stormwater Infrastructure feasibility for NPDES Basin 140, 20, & 139" from Craig Chatburn to Tracy Tackett, dated June 29, 2010.

F.4.1.8. North Union Bay: Use areas developed in "NUB Street Feasibility.xlsx" workbook, sent via email on June 10, 2010.

F.4.1.9. Portage Bay: Delineate ROW areas for GSI in GIS based on SPU field markups sent 8/5. Because only one area, reported directly in Summary sheet.

GSI Modeling Methods

Revised: July 8, 2011

The [Basin Name]_AreasSummary.xlsx spreadsheet created for the feasibility analysis is modified to generate input values for modeling GSI practices in PCSWMM. This section describes the methods needed to convert the [BasinName]_AreasSummary.xlsx spreadsheet to [BasinName]GSI_input.xlsx spreadsheet, to use the [BasinName]GSI_input.xlsx spreadsheet to create a GSI input file for PCSWMM, and to generate CSO results using a combination of PCSWMM and ACU-SWMM.

Example files: Ballard_AreasSummary.xlsx; Ballard_GSI_input.xlsx; 011-176_gsi.inp

Required Software: Microsoft Excel, PCSWMM v4.1.878 (uses SWMM v.5.0.021), ACU-SWMM v.1 (October 24, 2010 update), TXT2CSV.xlsx macro

Optional Software: Microsoft Access

M.1. Create a GSI Model Input Spreadsheet

Create a GSI Model Input spreadsheet from the [CSO area name]_AreasSummary spreadsheet, using the format, structure and formulas in the example Ballard_GSI_input.xlsx spreadsheet.

M.1.1. ROW Pivot table

Add a tab named "ROW_Pivot" to the [CSO area name]_AreasSummary.xlsx spreadsheet . **Insert** a pivot table based on the data in the feasible ROW tab (named "ROW_potential_2_ROWMontlakeIntB" for Montlake and *row_gsi* for Ballard). Because feasible ROW is calculated a bit differently for each basin, this step may need to be modified for basins other than Ballard and Montlake. *The overall purpose of this pivot table is to summarize the feasible/potential effective impervious area of ROW that can be captured by Rain Gardens and Green Alleys by model subcatchment ID. Areas routed to Rain Gardens need to be separated from areas routed to Green Alleys. There are multiple entries for the same subcatchment, so a pivot table is used to sum total effective alley and roadway impervious area for each subcatchment.*

The ROW data tab (*row_gsi* in Ballard) may need to be modified to sum effective impervious area (instead of total impervious area). *For Ballard row_gsi, Column "F" was added to lookup the calibrated % impervious for each subcatchment. The value in column "G" was revised to equal the effective impervious area (subcatchment area x % impervious).*

Add subcatchment IDs to the Pivot Table Row labels (often subcatchment ID is based on "S_IMSID" field from GIS). **Add** effective impervious area to the Pivot Table ∑ Values. Make sure the effective impervious area is summed, not counted.

Pivot Tables are used to quickly summarize data. This tool is found in the "Insert" menu (Excel 2007).

Select the data to be summarized (must have header row with column titles). **Click** "Insert Pivot Table", **Browse** to placement location. **Drag** column header names from the "PivotTable Field List" to the "Row Labels", "Column Labels", and "∑ Values" boxes. **Click** the drop-down menu for the ∑ Values item to change the "Value Field Settings" from Count to Sum (as appropriate).

M.1.2. Add sub-Model filters to the data (if using submodels)

Models that are divided into multiple submodels need to have GSI input data separated by submodel. This step is not necessary for un-divided models (for instance, Interbay). **Add** a tab called "Model_Division". **Import** the subcatchments that go with each sub-model (this list may already exist on the "row_gsi" tab). **Add** a column to the *row_gsi* and *Bldg_subcatchments* tabs to lookup the submodel for each subcatchment.

M.1.3. LID Controls Assumptions

This worksheet contains base assumptions for sizing of practices. Note the formulas that calculate the cistern coefficient are based on the size of the cisterns; this will need to be updated in the model if a different cistern size is used for RainWise. Also, note the sizing formula for the tributary area to each cistern is embedded in the formula. **Copy** the "LID_Controls_Assumptions" tab from the example workbook into the new basin workbook.

M.1.4. Individual GSI practice worksheets (Input_[practice name])

Create a new tab in the [CSO area name]_AreasSummary.xlsx spreadsheet for each of the GSI practices to be modeled (RW_RG, RW_Cisterns, RW_Disconnect, ALLEY_GSI, ROW_GSI). For each of these new practice worksheets, **Copy** the column headings and formulas from the example Input spreadsheet into the [CSO area name]_AreasSummary.xlsx spreadsheet. **Reconnect** the formulas to the appropriate locations in the new basin Input spreadsheet. It is easiest to do this for the top row, and then fill down. **Delete** any reference to the Ballard_AreasSummary.xlsx spreadsheet within each of the formulas. **Check** that references to pivot table values are relative to the row name (not absolute).

Column headings and location within the [CSO area name]_AreasSummary.xlsx may be different than those in the example Ballard_AreasSummary.xlsx spreadsheet. **Double-check** that the formulas are connected to the correct columns by comparing the column name in the target spreadsheet to the column name in the template spreadsheet. *For instance, if the template spreadsheet refers to "% Impervious" in column K, and the target spreadsheet has "% Impervious" in column "M", change formulas copied from the template spreadsheet referring to cell "K3" to "M3".* **Fill down** the formulas for all subcatchments. Make sure that hard coded cell values don't change when filled down (for instance, 0 filled down turns to 0,1,2…). **Add** filters to the data to filter out subcatchments without GSI practices.

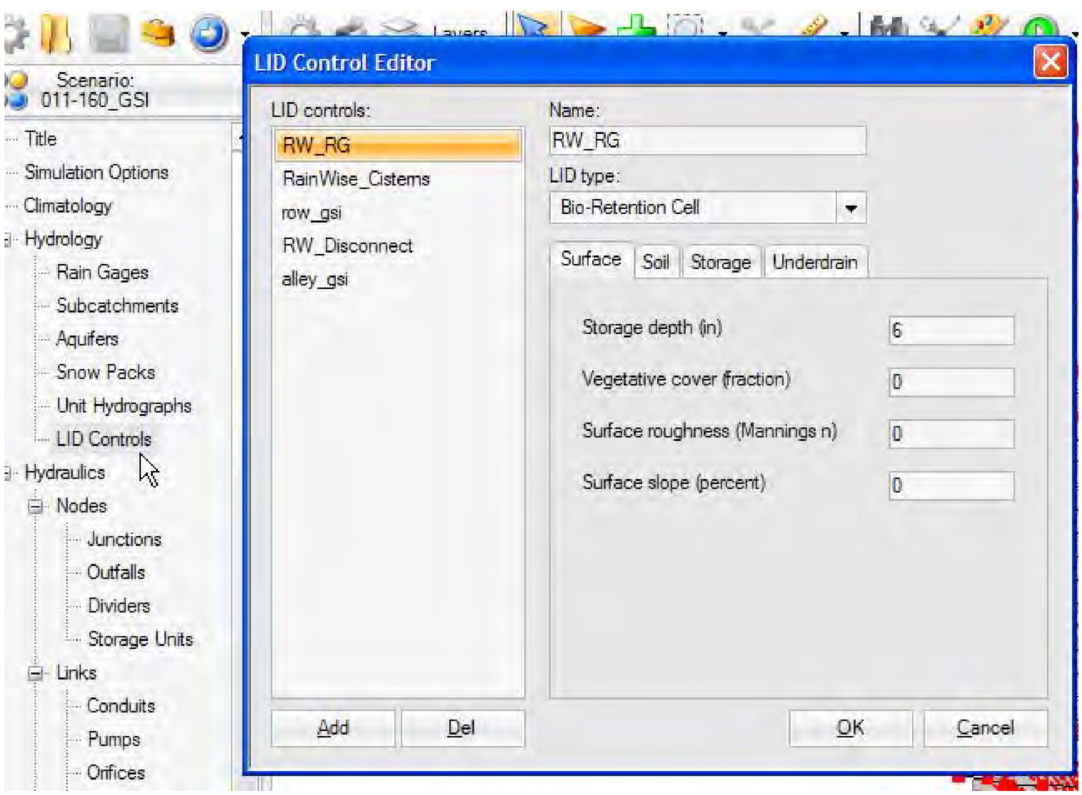
For each of the practices for RainWise, (Cisterns, Rain Gardens and disconnections) the worksheets reference the data in the "Bldg_Subcatchments" tab and translate them into the values necessary for the SWMM model. There should be one row for each model building subcatchment. If GSI is not possible in a given subcatchment, the corresponding area will be zero.

For each of the ROW practices (roadside raingardens and alleys) the worksheets reference the ROW pivot table. There should be one row for each model ROW subcatchment. If GSI is not possible in a given subcatchment, the corresponding area will be zero.

Number and size of each practice: These values multiplied through should equal the area to each practice times the sizing factor. For rain gardens, the size of each practice varies so that the actual sizing factor is preserved without being affected by the rounding of the number of practices. For cisterns a common area is preserved for each practice; otherwise the drain coefficient is incorrect. The orifice is always 0.25" diameter but the drain coefficient depends on the size of the tank. To create input files for a new basin, the format and formulas on these tabs should be copied from a template workbook into a new basin workbook, taking care to re-connect appropriate formulas.

M.2. Model Setup: LID Controls

LID controls in the model can be **created** manually in PCSWMM, or by **copying** the lines following "[LID Controls]" from a template (Ballard) .inp file to another using text editor. For the manual entry just **click** on the "LID Controls" line in the model to bring up the LID Controls Editor



To copy and paste from the Ballard .inp file, **copy** the data from here.

```
[LID_CONTROLS]
;;               Type/Layer Parameters
;;-------------- ---------- ----------

RW_RG            BC
RW_RG            SURFACE    6          0          0          0          5
RW_RG            SOIL       11         0.4        0.13       0.04       1.5        10         2.42
RW_RG            STORAGE    1          .667       0.25       0
RW_RG            DRAIN      0          0          0          6

RainWise_Cisterns BC
RainWise_Cisterns SURFACE   0.5        0          0          0          3
RainWise_Cisterns SOIL      2          0.4        0.13       0.04       50         10         2.42
RainWise_Cisterns STORAGE   34.7       99         0          0
RainWise_Cisterns DRAIN     0.1622     0.5        0          0

row_gsi          BC
row_gsi          SURFACE    6          0          0          0          3
row_gsi          SOIL       11         .4         0.13       0.04       1.5        10         2.42
row_gsi          STORAGE    1          0.667      0.25       0
row_gsi          DRAIN      0          0          0          6

RW_Disconnect    VS
RW_Disconnect    SURFACE    0          0.0        0.1        1.0        4

alley_gsi        PP
alley_gsi        SURFACE    0.0        0.0        0          0          5
alley_gsi        PAVEMENT   8          0.15       .75        20         0
alley_gsi        STORAGE    24         0.667      0.25       0
alley_gsi        DRAIN      0          0          0          6

[LID_USAGE]
;;Subcatchment   LID Process      Number  Area       Width      InitSatur  FromImprv  ToPerv     Report File
;;-------------- ---------------- ------- ---------- ---------- ---------- ---------- ---------- -----------
```

To locate this in a file with GSI in the input file just search for "LID" in notepad. To **paste** into "non-GSI" input files, search for "aquifer" and the "[LID_Controls]" and "[LID_USAGE]" data sections are listed immediately before the "[Aquifer]" section.

M.3. Model Setup: LID Usage Import

Next, **copy and paste** the data directly from each of the 5 GSI practice worksheets into the [LID_Usage] Section of the input file, as viewed in text editor.

From Excel, first **filter** on the correct model version in column A (for divided models such as Ballard; does not apply to undivided models such as Interbay), then **filter out** lines with either zero area or zero number of practices (Columns D or E) and **copy** only the data values from Columns B through I (do not include the headers).

	A	B	C	D	E	F	G	H	I	J
1										
2		[LID_USAGE]								
3	Model	;;Subcatchme	LID Process	Number	Area	Width	InitSatu	FromIm	ToPerv	Report
272	Upper 15	BLD_002-234	RW_RG	1	1.85	0	30	1.73	0	
273	Upper	Model:	RW_RG	1	2.96	0	30	2.12	0	
274	Upper	Equals "Upper 150"	RW_RG	1	1.59	0	30	0.93	0	
275	Upper 150	BLD_002-237	RW_RG	1	3.06	0	30	2.06	0	
276	Upper 150	BLD_002-238	RW_RG	1	2.57	0	30	2.08	0	
277	Upper 150	BLD_002-239	RW_RG	1	3.18	0	30	1.81	0	
278	Upper 150	BLD_002-240	RW_RG	1	1.64	0	30	1.75	0	
279	Upper 150	BLD_002-241	RW_RG	1	2.10	0	30	1.77	0	
280	Upper 150	BLD_002-242	RW_RG	1	1.94	0	30	1.75	0	
281	Upper 150	BLD_002-243	RW_RG	1	1.56	0	30	2.25	0	
282	Upper 150	BLD_002-244	RW_RG	1	1.18	0	30	1.97	0	
283	Upper 150	BLD_002-245	RW_RG	1	1.50	0	30	1.81	0	
284	Upper 150	BLD_002-246	RW_RG	1	1.62	0	30	1.98	0	
285	Upper 150	BLD_002-247	RW_RG	1	2.71	0	30	1.98	0	
286	Upper 150	BLD_002-248	RW_RG	1	2.09	0	30	1.75	0	
287	Upper 150	BLD_002-249	RW_RG	1	2.56	0	30	1.91	0	
288	Upper 150	BLD_002-250	RW_RG	1	2.49	0	30	1.83	0	
289	Upper 150	BLD_002-251	RW_RG	1	1.86	0	30	1.90	0	
290	Upper 150	BLD_002-252	RW_RG	1	2.71	0	30	1.84	0	
291	Upper 150	BLD_002-253	RW_RG	1	1.58	0	30	1.75	0	
292	Upper 150	BLD_002-254	RW_RG	1	1.38	0	30	1.80	0	
293	Upper 150	BLD_002-255	RW_RG	1	1.88	0	30	1.79	0	
294	Upper 150	BLD_002-256	RW_RG	1	2.96	0	30	1.90	0	
295	Upper 150	BLD_002-257	RW_RG	1	2.53	0	30	1.87	0	
296	Upper 150	BLD_002-258	RW_RG	1	1.58	0	30	1.34	0	
297	Upper 150	BLD_002-259	RW_RG	1	2.03	0	30	1.77	0	

Then **paste** into the .inp file below “[LID_Controls]”. Upon first import be sure to **add** the headers from the template GSI input file.

```
RW_Disconnect     SURFACE    0          0.0        0.1        1.0        4

alley_gsi         PP
alley_gsi         SURFACE    0.0        0.0        0.013      2          5
alley_gsi         PAVEMENT   12         0.15       .75        100        0
alley_gsi         STORAGE    12         0.4        0.5        0
alley_gsi         DRAIN      0          0.5        0          6

[LID_USAGE]
;;Subcatchment   LID Process      Number  Area       Width      InitSatur  FromImprv  ToPerv     Report File
;;-------------- ---------------- ------- ---------- ---------- ---------- ---------- ---------- -----------
BLD_001-001      RainWise_Cisterns 2       11.14081996 0          0          16.01      0
BLD_001-002      RainWise_Cisterns 3       11.14081996 0          0          30.80      0
BLD_001-003      RainWise_Cisterns 2       11.14081996 0          0          24.49      0
BLD_001-004      RainWise_Cisterns 2       11.14081996 0          0          15.13      0
BLD_001-015      RainWise_Cisterns 2       11.14081996 0          0          15.40      0
BLD_001-005      RainWise_Cisterns 2       11.14081996 0          0          17.27      0
BLD_001-014      RainWise_Cisterns 2       11.14081996 0          0          14.19      0
BLD_001-013      RainWise_Cisterns 1       11.14081996 0          0          14.17      0
BLD_001-006      RainWise_Cisterns 2       11.14081996 0          0          19.03      0
BLD_001-012      RW_RG            1       4.49       0          30         1.94       0
BLD_001-012      RainWise_Cisterns 2       11.14081996 0          0          15.69      0
BLD_001-007      RainWise_Cisterns 1       11.14081996 0          0          13.85      0
BLD_001-011      RainWise_Cisterns 1       11.14081996 0          0          24.45      0
BLD_001-016      RainWise_Cisterns 1       11.14081996 0          0          15.65      0
BLD_001-010      RainWise_Cisterns 1       11.14081996 0          0          20.80      0
BLD_001-022      RainWise_Cisterns 1       11.14081996 0          0          15.01      0
BLD_001-026      RW_RG            1       1.43       0          30         2.04       0
BLD_001-029      RainWise_Cisterns 1       11.14081996 0          0          21.23      0
BLD_001-032      RW_RG            1       1.18       0          30         1.54       0
BLD_001-039      RW_Disconnect    1       166.1354488 6          0          1.75       1
BLD_001-038      RW_Disconnect    1       21.80692031 6          0          0.19       1
BLD_002-084      RW_RG            1       1.50       0          30         1.34       0
BLD_002-084      RainWise_Cisterns 1       11.14081996 0          0          10.89      0
BLD_002-088      RainWise_Cisterns 1       11.14081996 0          0          19.01      0
BLD_002-106      RainWise_Cisterns 1       11.14081996 0          0          22.02      0
BLD_002-140      RW_RG            1       2.56       0          30         2.74       0
```

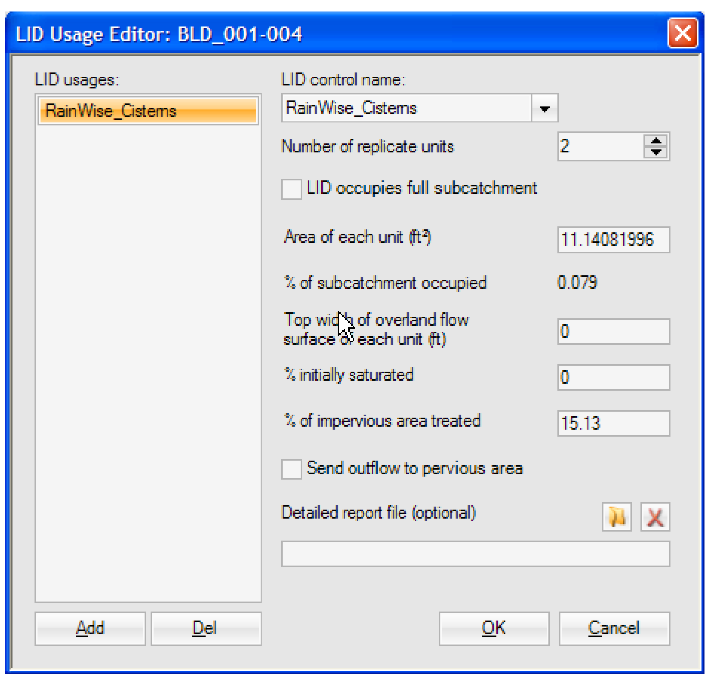
To **update** data, **delete** the sections to be replaced and then **re-paste** in the new data. Note that SWWM will automatically re-sort based on the subcatchment ID, so you will need to replace all the data for buildings and ROW as the various practices will be intermingled in the text file.

M.4. Open and Run Model

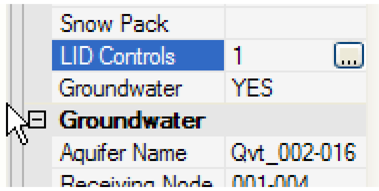
M.4.1. Run a short duration simulation

Re-open the input file (inp) from PCSWMM. It will ask you if you want to update the GIS with the input file or vice versa. Choose to update the GIS (first option). The import will then tell you it updated a number of subcatchments without error messages if the import worked correctly. To **check** the data, **select** a catchment in the subcatchments table, and then **select** the button next to "LID Controls".

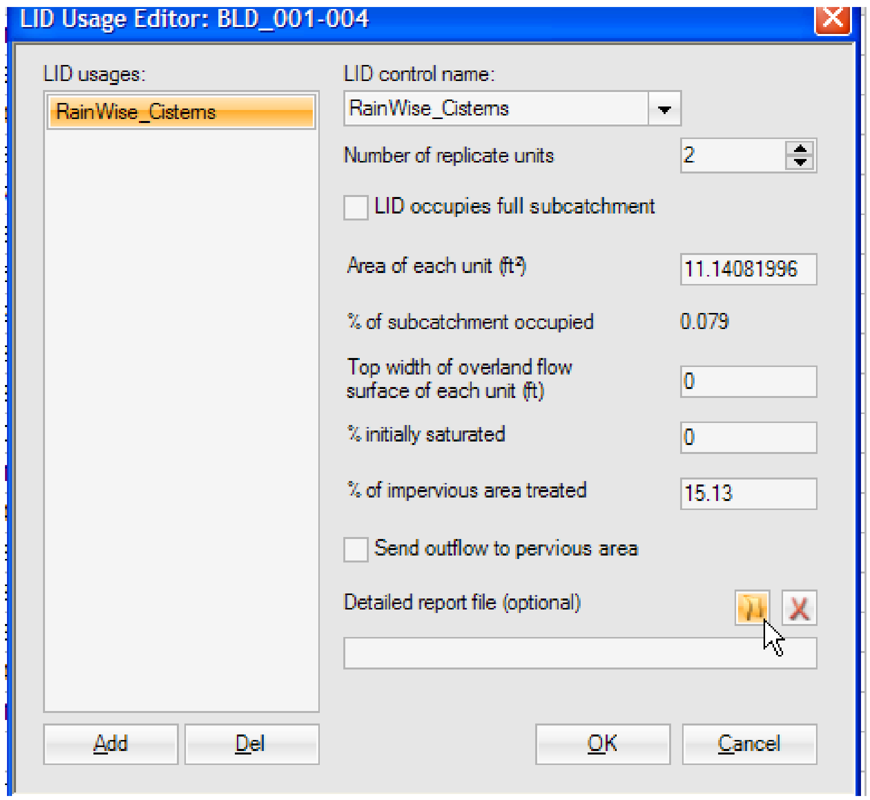
Note the number may still say zero there. This is because it is from the GIS data. The data is really there and the model appears to run the LID Controls as entered even if this value is zero. See below:



Click "OK" and the number will update.

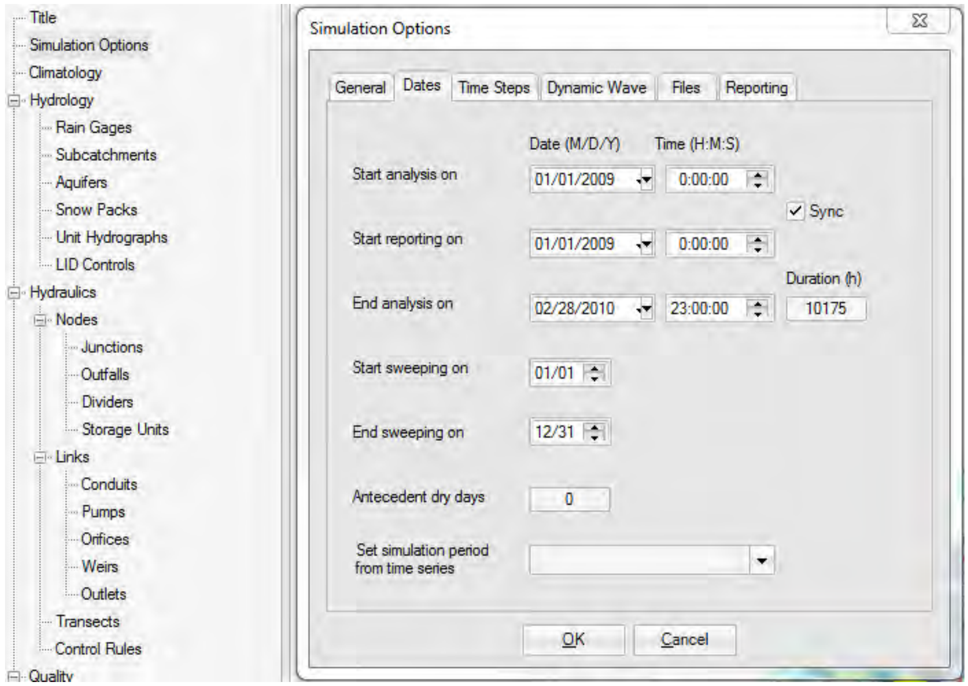


To **check** the data, it is helpful to grab a couple of subcatchments and **map an LID report file** for the data. **Select** the folder icon next to "Detailed report file (optional)", browse to an appropriate location, and include an appropriate file name.

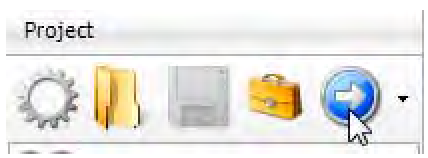


This will create a text file with the results for that GSI practice.

In the *Simulation Options* **Dates** tab, choose a relatively short duration (a few weeks to a few months during which precipitation occurred) for the model simulation. Be sure to change both "Start analysis on" and "Start reporting on".



Run the GSI and non-GSI models just like any other simulation by selecting the run button. You can open and run multiple PCSWMM models at one time, but this can slow down computer processing.



M.4.2. Review the short duration results

M.4.2.1. LID Performance

Once the model run is complete, summary data for each practice can be viewed by selecting the "status" tab and scrolling down to the "LID Performance Summary"

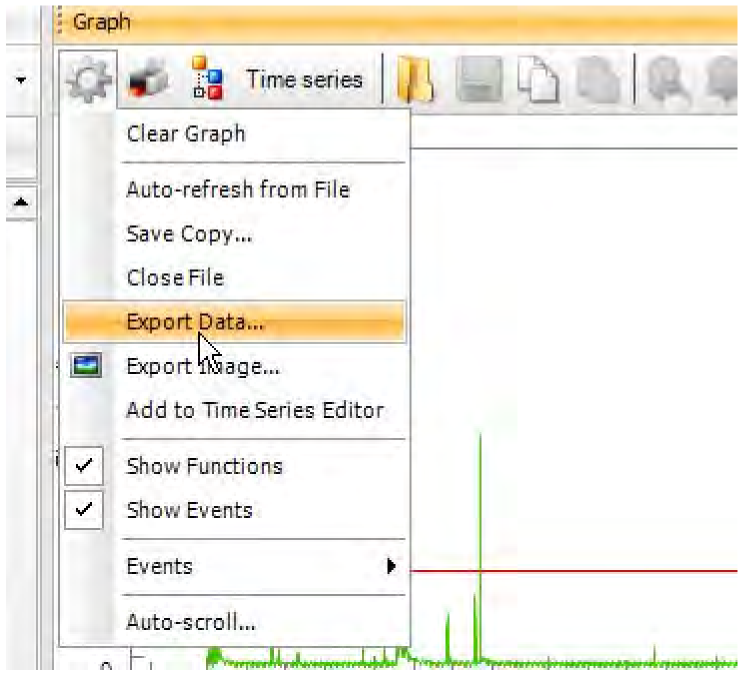
****
LID Performance Summary
****

Subcatchment	LID Control	Total Inflow in	Evap Loss in	Infil Loss in	Surface Outflow in	Drain Outflow in	Init. Storage in	Final Storage in	Pcnt. Error
BLD_001-001	RainWise_Cisterns	1114.40	0.00	0.00	101.29	1003.50	0.00	9.78	-0.02
BLD_001-002	RainWise_Cisterns	1190.66	0.00	0.00	126.63	1053.74	0.00	10.44	-0.01
BLD_001-003	RainWise_Cisterns	1300.76	0.00	0.00	169.47	1119.75	0.00	11.71	-0.01
BLD_001-004	RainWise_Cisterns	1508.88	0.00	0.00	269.77	1224.68	0.00	14.61	-0.01
BLD_001-015	RainWise_Cisterns	1140.48	0.00	0.00	110.83	1019.73	0.00	10.08	-0.01
BLD_001-005	RainWise_Cisterns	1064.30	0.00	0.00	84.04	971.43	0.00	9.02	-0.02
BLD_001-014	RainWise_Cisterns	1065.50	0.00	0.00	92.45	965.80	0.00	7.40	-0.01
BLD_001-013	RainWise_Cisterns	1492.57	0.00	0.00	235.16	1245.83	0.00	11.72	-0.01
BLD_001-006	RainWise_Cisterns	901.53	0.00	0.00	46.37	849.72	0.00	5.60	-0.02
BLD_001-012	RainWise_Cisterns	880.12	0.00	0.00	43.47	831.41	0.00	5.39	-0.02
BLD_001-012	RW_RG	550.84	14.98	366.69	164.60	0.00	1.87	6.77	-0.06
BLD_001-007	RainWise_Cisterns	1529.89	0.00	0.00	251.65	1266.27	0.00	12.12	-0.01
BLD_001-011	RainWise_Cisterns	970.55	0.00	0.00	56.55	908.37	0.00	5.80	-0.02
BLD_001-016	RainWise_Cisterns	662.27	0.00	0.00	4.24	655.17	0.00	3.03	-0.03
BLD_001-010	RainWise_Cisterns	970.96	0.00	0.00	58.48	906.68	0.00	5.96	-0.02

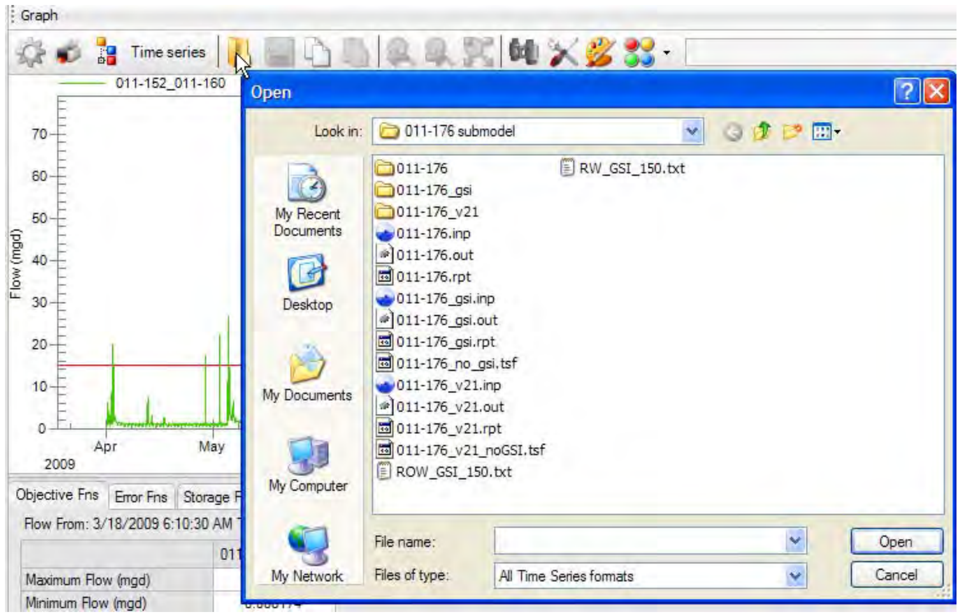
Look the Pcnt. Error, and verify that it is low and that the model is simulating Infiltration loss for rain gardens or drain outflow for cisterns. For undersized practices, (likely all with the default values) Surface Outflow should be greater than zero.

M.4.2.2. Compare to Non-GSI Models

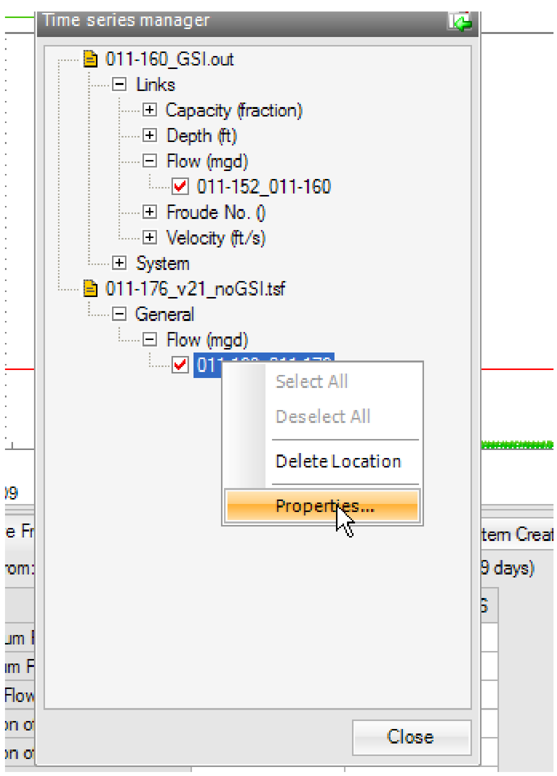
To **compare** hydrographs, **export** a hydrograph from the non-gsi model run to a .tsf file.



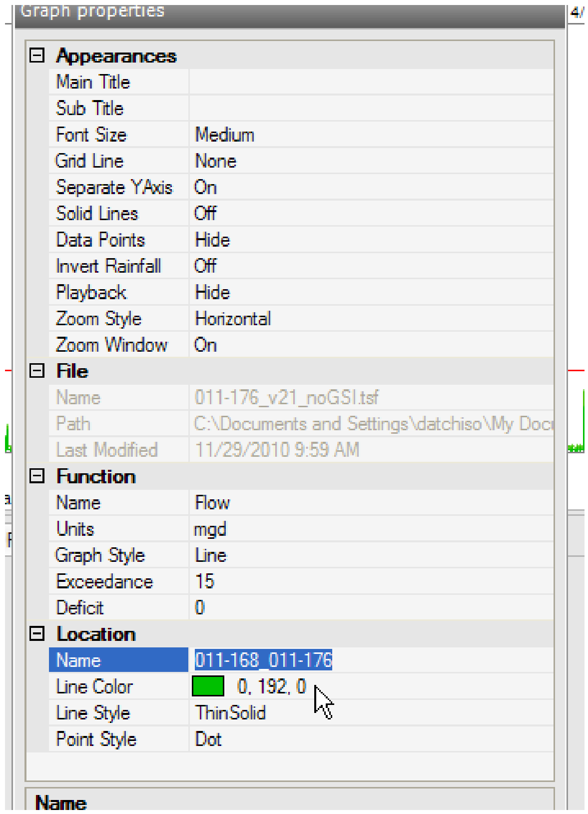
Then **open** that file into the graph for the GSI model run, and compare. The total overflow volume for the GSI model run should be less than that for the non-GSI run.



To change the format of the non-GSI hydrograph, go to the time series manager and right click on the new profile and select "properties".



Change the name of the time series and the properties of the line color



M.4.2.3. Review the LID Report File

Open the LID report file (mapped in step M.4.1) as tab-delimited from Excel. It will show the various statistics, for each water balance and storage term for the practice. **Plot** this data to show a relative mass balance for the practice and indicate if overflow is occurring due to lack of surface infiltration (e.g. too much flow to get into the practice) or from saturation from the bottom (native soil restricts from the bottom and the facility can't drain).

SWMM5 LID Report File

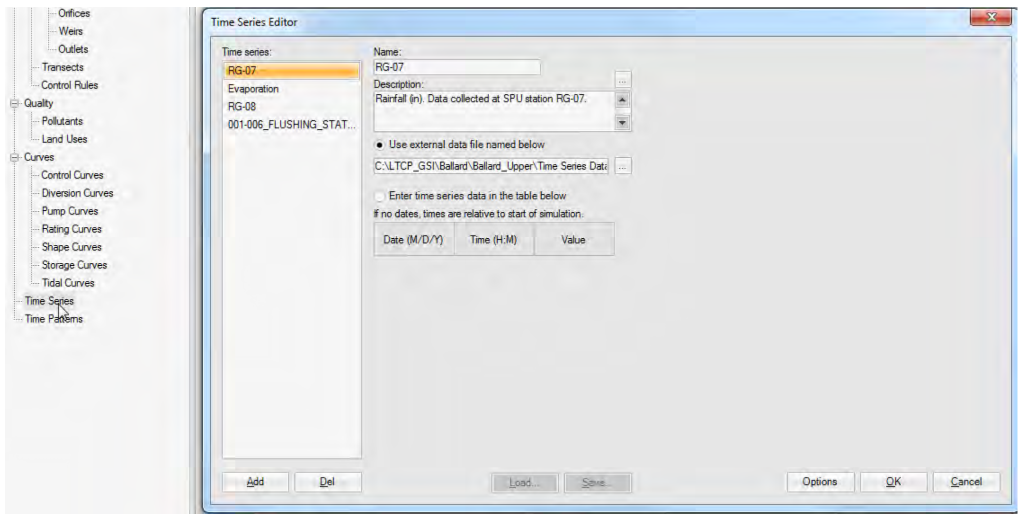
Project: CURRENT
LID Unit: row_gsi in Subcatchment ROW_002-082

Elapsed Time Hours	Total Inflow in/hr	Total Evap in/hr	Surface Infil in/hr	Soil Perc in/hr	Bottom Infil in/hr	Surface Runoff in/hr	Drain Outflow in/hr	Surface Depth inches	Soil/ Pave Moist	Storage Depth inches
-------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
0.083	0	0	0	0.08	0.25	0	0	0	0.15	0.26
0.167	0	0	0	0.08	0.25	0	0	0	0.15	0.21
0.25	0	0	0	0.08	0.25	0	0	0	0.15	0.16
0.333	0	0	0	0.07	0.25	0	0	0	0.15	0.11
0.417	0	0	0	0.07	0.25	0	0	0	0.15	0.06
0.5	0	0	0	0.07	0.22	0	0	0	0.15	0.01
0.667	0	0	0	0.07	0.1	0	0	0	0.15	0.01
0.75	0	0	0	0.07	0.07	0	0	0	0.15	0.01
0.833	0	0	0	0.07	0.07	0	0	0	0.15	0.01
0.917	0	0	0	0.07	0.08	0	0	0	0.15	0.01
1	0	0	0	0.07	0.07	0	0	0	0.15	0.01

M.4.3. Run Long Term Simulation

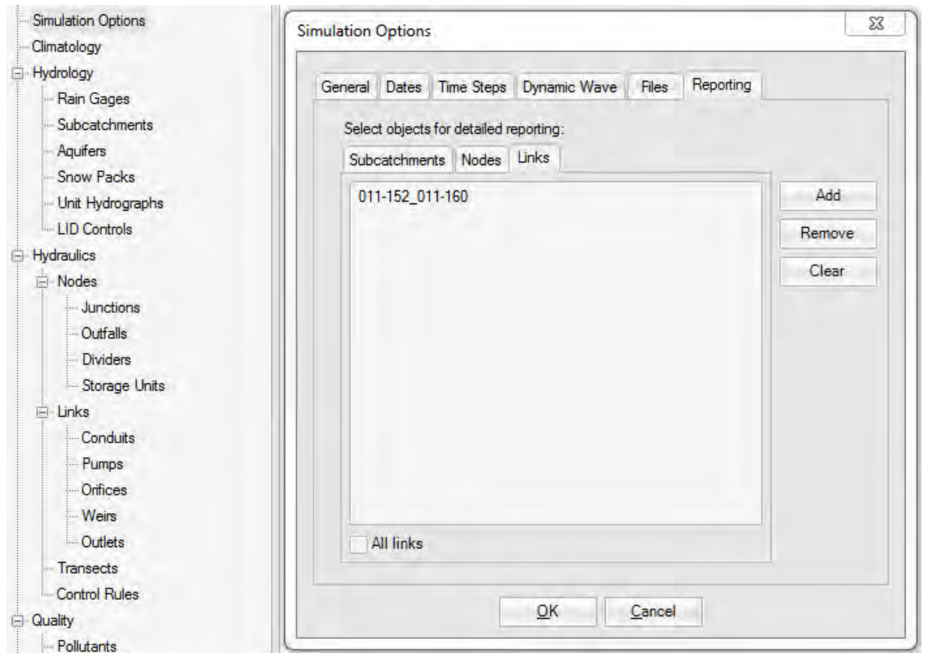
M.4.3.1. **Open** the model input file. In the *Simulation Options* **Dates** tab, choose the long term simulation duration (typically 9/1/1977 00:05:00 to 12/31/2009 23:55:00) for the model simulation.

Long term simulations can take a very long time to run (some models over 24 hours). It is a good idea to make sure the start and end times are included within all of the external time series (*Time Series Editor*). It may also be a good idea to run the first few days and the last few days of the long term simulation to verify no critical errors occur at these locations in the simulation.

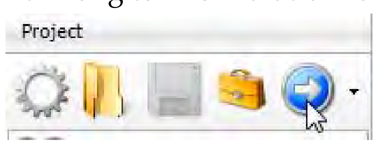


Long term simulations can also occupy large amounts of hard drive space (200+ MB). Consider limiting the results exported to only the outfall pipes considered for CSO analysis. This limits future analysis, but can speed processing time and reduce storage space needed.

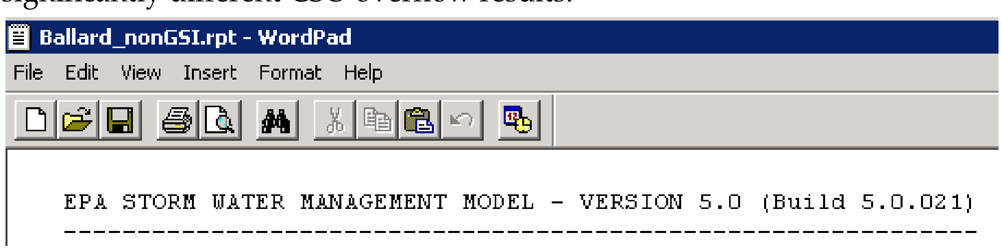
M.4.3.2. In the *Simulation Options* **Reporting>(Subcatchments, Nodes, and Links)** tabs, **verify** that only the outfall links (and any other desired links or nodes) are included for reporting. **Remove** all others.



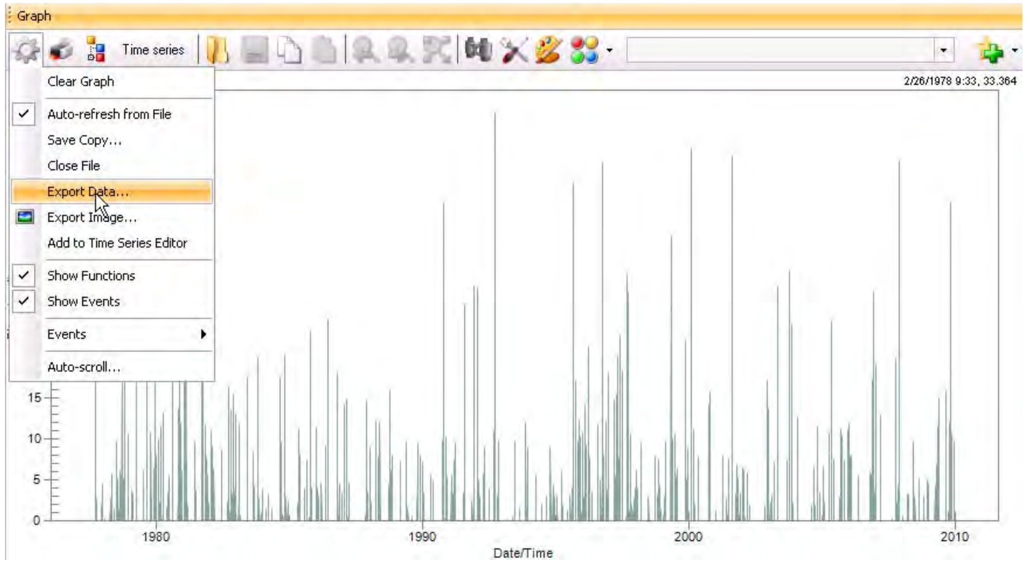
M.4.3.3. **Run** long term simulation for both the GSI and non-GSI version.



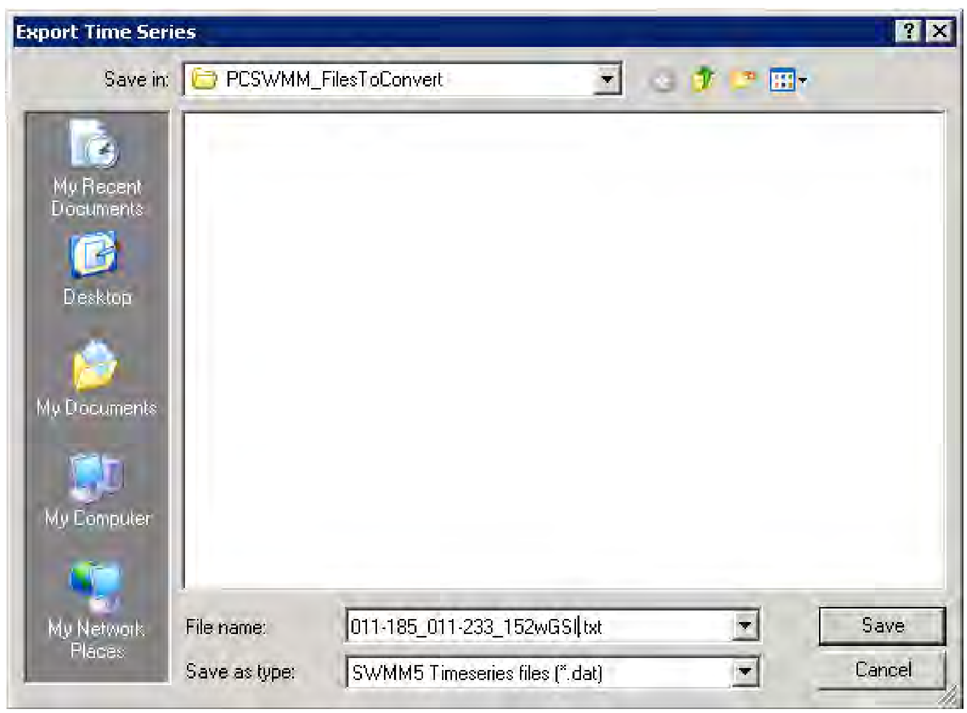
If the results from a non-GSI version of the long term simulation already exist, there is no need to run again. However, be sure that the non-GSI results you are comparing to were run using SWMM engine v.5.0.021 (and not 5.0.018). You can check the version in the model report file (.rpt), which can be opened in text editor. Versions prior to 5.0.021 used different methods for working with evaporation (among other differences), and can create significantly different CSO overflow results.



M.4.3.4. **Export** results to text file.
Graph the entity you want to export (outfall pipe flow), and click on "Export Data".



Export as type "SWMM5 Timeseries files (*.dat)", but manually change the suffix to .txt. Exporting as a .dat ensures the proper syntax within the file, and saving as a .txt ensures that the file can be converted to a .csv (Step M.5.2). Export to a common location with other .txt output files that will be converted to .csv files in step M.5.2.



M.5. Generate ACU-SWMM Overflow Statistics

The steps listed here are modified from the ACU-SWMM Users Manual. ACU-SWMM is used for GSI modeling only to generate overflow statistics (not to run PC-SWMM in batch run mode, as originally intended). For more information on ACU-SWMM, see the Users Manual.

M.5.1. Create dummy ACU-SWMM database

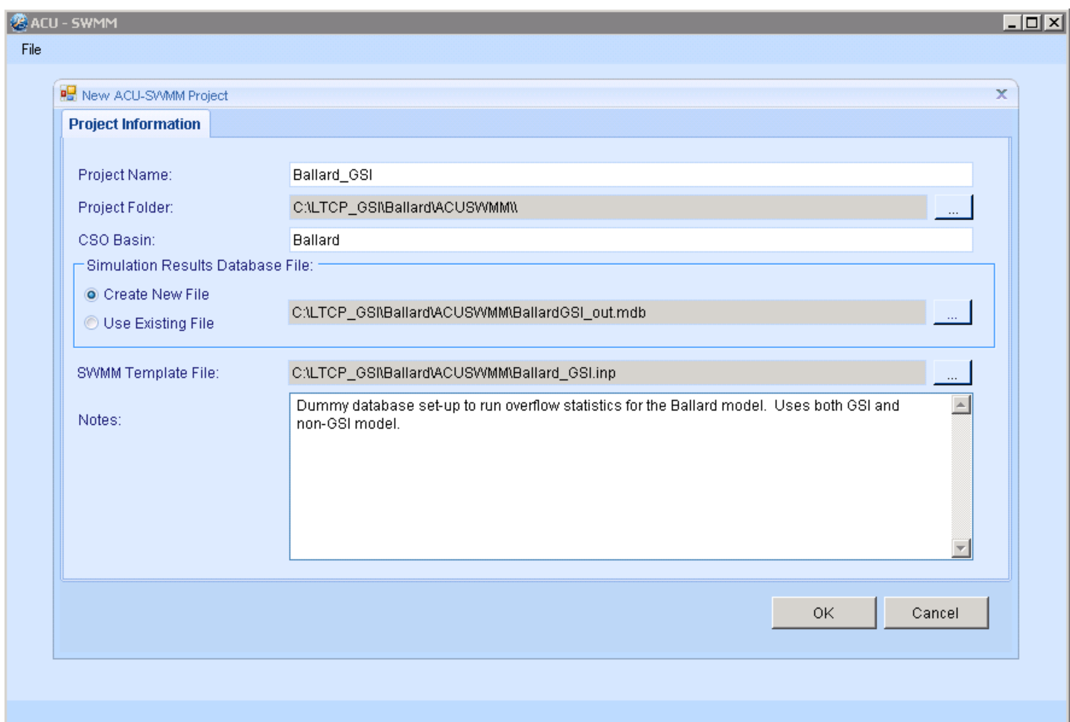
It is easiest to keep the dummy ACU-SWMM database and associated files separate from those being run in PCSWMM. A separate folder will suffice.

Select **File** - > **New Project**

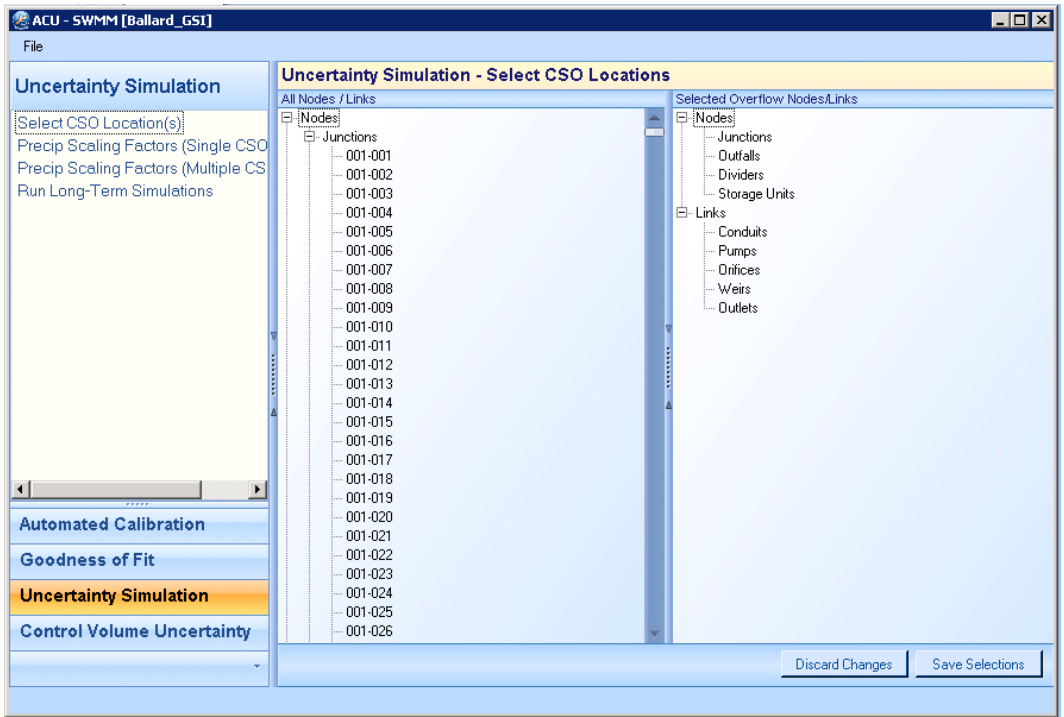
Set up the ACU-SWMM project information. This interface creates two MS Access databases (.mdb): the ACU-SWMM input database in the "Project Folder" with the name [Project Name].mdb, and the ACU-SWMM output database at the path the user defines in the "Simlation Results Database File" box. Note- be sure that the output database has a different name than the [Project Name] to avoid confusion (_out is used in the example).

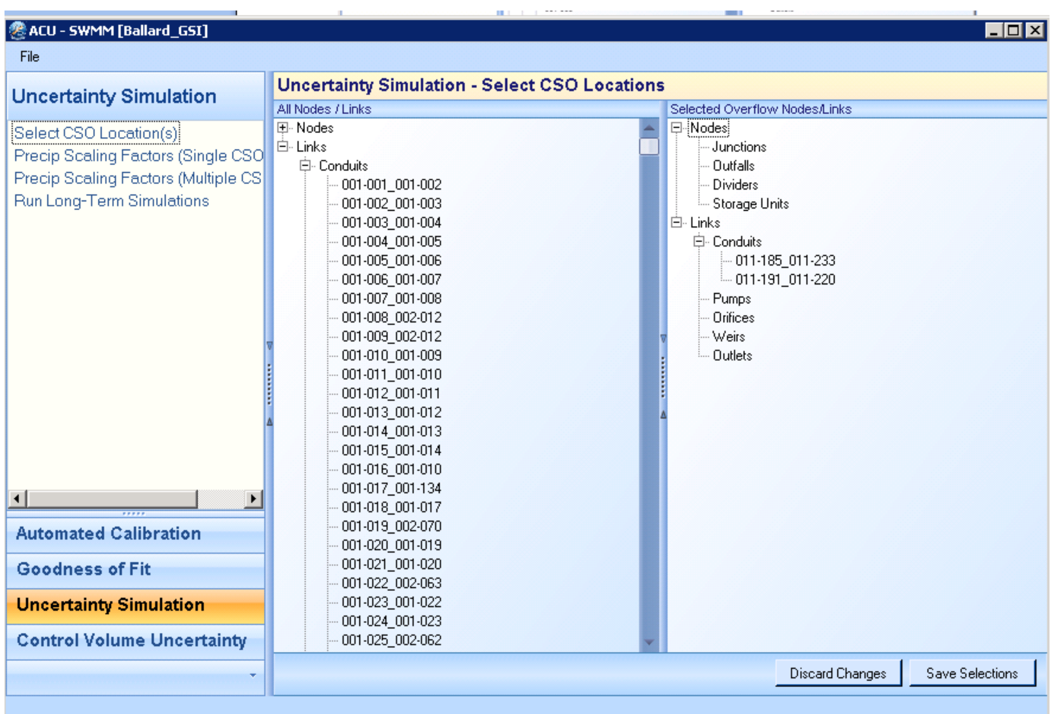
Place a copy of the model (with or without GSI) in the ACU-SWMM folder. **Link** to this as the "SWMM Template File".

Click **OK**.



Skip directly to the "Uncertainty Simulation" module in the list on the left of the screen. A list of the available nodes, links and conduits from the SWMM Template File is available in the middle of the screen. **Drag** model elements for which overflow statistics are needed from the middle screen to the right screen. For most models this is the overflow pipe(s). **Save** selections.

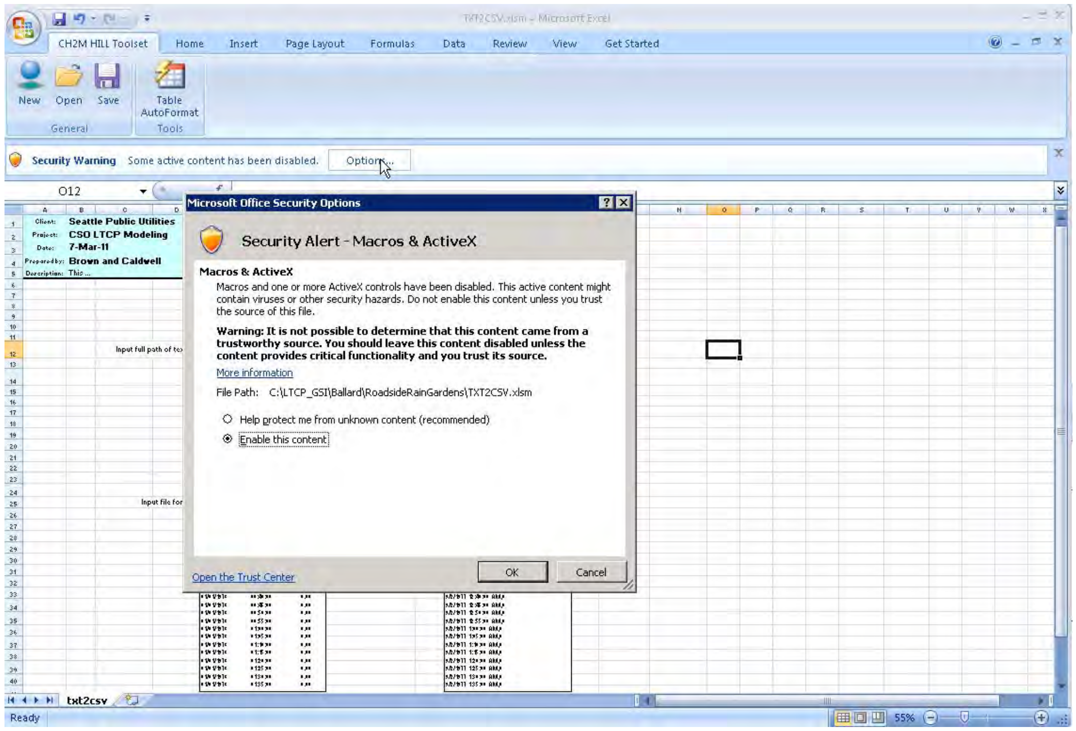




Because ACU-SWMM is only being used to generate statistics, and is not being used to run Long-Term Simulations, elements of the "Uncertainty Simulation" module beyond "Select CSO Location(s)" are not needed.

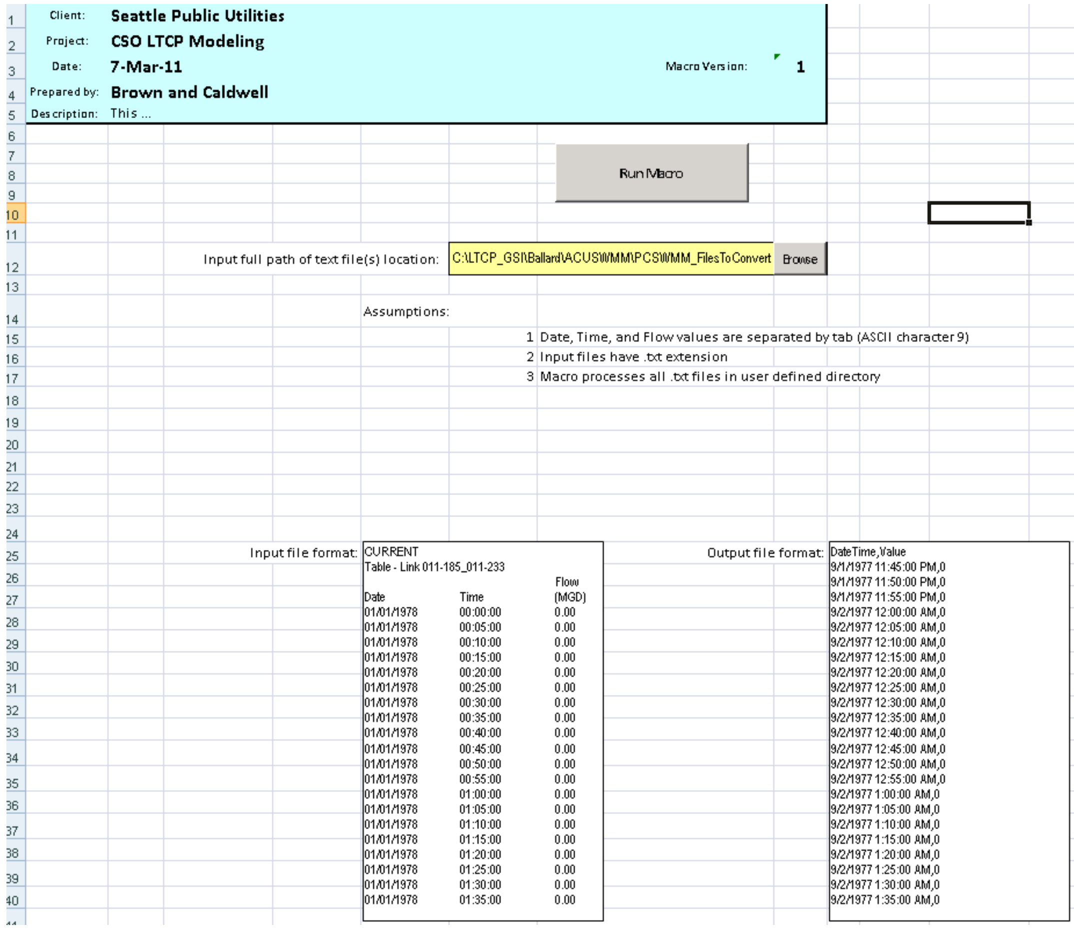
M.5.2. Convert PCSWMM output into ACU-SWMM input

Open the “TXT2CSV.xlsm” spreadsheet in Excel. Make sure macros are **enabled**.



If not already, **move** all PCSWMM output .txt files to one folder, without any other .txt files. All the .txt files in this folder will be converted.

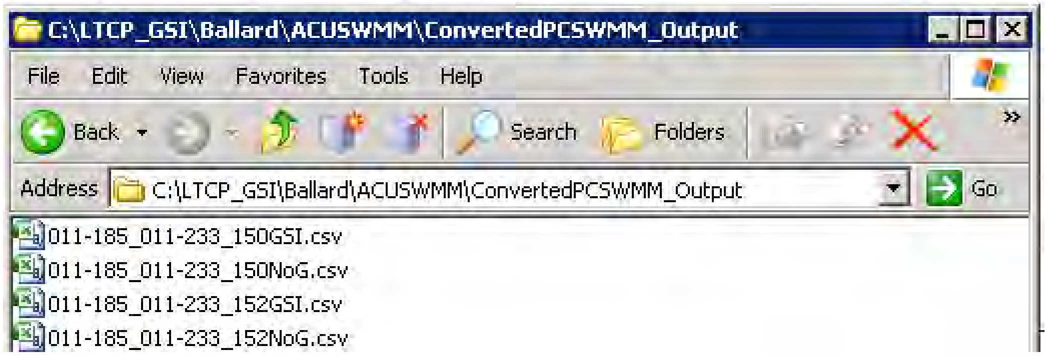
Browse to this folder using the **Browse** button. **Select** one file (note- even though one file is selected, all .txt files will be converted). **Run Macro**. A single 30-year simulation may take up to 120 seconds to process, depending on frequency of overflows.



Check the target folder to make sure the macro worked. If not, re-enter the path through the Browse button (sometimes just having the correct path in the target cell is not enough- it has to be entered through the "Browse" interface).

Move the result CSV files to an appropriate location to be accessed by ACUSWMM. **Rename** the files if necessary. Use the following convention: [Model Link ID, such as '011-191_011-220'][7 characters to describe file, such as '152_GSI'].csv.

Notes on CSV file syntax: the last 7 characters are reserved for description (typically used for precipitation scaling factor). Remaining characters should match "Model CSO Name", so that the threshold and user CSO name are correctly linked.



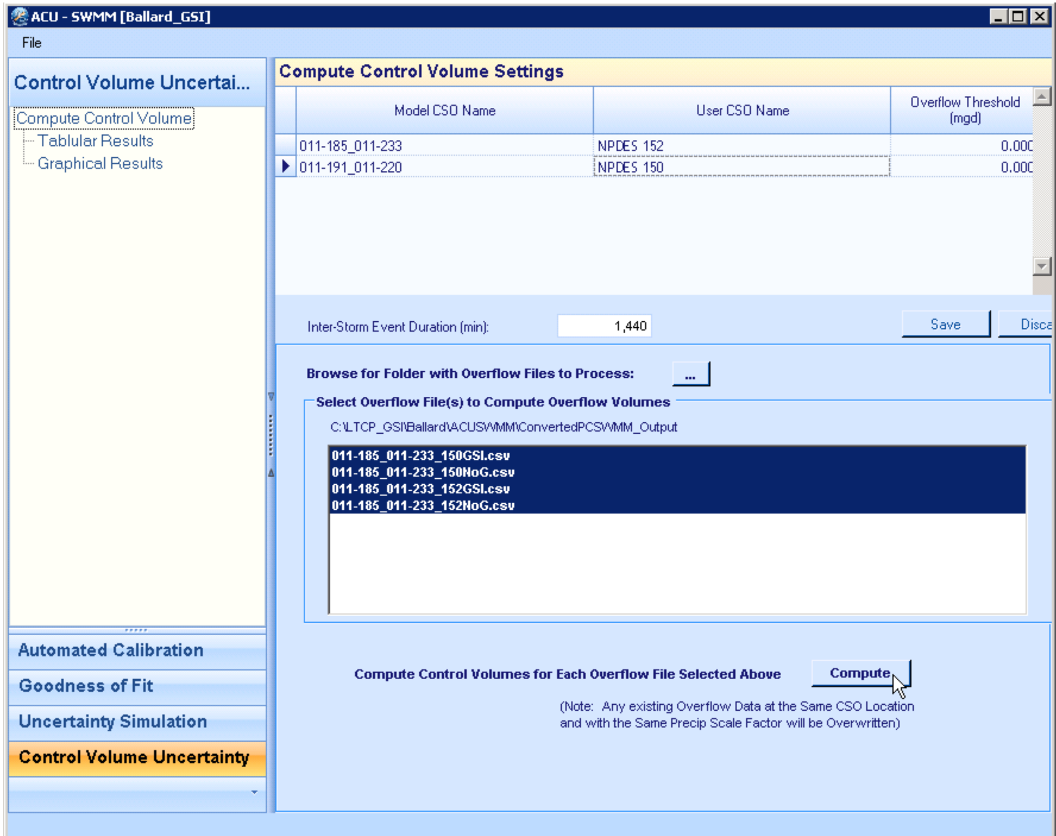
M.5.3. Run ACU-SWMM Control Volume Uncertainty

Open ACU-SWMM, **browse** to and **open** the ACU-SWMM Input Database. **Skip** to the "Control Volume Uncertainty" Module. The first time this is opened, **define names** for each of the model elements for which statistics are generated. **Save** these settings.

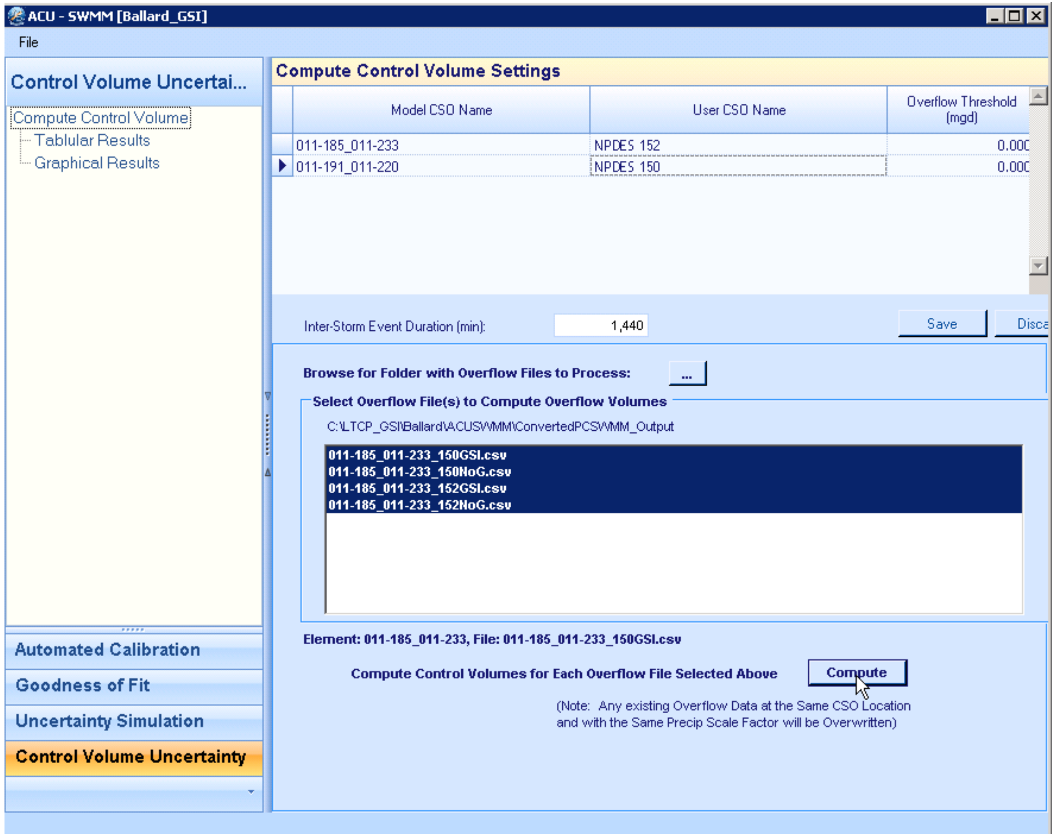
The user can also set a flow threshold below which flow in the overflow pipe will not be counted as an overflow. The value for this threshold is up to the discretion of the modeler, and may be unique to individual model conditions and instabilities. Generating statistics based on this value is easily repeated, so the user can quickly test the sensitivity of the statistics to this threshold.

The user can also set the inter event period that defines individual CSO events.

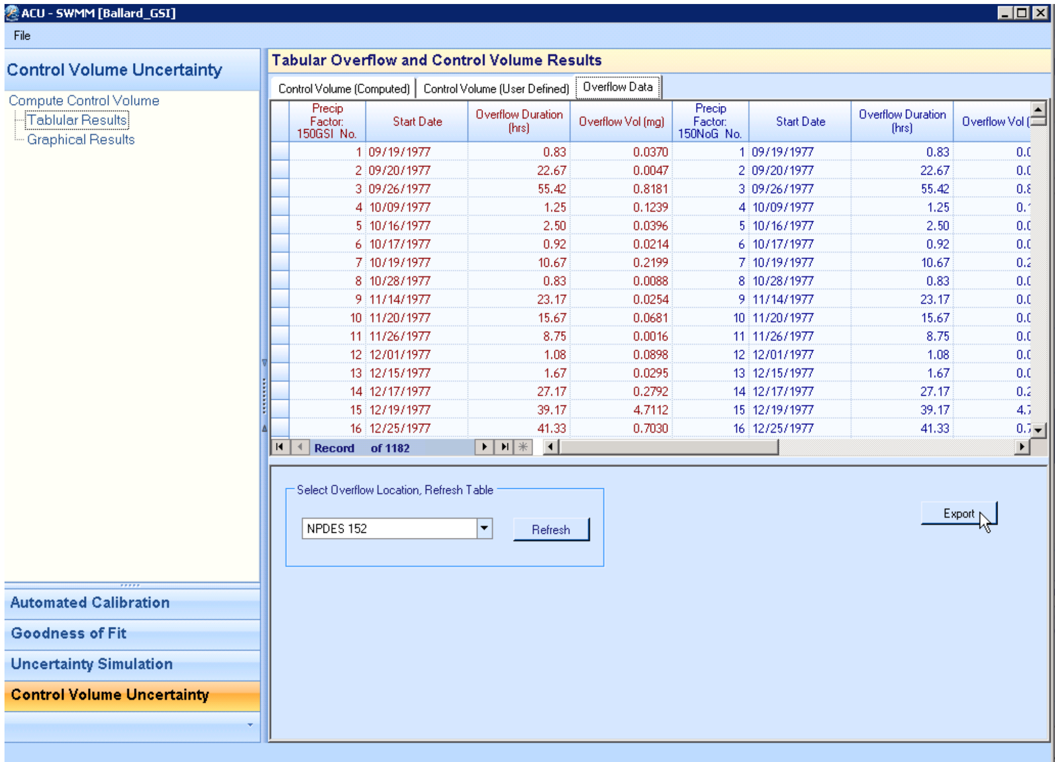
Click "Browse for folder with Overflow Files to Process". **Select** the folder containing the CSV files created by converting PCSWMM model output using the "TXT2CSV.xlsm" tool (Step M.5.2). All files in the folder will be listed. **Select** one or multiple files (keep CTRL pressed down to select multiple) to use for statistics generation. **Press** "Compute".



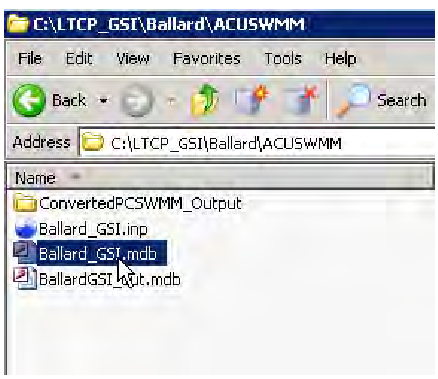
Statistics generation may take a few minutes, depending on the number and length of files. One 30 year simulation takes approximately 10-20 seconds to process. Text above "Compute Control Volumes…" indicates processing progress.

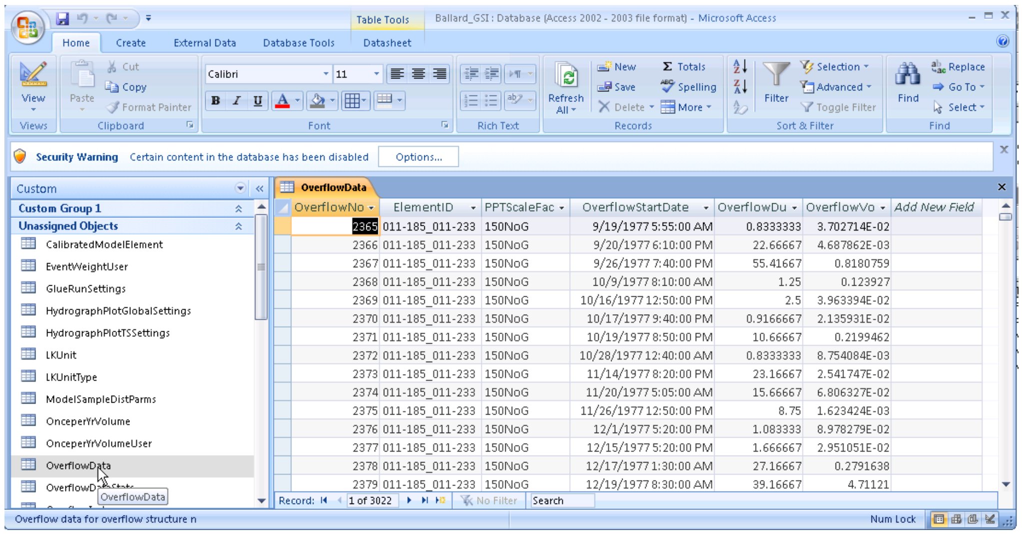


Click "Tabular Results" at the upper left. The Control Volume (Computed) is the (n+1) ranked event of a model export of n years (for example, 31st event of 30 years). Complete results can be exported from the "Overflow Data" tab in columns based on the model run description (the last 7 characters of the model output CSV file), using the "Export" button at the bottom right.



Optional: A single table of results (useful for pivot tables in Excel) can be exported directly from the ACU-SWMM Input Database. These results are in the "OverflowData" table of the Input Database, and can be copy-pasted from MS Access, or imported directly into Excel using data import functions.





M.5.4. Compare GSI-results to non-GSI results

The 32nd ranked overflow volume in a 31 year simulation is considered the control volume. The difference in the 32nd ranked volume between the GSI and the non-GSI model runs for a given outfall is equal to the reduction in CSO control volume due to GSI. The 32nd ranked volume may belong to a different event in each of the result sets. Analysis of the overflow data can be quite simple (difference in volume of 32nd event)Other comparisons between the two sets of results can include:

- Total number of overflow events
- Individual event CSO volume (requires matching individual CSO events by start date/time)
- Total CSO volume over 31 years
- CSO control volume reduction per square foot mitigated (should be approximately 0.25 – 1.0 gal/sf)

Example results from North Union Bay are shown below.

Basin	# CSO Overflows		Total CSO Volume (MG)		32nd CSO Volume (MG)		GSI CSO Volume Reduction	
	v.21 w/o GSI	v.21 w/ GSI	v.21 w/o GSI	v.21 w/ GSI	v.21 w/o GSI	v.21 w/ GSI	Absolute (MG)	%
18A	228	205	22.1	19.5	0.194	0.163	0.031	16.0%
18B	108	89	480.0	430.5	4.274	4.000	0.274	6.4%

Appendix K
GSI Modeling Results

Ballard NPDES Basins 150/151 and 152 GSI Model

Model Development

The Ballard model consists of three submodels, one each for the upper portions of Basin 150/151 (011-176.inp) and Basin 152 (011-160.inp) and one for the lower basin (Ballard_Lower.inp), which includes both CSO outfalls. The Ballard model was divided into the three submodels so that run-time dependent time steps could be optimized, and so that adjustments to hydraulics in the lower basin could be decoupled from the hydrology in the upper basin. Inclusion of GSI in the model applies to all three submodels. Flow time series files from both upper basin submodels are used as boundary condition inputs for the lower basin model.

Model Results – Most Practical Implementation

The model was run with a precipitation scaling factor of approximately 1.06 (1.0609 upper Basin 150/151, 1.0549 for upper Basin 152, and 1.0609 for the lower basin) to match the scaling factor that most closely produces the Best-Estimate Control Volume used for the alternatives development and analysis. The net reduction due to the most practical implementation is estimated to be approximately 0.99 MG for Basin 152 and 0.17 MG for Basin 150/151. CSO control volumes are summarized in Table 2.

Table 2. Ballard CSO Control Volume Summary

Basin	Best-Estimate CV (mg)	Precip Scaling Factor ~1.06 (1.0609 & 1.0549)			
		v. 5.0.018 - no GSI (mg)	v. 5.0.021 - no GSI (mg)	v. 5.0.021 - with most practical GSI (mg)	**Net Most Practical GSI CV Reduction (mg)**
150/151	0.467	0.454	0.580	0.406	**0.174**
152	4.070	3.869	5.156	4.163	**0.993**

Relative Control Volume Reduction of Individual GSI Practices

Separate runs isolating the effectiveness of individual GSI practices for control volume reduction were conducted. In general, it was found that raingardens (especially roadside raingardens where implementation is not voluntary and therefore more widespread) provide the greatest percentage of control volume reduction in Ballard. Another observation based on the data is that cisterns appear to have a reduced effectiveness in Basin 152. This may be due to the high frequency of overflows under existing conditions, whereby delay (or detention) of flows has less impact on reducing overflows as the water still contributes to periods of overflow.

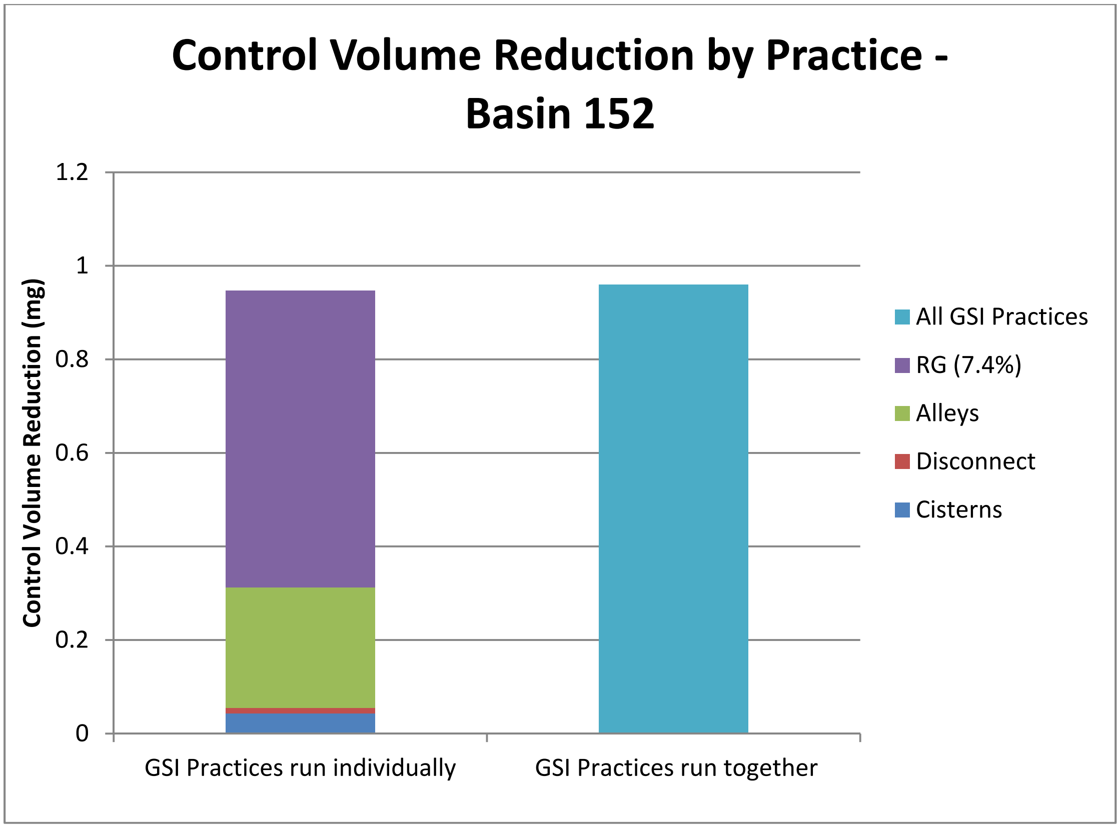


Figure 1. CV Reduction of Individual Practices in Basin 152

Output from this analysis is included in the attached spreadsheet titled "BallardGSI_RG_Sizing_and_PracticeSensitivity.xlsx".

Raingarden Performance Sensitivity to Sizing Factors

Separate model runs were conducted varying the sizing factor for raingardens to confirm the sensitivity of relative raingarden performance and the appropriate sizing factor to maximize the efficiency of raingardens for CSO reduction. The analysis determined that a sizing factor between 7.4% (the current GSI sizing factor for native infiltration rate of 0.25 inches/hour) and 11.0% would result in a raingarden that overflows an average of once per year, see exhibit 2 below. Analysis of the change control volume reduction by varying the sizing factor indicates that the greatest increase in control volume reduction in Basin 150/151 occurs between the 7.4% and 11% sizing factors.

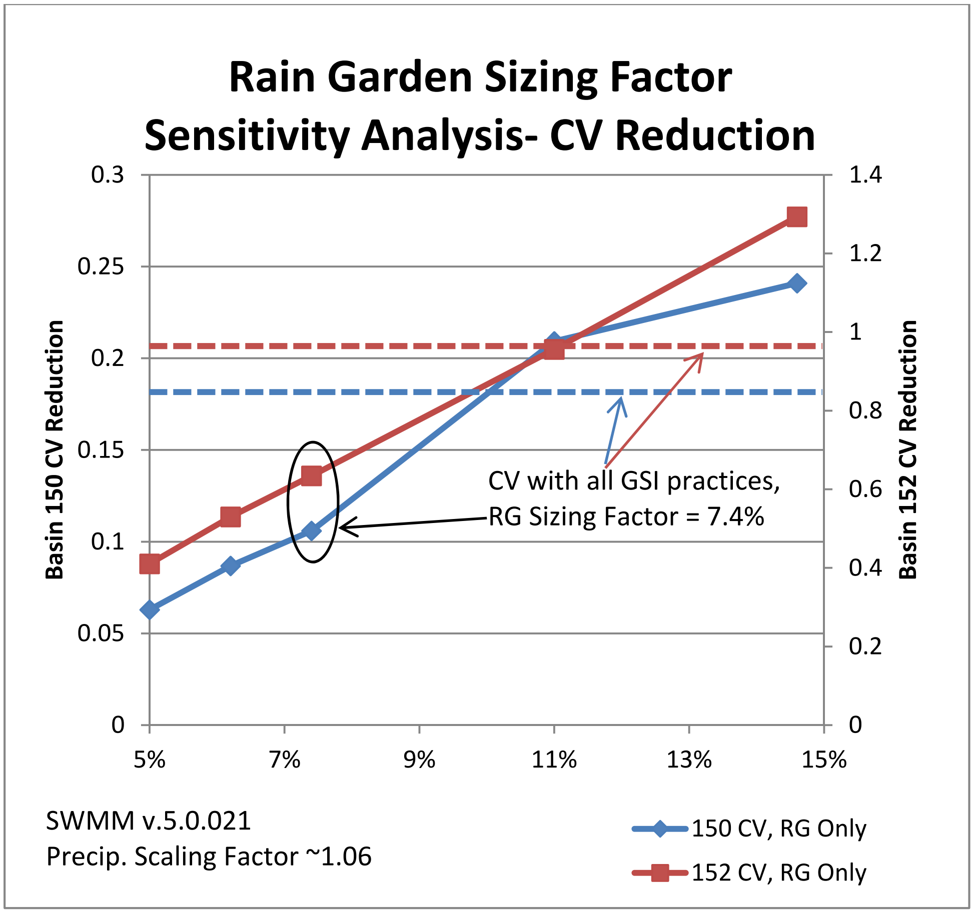


Figure 2. Raingarden Sizing Factor Sensitivity

Output from this analysis is included in the attached spreadsheet titled “BallardGSI_RG_Sizing_and_PracticeSensitivity.xlsx”.

Analysis of Ballard Raingarden (28th Avenue) Orifice Retrofits

Additional analysis was also conducted to advise SPU on the appropriate orifice size to install on the Ballard Raingardens to result in overflow on a frequency of approximately once per year. To evaluate the correct orifice to achieve this performance, the model was revised to include only the raingardens constructed for Phase I of the Ballard Raingardens project where engineered fixes (installation of orifices) are planned. The total area of raingardens (regardless of size and side of the street) and tributary area were aggregated by subcatchment. In general this combined no more than 4 swale series within a single subcatchment. The LID controls for these practices were modified to assume zero infiltration from the bottom of the facilities and to simulate underdrain discharge from the storage zone of the practice. Note: the actual live storage in the retrofitted raingardens will actually occur within the ponding zone, however, the model does not vary discharge from the underdrain based on head within the surface or soil zones of the practice. Therefore the model input was revised to provide negligible storage in the upper two layers and simulate all storage as if it occurred in a storage zone with a porosity of 1.0.

The model was run iteratively to simulate different orifice sizes for a five year period from October 1980 to October 1985 (a period identified based on having exactly 5 overflow events ranking in the top 32 without GSI in Basin 152). The number of overflows was plotted versus the total volume stored in the swales (expressed as inches relative to the tributary impervious area) and the discharge rate of the orifice (also expressed as inches per hour relative to the tributary area). The results found that an orifice with a discharge rate equaling 0.27 inches per hour relative to the tributary area resulted in a bioretention swale that overflowed approximately 5 times (once per year on average) during the simulation period. The result of this analysis yields the following equation for approximating the required orifice size to meet the CSO control standard of one overflow per year on average:

$$D = 0.051 * SQRT(A_t)$$

Where: D is the orifice diameter in inches,
A_t is the tributary impervious in square feet.

Table 3. Ballard Retrofit Orifice Sizing

Cell series	Ponding (in.)	Drain Area (sf)	Ratio (RG Area/Tributary Area)	Subcatchment	Orifice Diam (in.)
71E4	7	6,199	**2.0%**	ROW-002-024	**4.03**
71E2	9	4,224	**4.3%**	ROW-002-024	**3.32**
71E1	9	2,249	**6.0%**	ROW-002-024	**2.42**
66W1	7.5	21,075	**5.5%**	ROW-002-031	**7.42**
65W2A	8	10,674	**3.9%**	ROW-002-032	**5.28**
65W1	6	1,858	**11.1%**	ROW-002-032	**2.20**
28N1C	5	2,185	**20.9%**	ROW-002-094	**2.39**
28S1D	7	4,616	**13.3%**	ROW-002-094	**3.47**
77W2A	10	7,764	**3.5%**	ROW-002-094	**4.50**
77E2A	8	6,228	**2.7%**	ROW-002-094	**4.03**

Future evaluation steps may include expanding the simulation period to the full 31-year long-term period to verify the once-per-year overflow frequency and to evaluate the relative effectiveness of reducing control volume at the outfall.

Results and input for the Ballard Raingarden retrofit modeling are included in the attached spreadsheet titled “28th Orifice Model_input_results.xlsx”.

North Union Bay Basin 18 GSI Model

Model Development

The North Union Bay consists of five submodels: three for upper portions of Basin 18B, one for the upper portion of Basin 18A, and one for the lower portions of both Basins 18A and 18B. The North Union Bay model was divided into the five submodels so that run-time dependent time steps could be optimized, and so that adjustments to hydraulics in the lower basin could be decoupled from the hydrology in the upper basins. Inclusion of GSI in the model applies to all five submodels. Flow time series files from both upper basin submodels are used as boundary condition inputs for the lower basin model.

Differences in the evaporation functionality between SWMM5 version 5.0.018 and 5.0.021 exacerbated model instabilities during GSI simulations. The following edits were made to the model, with respect to the calibrated model (City of Seattle, 2011).

- ponding was turned off
- Aquifer Bottom Elevation for “Silty_Loam_025-018” was changed from 38.287 to 20
- Aquifer Water Table for “Silty_Loam_025-018” was changed from 38.7 to 21
- Groundwater Surface Elevation for Subcatchment “BLDG_025-019” was changed from 38 to 48
- Groundwater Surface Elevation for Subcatchment “BLDG_025-018” was changed from 38 to 48
- Groundwater Surface Elevation for Subcatchment “C_025-019” was changed from 38 to 48
- Groundwater Surface Elevation for Subcatchment “C_025-018” was changed from 38 to 48

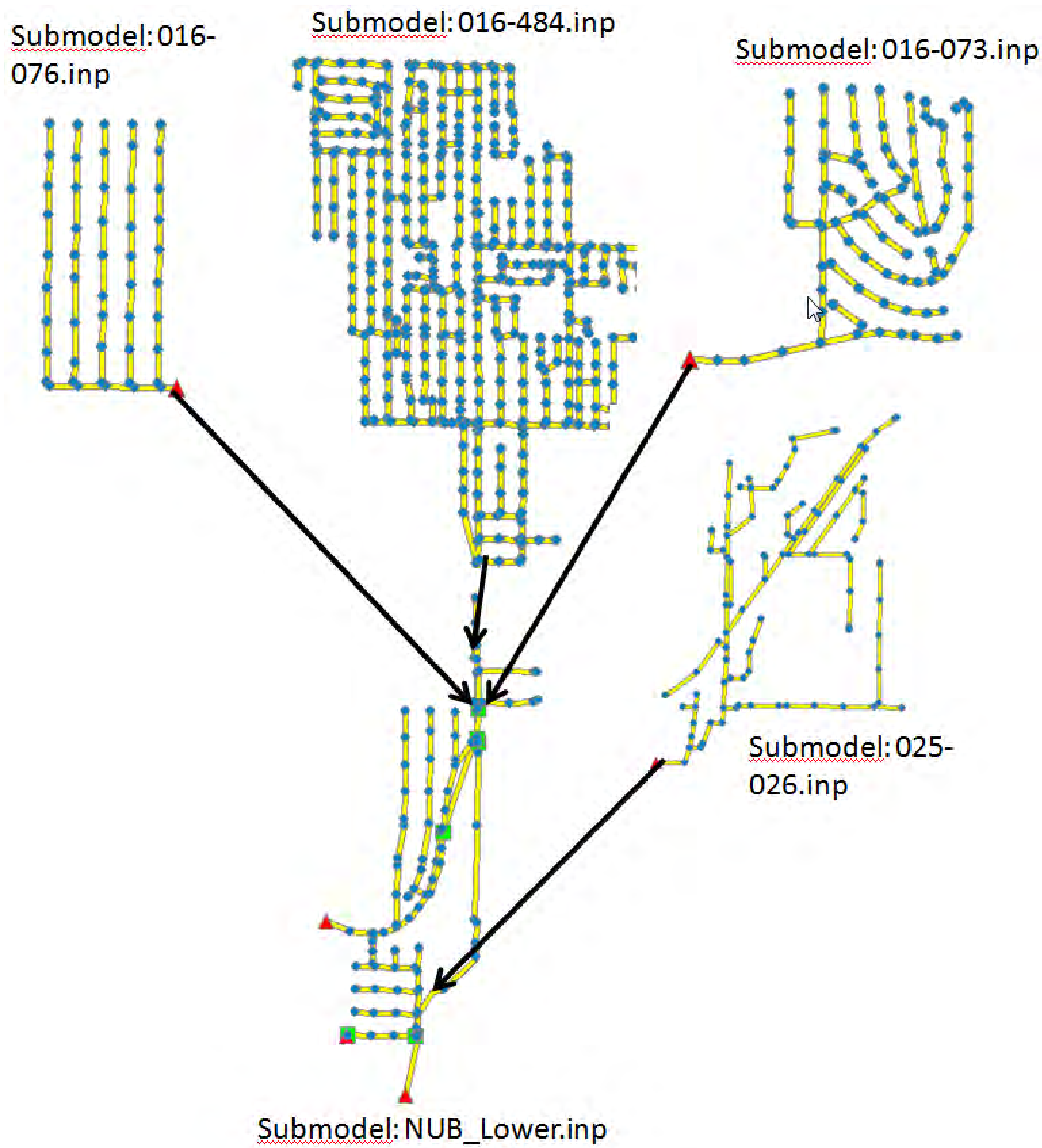


Figure 3 North Union Bay Model Layout

Model Results – Most Practical Implementation

The model was run with a precipitation scaling factor of approximately 1.08 to match the scaling factor that most closely produces the Best-Estimate Control Volume in the basin with the largest control volume, Basin 18B. The net reduction due to the most practical implementation is estimated to be approximately 0.031 MG for Basin 18A and 0.27 MG for Basin 18B. CSO control volumes are summarized in Table 4. Figures 4 and 5 show the top 50 ranked CSO events for the 18A and 18B models, for three different sets of model simulations. The 32nd ranked event out of a 31-year model simulation is considered the control volume.

Table 4. North Union Bay CSO Control Volume Summary

Basin	Best-Estimate CV (mg)	Precip Scaling Factor = 1.0848			
		v. 5.0.018 - no GSI (mg)	v. 5.0.021 - no GSI (mg)	v. 5.0.021 - with most practical GSI (mg)	**Net Most Practical GSI CV Reduction (mg)**
18A	0.147	0.154	0.194	0.163	**0.031**
18B	2.145	2.114	4.274	4.000	**0.274**

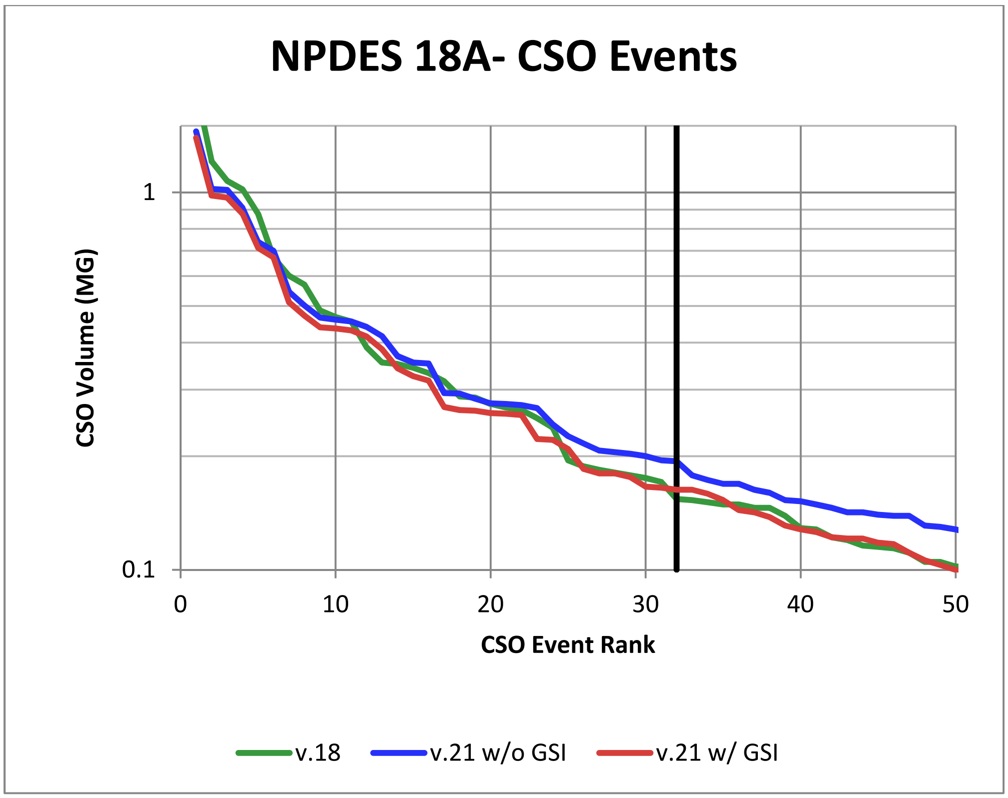


Figure 4. CSO Volume for the 50 largest events from each of the three model runs of the Basin 18A model. The 32nd ranked event in a 31-year simulation is considered the control volume.

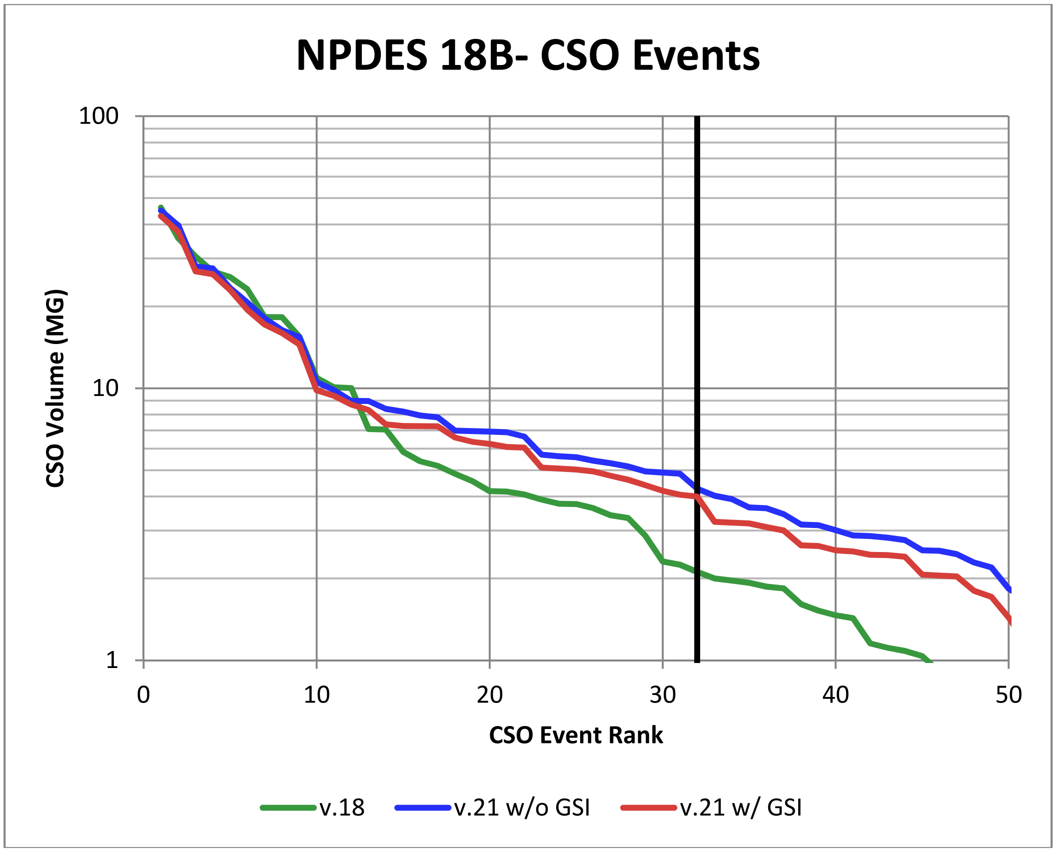


Figure 5. CSO Volume for the 50 largest events from each of the three model runs of the Basin 18B model. The 32nd ranked event in a 31-year simulation is considered the control volume.

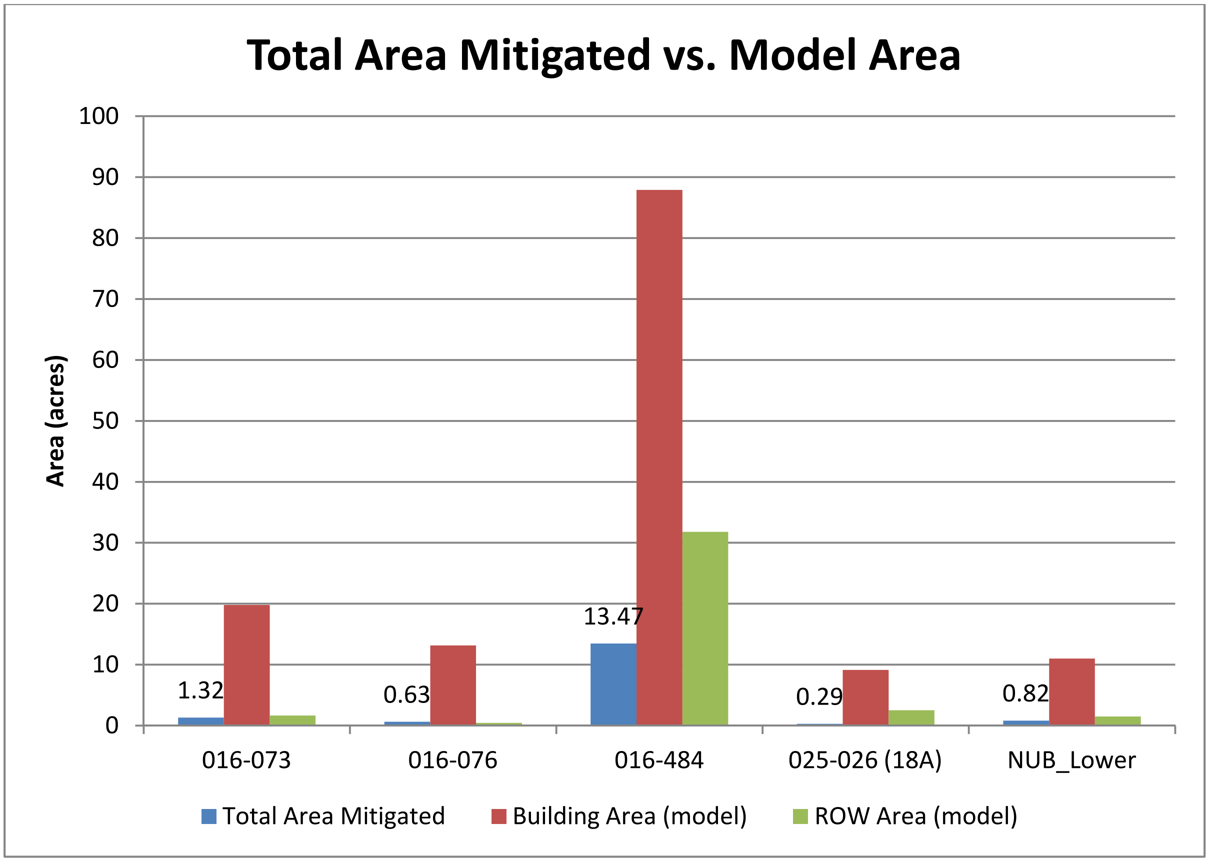


Figure 6. Relative size of total GSI mitigated area to the total area included in the North Union Bay model, by submodel.